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# THE ECONOMIC USE OF ALUMINIUM

## (BASED ON HUNGARIAN EXPERIENCE)*

UF/GLO/78/007

by

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## FOREWORD

On 8 October 1976, an agreement initiating the Joint UNIDO/Hungary Programme for Co-operation in the Aluminium Industry was signed by the President of the Hungarian Chamber of Commerce and the Executive Director of the United Nations Industrial Development Organization /UNIDO/. The aim of the Joint Programme is to assist developing countries to establish an aluminium industry. The present booklet on the economic uses of aluminium was prepared under this programme.

Aluminium has experienced a spectacular growth in recent years. It has become competitive with other metals, and the areas of its application have been constantly expanding, since the use of aluminium solves many technical problems in important fields such as transport, construction, packaging and electrical engineering. Hungary, using its own resources of bauxite, has developed a fully integrated aluminium industry and has attained a remarkable level of aluminium consumption.

Aluminium can be regarded as a valuable replacement material, especially in countries, whether developing or developed, that are poor in heavy non-ferrous metals, such as Hungary, India and Iraq.

Hungary's experience in replacing structural materials with aluminium and its knowledge of potential sources of technologies and the availability of know-how may be of interest to countries or companies that are planning to replace materials with aluminium and to develop their aluminium sector. The Hungarian experience in introducing an efficien system of aluminium promotion in connexion with the nationalization of the aluminium industry may also be of interest to other countries.

This booklet describes the main reasons for using aluminium and examples of methods of use. It summarizes

Hungarian experience in developing the industry. It is written to help those who face similar tasks and objectives.

The Secretariat of UNIDO

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## INTRODUCTION

The utilization of aluminium on an industrial scale in a diversity of fields had been a long process dating back to the 1930s. There was a significant rise in aluminium production - particularly on the North American continent and Germany - during the Second World War to meet the increasing demand of the war industries, especially in aircraft manufacture. Because of the scarcity of other strategic materials then, however, the scope of aluminium utilization encroached on other areas as well, electrical engineering and transport vehicle manufacture being the two most prominent end-using sectors, with chemical engineering and food processing following suit on a more modest scale.

In the post-war reconstruction period when large stocks of aluminium became available for civilian use, a series of new outlets were soon found including prefabricated utility houses, shipbuilding, as well as equipment for the electrical engineering and food processing industries. As from the second half of the 1950s, the major aluminium concerns of the world made substantial efforts to devise new strategies of boosting aluminium consumption, so as to find new markets for their rising production. This was the time when - on the basis of previous experiences - the outlines of such aluminium usages began to take shape, which in the long run have proved to be feasible from both a technical and economic point of view. The market position of aluminium at that time was greatly strengthened by the fact that marked shifts in the pricing of other structural materials had taken place in favour of aluminium, a trend perpetuating throughout the coming years.

In dealing with the unprecedented growth of aluminium consumption since then, next to reviewing general world trends, also a special case study on a particular country - Hungary - is presented hereunder. In Hungary certain geophysical and economic factors /abundance of bauxite resources, lack of heavy non-ferrous metals and timber, a narrow selection of steel products/ have already at a relatively early time necessitated the setting-up of an integrated aluminium industry. Even before large-scale aluminium operations could commence, as from the early 1950s several minor aluminium fabricating capacities were installed at different points, and various schemes were launched to train engineering specialists and skilled workers in different branches of non-ferrous metallurgy. In the post-war years, controls were imposed with a view to restricting the use of structural materials in short supply and substituting these by aluminium wherever possible. At the same time, the various scientific and technical development agencies operating under the auspices of the aluminium industry were called upon to update earlier designs of aluminium items and structures and to explore new aluminium outlets.

As a result, most non-ferrous metal operators have entered the aluminium fabricating field. The availability of aluminium metal coupled with the experience of those using it, permitted a diversification programme to be put into effect, in the wake of which large series of aluminium products meeting the most stringent international standards could be put on the market /e.g. liquid-gas bottles, heat-exchangers for power plants and oil pipelines/. In the face of such developments, in subsequent years the country's domestic per capita aluminium consumption rose at a dramatic rate, far ahead of general trends in other fields. At present, about 30 per cent of all aluminium finished items produced in Hungary are exported and only 3-5 per cent of finished product consumption is imported.

Thus Hungary, by dint of its highly integrated aluminium industry and backed by half-a-century's experience in production and consumption, is a case in point to demonstrate how and under what circumstances may aluminium consumption expand in a developing country in due course becoming a fairly well industrialized one.

This case study - believed to be applicable in many cases to other countries as well - is concerned with the interaction of various economic factors influencing growth of aluminium consumption; it is also aimed to describe experiences arrived at in the operating fields and consumer sectors; concrete examples as to aspects of design, prototype manufacture and serial production, both in Hungary and elsewhere, are cited to illustrate how optimum solutions may be sought for by taking utmost advantage of internal resources and, by adopting know-how obtained from abroad. In conclusion, issues of organization, training and scientific policy, all essential in promoting aluminium consumption, are dealt with. Under each chapter examples are cited without the claim of these being a panacea in solving all outstanding problems. Nor are such examples to be treated as fixed patterns to be strictly adhered to. Hungary's aluminium industry came into being between the two world wars and it had not been before the Second World War that it could gradually develop into what it is today. Obviously, its very existence had been influenced by a combination of specific political, economic, cultural and technological circumstances.

However, it is believed, certain useful inferences may be drawn from this exercise. And this is the reason, why this study had been completed. Whether and to what extent its contents may hold good for some other areas and countries of the world, has of course in each case to be carefully examined.

# 1. GENERAL CONSIDERATIONS

## 1.1 Scope of structural materials involved in this analysis and reasons why selected

Efforts in boosting aluminium consumption were at first concentrated on developing new technologies and introducing products permitting to replace traditional structural materials by a substitute of same superior properties /e.g. substitution of copper by aluminium in electric conductors, aluminium foil and collapsible tubes for packaging to replace tin, aluminium household holloware, etc./ In view of shifts in the pricing of non-ferrous metals within the last 40 years, no wonder that the promotion of aluminium usage has come into the focus of attention. Of course, the concrete scope and prospects have always depended on local conditions prevailing on site, that is, how far a given country had access to certain raw and/or structural materials, and to what extent the industrial policy and general economic setup in such an area had favoured such trends. In more recent times, a second significant factor giving further impetus to aluminium usage has entered into the picture: considerations of higher cost-effectiveness both at the producer's and consumer's end. Development work conducted with this end in view, it should be understood, will always hinge a great deal on the extent of industrialization and the general standards of economic development of a given country [1].

By referring to structural materials in this survey, not only such of ferrous and non-ferrous metals are meant, but in a broader sense also plastics, wood and cement as well. By using a multitude of data as to past and present-day aluminium consumption throughout the world, a complex techno-economic index system has been devised to point towards future perspectives of aluminium consumption in areas of different levels of economic development. In method, the present investigation is claimed to be fundamentally different from that of other authors. While in earlier reports correlations had been plotted for each specific usage of a material with the GDP of a given country, in this study an attempt was made to synthetize such correlations and to present consumption trends in a more complex manner.

Early in the annals of the aluminium industry have specialists realized that aluminium is an effective and economical substitute for copper in the conduction of electricity. Soon thereafter, tin had disappeared in most fields of packaging to give way to fresh advances by the aluminium industry. Next in line came chemical engineering and once more the electrical engineering industry, where lead could be replaced by aluminium /tanks and containers, cable-sheathing/. In the transport vehicle industry aluminium, thanks to its light weight, has soon become a competitor of cast iron. By reducing the self-weight of transport vehicles, considerable power economies could be arrived at, an important consideration in view of the present world energy situation. In the wake of fresh developments in the building trade, traditional designs featuring wood, reinforced concrete or steel had to be partly or fully shelved to give way to aluminium /e.g. window and door frames, claddings, load-bearing building structures/, whereby not only assembly time and maintainance costs could be reduced, but also complete building elements could be transported over long distances with ease to be assembled within the shortest possible time on site /e.g. cold-storage rooms/. Thanks to its good weatherproof properties, aluminium has also become a highly effective substitute in a variety of other fields, /e.g. building, transport vehicle and food packaging/ its corrosion-resistance comparing favourably with that of tinplate or zinc-coated steel. With shortages of some heavy non-ferrous metals /e.g. tin and zinc/ to continue, this trend is expected to perpetuate. Plastics too were included in this survey, so as to assess their potential impact on aluminium consumption in the long term.

## 1.2 World production and consumption of the structural materials under survey within the last decades; production and consumption trends outlined until 2000

### 1.21 Growth of production and consumption 1935-1977

Thanks to effective promotion efforts, world aluminium consumption has grown at an exceedingly steep rate within the last 40 years, being well ahead of that of traditional structural materials throughout this time /Tables 1 and 2/. Its growth was especially marked over the 1960-70 period. Although after the price explosion this trend has slightly declined, in comparison to other structural materials aluminium keeps on accounting for the highest ever consumption growth rates.

This unprecedented steady growth is based on a high standard of systematic research and development work throughout the world, relying, in turn, on effective cooperation between producers and consumers, irrespectively of the economic system or extent of industrialization in a given country.

With the aid of a set of calculations an attempt has been made to forecast future aluminium consumption trends based on numerous data released in earlier studies. In doing this, in the first place the consumption of principal structural materials in a number of selected countries of varied levels of economic development had been related to their GDP.

Table 1.

## World Consumption of Structural Materials

million metric tons

| | 1935 | 1950 | 1960 | 1965 | 1970 | 1975 | 1976 | 1977 /estimate/ |
|---|---|---|---|---|---|---|---|---|
| Aluminium | 0.3 | 1.5 | 4.5 | 6.5 | 10.2 | 11.3 | 13.1 | 15.0 |
| Copper | 1.8 | 3.2 | 5.0 | 6.1 | 7.6 | 7.5 | 8.5 | 9.0 |
| Lead | 1.4 | 1.8 | 2.7 | 3.1 | 4.0 | 3.9 | 4.3 | 4.9 |
| Tin | 0.2 | n.a. | n.a. | 0.2 | 0.22 | 0.23 | 0.25 | 0.25 |
| Zinc | 1.4 | 2.1 | 3.2 | 4.1 | 5.2 | 5.0 | 5.8 | 5.8 |
| Steel | 124.0 | 187.0 | 343.0 | 458.0 | 588.0 | 646.3 | 681.8 | 677.0 |
| Plastics | 0.22 | 1.3 | 6.87 | 14.69 | 30.36 | 37.0 | 43.0 | n.a. |
| Wood* | | 210.0 | 337.3 | 374.3 | 404.2 | 423.7 | n.a. | n.a. |
| Cement | 66.2 | 133.0 | 314.2 | 430.5 | 578.0 | 702.0 | 727.0 | n.a. |

* Timber, million cu.metres

Table 2

## World Consumption Growth Indices of Principal Structural Materials

| | 1977/1935 | 1970/1960 | 1977/1960 | 1977/1970 |
|---|---|---|---|---|
| Aluminium | 50.0 | 2.2 | 3.3 | 1.47 |
| Copper | 5.0 | 1.5 | 1.8 | 1.18 |
| Lead | 3.5 | 1.5 | 1.8 | 1.22 |
| Tin | 1.2 | 1.0 | 1.3 | 1.35 |
| Zinc | 4.1 | 1.6 | 1.8 | 1.11 |
| Steel | 5.5 | 1.7 | 2.1 | 1.14 |
| Plastics | 195.5/1/ | 4.4 | 6.3/2/ | 1.42/3/ |
| Wood | - | 1.2 | 1.3/4/ | 1.05/5/ |
| Cement | 11.0/1/ | 1.9 | 2.3/2/ | 1.28/3/ |

| | |
|---|---|
| Index /1/ | 1976/1935 |
| Index /2/ | 1976/1960 |
| Index /3/ | 1976/1970 |
| Index /4/ | 1975/1960 |
| Index /5/ | 1975/1970 |

### 1.21.1 Selection of countries considered in this survey

From the point of view of this survey, in the first place such countries have been considered, whose per capita GDPs had been compared earlier in a special study conducted by the Hungarian Institute of Economic Planning [2].

In the present survey the GDP per capita ratio is used throughout as an index indicating economic development, notably

- to permit comparisons in terms of time to be made, taking 1970 prices as a basis,

- for the sake of comparability converted into U.S. dollars and thereupon corrected. Such corrections were necessary, inasmuch as not the official rates of exchange were used in the calculations, but modified ones, wherein a correlation of 43 different indices of economic factors measured by natural units were taken into account. This correlation, at the time, was made by the Institute referred to above [2].

In international practice, as an index of economic development, the GNP per capita formula, too, is used. However, certain difficulties may arise from its use when it comes to comparing industrialized /market economy/ countries with developing ones [1].

In the calculations data from 23 industrial countries, 8 centrally planned economies and 7 developing countries /Argentina, Chile, Mexico, Brazil, Peru, Egypt and India/ have been considered. Their scope is large enought to permit general conclusions to be reached for the benefit of other countries as well.

### 1.21.2 Aluminium consumption

In the present survey aluminium consumption is classified according to the so-called CIDA nomenclature adopted by the OECD countries in 1973. A breakup of its principal headings is given below:

- Domestic primary aluminium consumption
- Domestic Secondary aluminium consumption, and
- Domestic consumption of imported semi-manufactures.

Consumption under the above headings, of course, does not include exports of semi-manufactures. In more detailed statistical returns semi-manufacture exports are listed in a separate line, permitting to read off domestic aluminium consumption forthwith. Such detailed statistics, however, are not always available and the comprehensive figures released usually include exports of semi-manufactures as well. In view of this, there had been no alternative but to accept these figures at their face value for inclusion in our tables and diagrams. Such vagueness of some data, however, had no significant bearing on the trend calculations. In dealing with a multitude of data there is always a high probability that small margins of errors become eventually outbalanced.

In Fig.1 1976 per capita aluminium consumption is plotted against GDP per capita. The numbered points along the median of the diagram refer to the relative position of each country under survey. 1976 may be regarded as a more or less stable year from an aluminium consumption point of view. No longer emerge by then new aluminium outlets calling for large tonnages. As will be observed, growth rates at that time are more or less in line with the trends of general economic growth.

Over the 1937-68 period the situation had been entirely different. In Fig.2 the medians of four characteristic years are displayed in a single diagram, so as to permit a comparison of growth trends in the long term. The rise of the medians clearly demonstrates that at a given level of economic development, per capita consumption in the long run continued to grow. E.g. at 500 dollar per capita GDP, per capita aluminium consumption rose from 0.5 kilogramme in 1966 to one kilogramme in 1968. In 1968 the median becomes stabilized suggesting that further growth may no longer be anticipated, unless the relative pricing of aluminium were to drop considerably or a number of new volume-intensive aluminium outlets could be found.

Growth of aluminium consumption in some selected countries is diagrammatically illustrated in Fig.3. Here the lines referring to individual countries connect points plotted for each of the four specific years of periods under survey. The deflections in the lines reveal a marked tendency by each country to approach the 1968-76 median. This trend is conspicuous even in case of such countries /e.g. Hungary/ which are still far away from it. A full convergence in the median, of course, may not be anticipated, because of the annual fluctuations of data. But the amplitude of fluctuations has in the past visibly narrowed down around the median and this trend is expected to persist also in future.

The straight median in Fig.3 permits a series of correlations to be read off as to international growth trends of industrial countries since 1968.

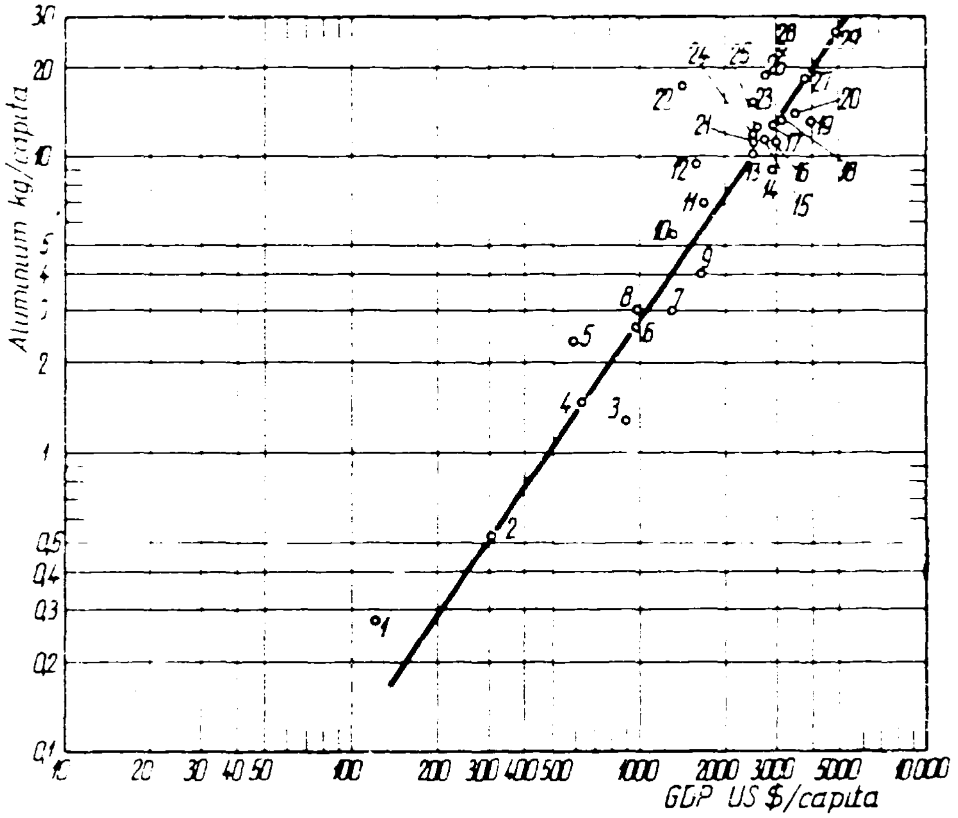

Fig.1 - Per capita aluminium consumption plotted against per capita GDP in 1976

Legend

1. India
2. Egypt
3. Portugal
4. Mexico
5. Brazil
6. South Africa
7. Argentina
8. Greece
9. Ireland
10. Spain
11. Israel
12. Italy
13. Austria
14. New Zealand
15. Belgium
16. Denmark
17. United Kingdom
18. Netherland
19. Canada
20. Australia
21. France
22. Hungary
23. Japan
24. Finland
25. Switzerland
26. Federal Republic of Germany
27. Sweden
28. Norway
29. United States of America

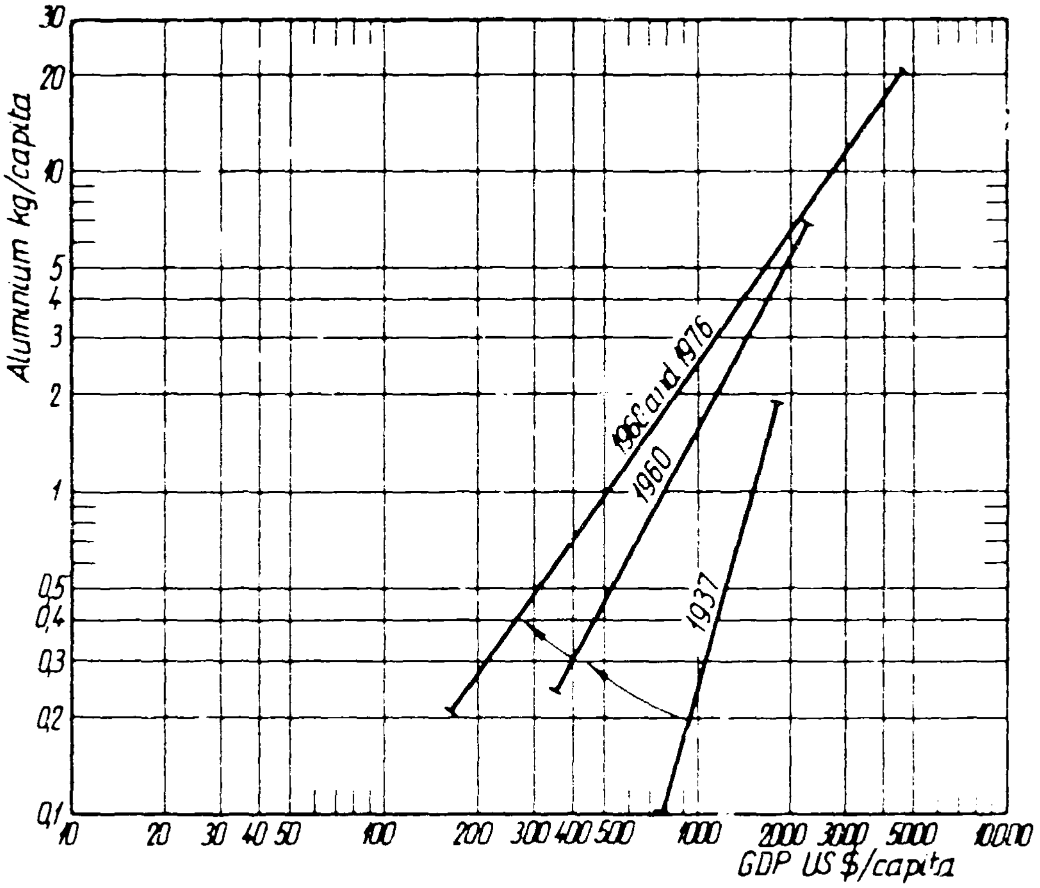

Fig.2 - Aluminium consumption medians for 4 different years summed up from data of 29 selected countries as per Fig.1

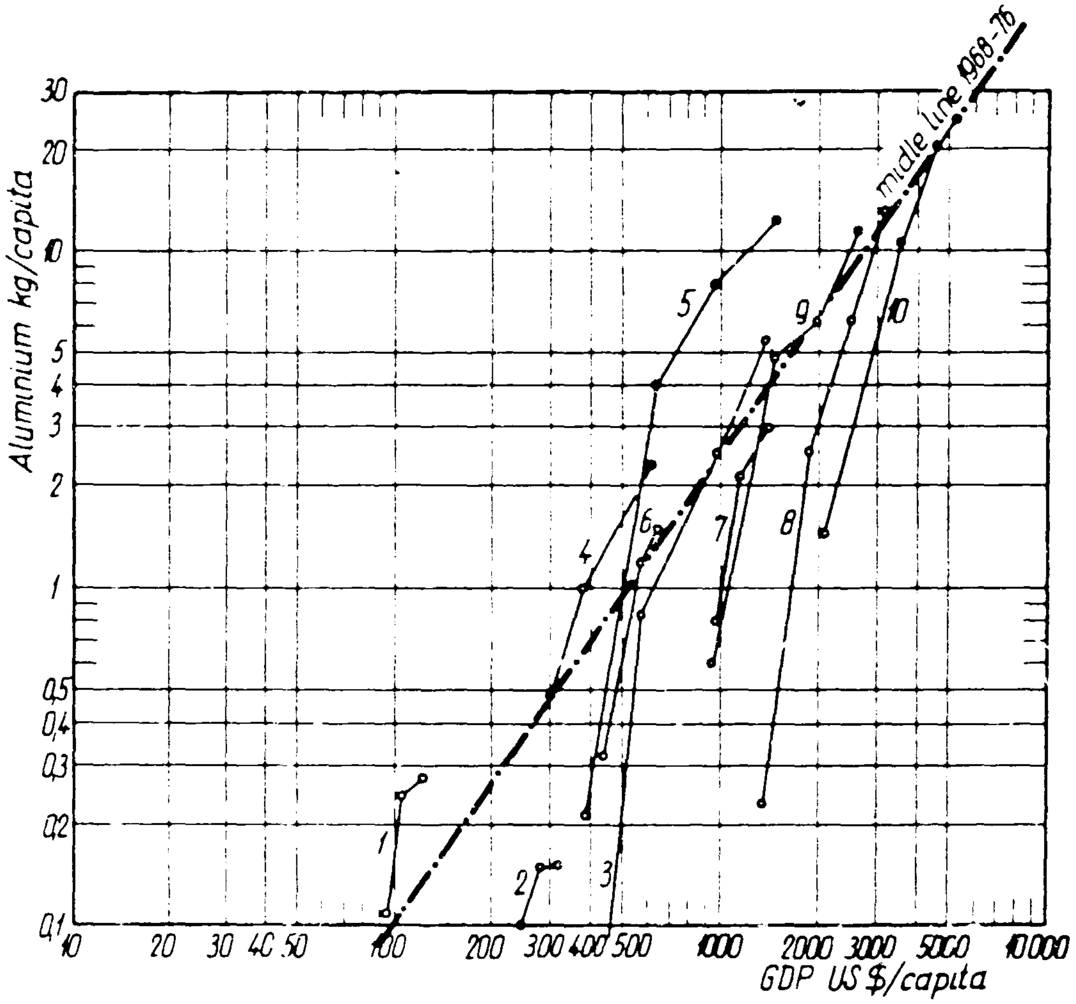

Fig.3 - Aluminium consumption of 10 selected countries in relation to time. Years under survey: 1937, 1960, 1968 and 1976 for industrial countries, and 1960, 1968 and 1976 for developing countries

Legend

| | |
|---|---|
| 1. India | 6. Mexico |
| 2. Egypt | 7. Argentina |
| 3. Spain | 8. Netherland |
| 4. Brazil | 9. France |
| 5. Hungary | 10. United States of America |

Table 3

GDP per capita in relation to aluminium consumption

| GDP<br>$ per capita | Aluminium consumption | |
|---|---|---|
| | kilogramme per capita | kilogramme per $ 1,000 GDP |
| 300 | 0.50 | 1.66 |
| 500 | 1.00 | 2.00 |
| 1,000 | 2.6 | 2.6 |
| 2,000 | 6.75 | 3.38 |
| 4,000 | 17.5 | 4.38 |

It will be observed from the above that aluminium consumption tends to rise at a much faster rate than GDP.

The ratio of the two trends is expressed by what is termed the "elasticity coefficient". It is an index pointing to what percentage of growth in per capita consumption /or any other variable for that matter/ may be related to one per cent growth of GDP. In our case the mean elasticity coefficient is 1.43%.

Hence, if future trends of GDP are known, trends of per capita aluminium consumption too may be forecast. In the following, an elasticity coefficient of 1.4% may be used with fair accuracy in case of aluminium, insofar as international trends apply to a given country. For countries sited below the median the use of a higher, and for such sited above the median the use of a lower elasticity coefficient is advisable. Assuming normal economic growth, in both cases their relative positions will, anyway, tend to converge towards the median /Fig.3/.

### 1.21.3 Steel consumption

In contrast with aluminium, it is a characteristic feature of steel that international mainstream consumption trends expressed by the median have not changed in industrial countries since 1937 /Fig.4/a/. /With no data available for 1976, this is true up to 1966./ Steel consumption, it appears, tends to keep on to its traditional consumption pattern with an elasticity coefficient of 1.5%, despite the fact that in the meantime new and competitive materials have made heavy inroads on the steel market /aluminium, plastics/. Obvious reasons for this stable figure are not only the large steel volumes involved coupled with little scope for substitution, but also technical advances in this field [3]. At this point, a brief reference has to be made to tinplate, a serious competitor of aluminium in the food processing industry /canning of fish and beer/. /See 4.23/.

### 1.21.4 Copper consumption

Data for refined copper consumption are available only for the years 1966 and 1976.

Hungary with its 2.1 kilogramme per capita consumption is one of the world's most modest copper consumers. This is obviously due to the country's very high aluminium consumption in relation to its economic development. Countries of similar economic development, by contrast, have accounted for about 5 kilos copper consumption per capita.

From 1968 to 1978, the median of copper consumption has been rotating around the $ 620 per capita mark. Where it has been over this level /i.e. in all developed countries and such of medium development/, per capita copper consumption has dropped to 1.5 kilogramme, corresponding to that of steel.

In 1976 aluminium consumption per one kilogramme of copper was 1.4-1.8 kilogramme in developed countries, 6.2 kilogrammes in Hungary and 15 kilogrammes in Norway.

While the pricing of aluminium is a detrimental factor in its competition with steel, the situation with regard to copper is the reverse: here, for many end-uses, copper could be replaced by aluminium after prices of the latter had dropped in relation to that of copper considerably. A further encroachment of aluminium on copper seems today largely limited by technological factors only /e.g. flexibility of electrical coil wire, see 4.1/.

### 1.21.5 Timber consumption

Half of the world's wood consumption may be accounted for as fuel, with the other half being used for industrial ends. One-third of the latter is timber, a product we are concerned with in this part of our analysis. Data of fair accuracy were available only for Europe covering the 1950-70 period.

There had been times when the more developed countries used to consume more timber than the less developed ones. Nowadays, however, per capita timber consumption in developed countries may, generally, no longer grow even with GDP per capita constantly rising.

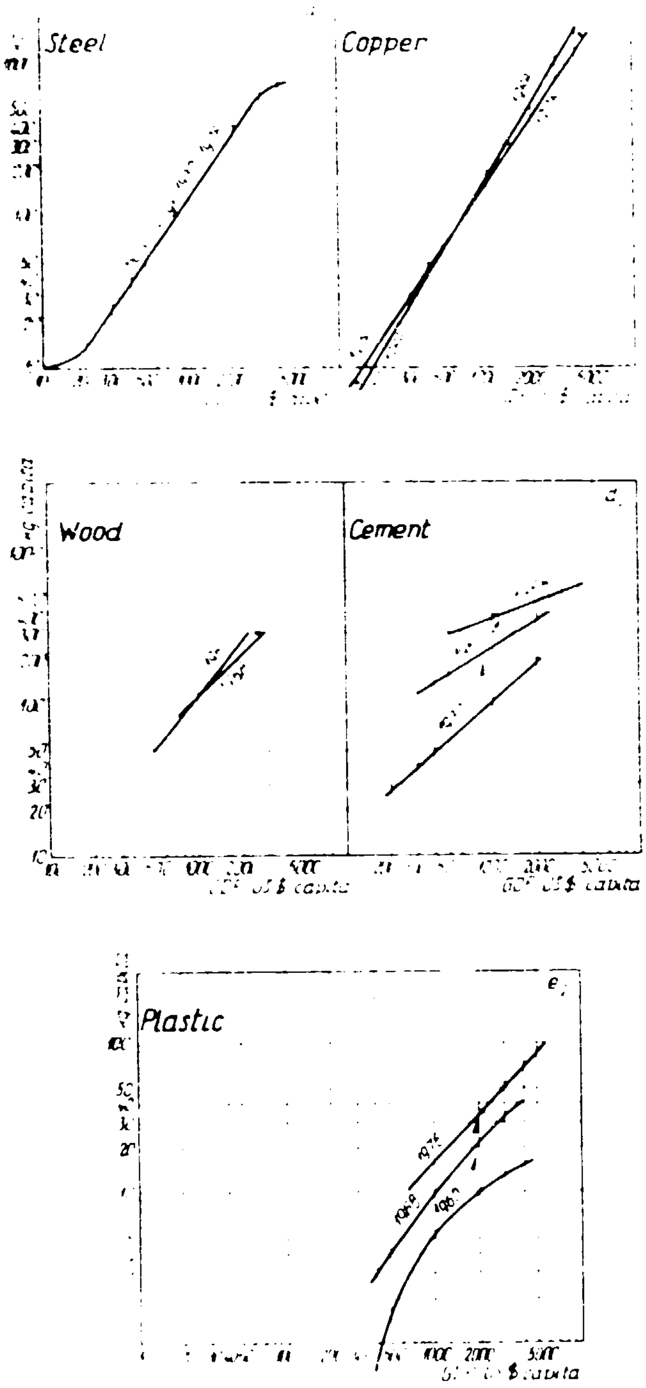

**Fig.4** - Medians of some structural materials related to GDP at different times /Roughly in respect of the same countries as specified in **Fig.1**/

The shortening of the medians and the steepness of their gradients in Fig.4c clearly indicate that timber consumption by the less developed countries tends to approximate that of the more developed ones. /In plotting the medians, countries of the North with their vast wood resources have not been taken into account./ In the more developed countries timber consumption tends to be stagnating or decreasing, in contrast with developing ones, where it is generally growing. This phenomenon may be due to more recent developments in the international division of labour, whereby the utilization of timber, in earlier days almost exclusively determined by the geographical site of resources, has to a large extent become more balanced in the world.

### 1.21.6 Cement consumption

Here numerous data were available for 1937, very few for 1968, and none for 1976, necessitating several estimates to be made in respect of 1967. In view of this, the medians may be less accurate than the others.

With time, the medians tend to attain higher and higher levels revealing more and more pronounced gradients /Fig.4/a/. Accordingly, per capita cement consumption related to GDP has a strong tendency to rise, with its elasticity coefficient tending to drop, e.g. at a $ 100 per capita level from 0.8% in 1937 to 0.3% in 1968.

### 1.21.7 Plastics consumption

Special features:

- The median for each year is sited higher than the one preceding it;

Some of the medians are curved.

Of course, no data were available for 1937 when the plastics industry had still been in its infancy. Also, no 1976 data were available in respect of developing countries.

The medians plotted from available data in Fig.4c/point, at a constant GDP per capita level, to a rising trend of per capita plastics consumption, implying that here we are faced with a vigorous material open for a great variety of end-uses. /Plastics present a typically reverse picture of that of timber/. The increase of plastics consumption, though in some specific fields simultaneous with and a corrollary of that of aluminium /e.g. cable manufacture, heat-insulated sandwich panels, packaging, etc./, may at times also adversely affect aluminium marketing interests /e.g. in the building trade, the transport vehicle industry and the manufacture of some consumer goods/. It is indeed often hard to say, whether the two industries are cooperating partners or competitors. However, with the median of aluminium rising less steeply than of plastics. it seems that in industrial countries plastics tend more and more expand their markets to the detriment of aluminium.

## 1.22 Production and consumption forecasts for aluminium and other structural materials until the year 2000

All authors prognosticating future aluminium trends agree that the dramatic rise of aluminium world consumption over the 1960-70 period corresponding to an annual growth rate of 8-10% is to drop in the coming years to about one-half.

Moreover, it seems highly probable that in the years ahead the share of developing countries in aluminium operations and consumption will grow considerably [4]. Over the 1975-85 period, the aluminium production of industrial countries is expected to grow from 9.1 million tons to 19 million tons. During the same time, aluminium smelter capacities of the developing countries are to become five-fold, expanding from 800,000 tons to 4 million tons. The reality of the latter forecast seems to be confirmed by the following table:

Table 4

Aluminium smelter capacities in developing countries 1960-2000

1,000 tons

| Year | 1960 | 1970 | 1975 | 1977 | 1978 | 1985 | 2000 |
|---|---|---|---|---|---|---|---|
| Source of information | [5] | [5] | [4] | [6] | [6] | [4] | Estimate |
| Capacity | 88.6 | 538.2 | 842 | 1,104 | 1,318 | 4,000 | 12,000-<br>15,000 |

It will be observed from the above that by 1985 the share of developing countries in world smelter capacities may reach 17% of total installed world smelter capacities. Under these circumstances, the target suggested at the 1975 UNIDO General Conference in Lima, that at the turn of the century developing countries should account for 25 per cent of total world industrial production, appears to be a thoroughly fair percentage that can be reached by developing countries as far as the share in world aluminium smelter capacities is concerned.

At the turn of the century aluminium world demand is estimated to be in the order of 54 million tons [8]. This earlier forecast was confirmed in 1978 by the persuasive calculations of Dowding, as summed up in the table hereunder [9]:

Table 5

World consumption of principal structural metals over 10-year periods [9]

million tons

| Metal | 1971-1980 | 1981-1990 | 1991-2000 |
|---|---|---|---|
| Copper | 82.5 | 136 | 206 |
| Aluminium | 133.0 | 218 | 358 |
| Lead | 48.0 | 50 | 61 |
| Zinc | 58.0 | 79 | 102 |
| Steel | 6900.0 | 10,200 | 13,800 |

For aluminium, Dowding forecasts a 5% annual growth rate, This has been compared to and reconciled with our own findings, whereupon the following two tables may now be presented:

Table 6

## Forecasts of aluminium world consumption*

/Estimate/

million tons

| Group of countries | 1978 | 1985 | 1990 | 2000 |
|---|---|---|---|---|
| Developing countries | 1.2 | 3.0 | 4.8 | 10.0 |
| Centrally planned economies** | 4.3 | 6.0 | 7.7 | 12.0 |
| Developed market economies | 14.5 | 19.0 | 23.5 | 36.0 |
| World | 20.0 | 28.0 | 36.0 | 58.0 |

* Including secondary aluminium

** Bulgaria, Czechoslovakia, German Democratic Rep., Hungary, Poland, Romania, USSR and the People's Rep. of China

Table 7

## Forecasts as to annual growth rates of aluminium consumption /based on Table 6/

/Estimate/

per cent

| Group of countries | 1978-1985 | 1986-1990 | 1991-2000 |
|---|---|---|---|
| Developing countries | 14.0 | 10.0 | 8.6 |
| Centrally planned economies* | 4.9 | 5.1 | 4.8 |
| Developed market capacities | 3.9 | 4.5 | 3.9 |
| World | 5.0 | 5.1 | 5.1 |

* Bulgaria, Czechoslovakia, German Democratic Rep., Hungary, Poland, Romania, USSR and the People's Rep. of China

Dowding's analysis also includes forecasts as to annual growth of GDP by group of countries [9]. On relating these to the annual growth of aluminium consumption, it appears that while in developed countries the annual growth of aluminium consumption is 1.2-1.3-times that of GDP, the coefficient of elasticity for developing countries is

1.9 for 1978-85,
1.5 for 1985-90 and
1.4-1.6 for 1990-2000.

Hence, until the year 2000, world aluminium consumption is expected to keep on growing faster than GDP. At the turn of the century growth rate in developing countries may reach the same level as that of developed countries in 1960-70.

Findings in the present study are also substantiated by Altenpohl's analysis claiming that in developed countries an annual growth rate of 3% and in some developing countries /e.g. Brazil, Iran/ such of 10-20% may in the long term be anticipated [10].

The aluminium consumption of developing countries in terms of volume has grown from 119,000 tons in 1960 to 479,000 tons in 1972, by 1972 reaching even the 605,000-ton mark [11]. Per capita aluminium consumption by geographic location was as follows:

| | |
|---|---|
| Africa | 0.14 kilogramme per capita |
| Asia | 0.25 kilogramme per capita |
| South America | 1.1 kilogramme per capita |
| Average | 0.33 kilogramme per capita. |

Growth of aluminium consumption in a given country or geographic area is not solely determined by standards of general economic development. A great deal depends also on the availability of aluminium and on the organizational pattern of how aluminium usage is promoted on site. In 1976 world smelter aluminium consumption amounted to 13.9 million tons. Of this the USA and Canada accounted for 35%, Western Europe for 25%, the Soviet Union for 12% and Japan for 11%. The remaining 17% was produced by other countries [12] . The share of developing countries within this latter figure was 7-8%, with the rest to be accounted for by other developed countries /Australia, South Africa/ and other centrally planned economies. If developing countries may sustain the growth trends of the present decade, by the second half of 1980 an annual aluminium consumption of 3 million tons could be arrived at by them.

Aluminium consumption is always affected by competition from other materials from the point of view of technological and economic feasibility. Several correlations in this respect are to be found in Fig.5 [13]. The prognostications therein are insofar of more interest than further general predictions, as they raise several issues relevant to the substitution of aluminium and other structural materials with one another.

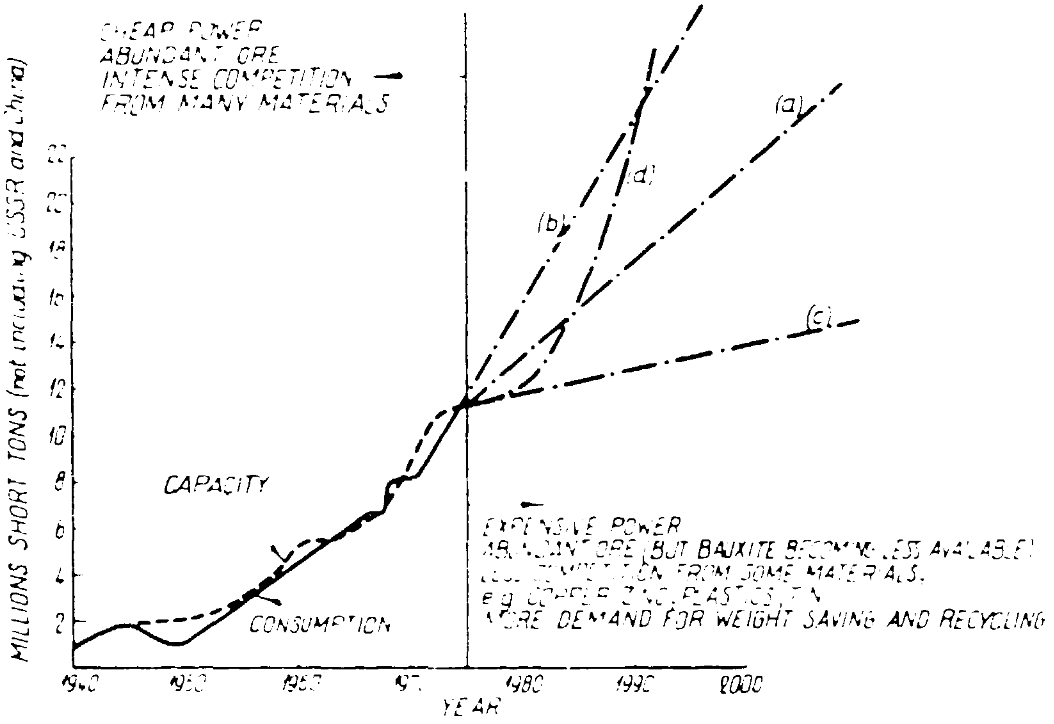

Fig.5 Growth of aluminium industry within the last 25 years and some future trends /after Woodward/

a/ The growth rate is similar to that of the earlier 25 years;

b/ The growth rate is sustained and more aluminium is used to replace costlier structural materials or such as are in short supply /e.g. copper, zinc, plastics/;

c/ The growth rate is influenced by the insufficiency of smelter capacities and rising energy prices; such developments have a marked effect on the aluminium market situation in the building, transport vehicle and electrical engineering sectors;

d/ The trend of the curve implies that more aluminium is used to replace other structural materials, but such surplus demand has to be met with by the available capacities. The new smelter capacities expected to go on stream in the mid-eighties to meet such extra demand are calculated to embody new technologies based on other raw materials than bauxite.

Fig.5 looks like a useful instrument in going ahead with further speculations about future consumption trends, permitting an analysis of more depth in assessing major likely end-uses to be involved in different parts of the world. But this exercise, however intriguing and useful it may appear at first sight, has also some pitfalls. In the absence of a great many necessary data and the presence of many variables and unforeseen circumstances, at this juncture only rough outlines may in this respect be given. As a starting point, in Table 8 a breakup of aluminium consumption by end-use is given in respect of different countries and areas for several years of the 1970s. These figures have to be handled with utmost care in making comparisons and prognostications. As will be observed, the end-use data reveal considerable standard deviations even within the same group of countries. E.G. in industrialized Sweden aluminium usage by the building trade accounts for 25-27%, whereas in France and Norway the corresponding figures are 8.5% and 5%, respectively. In Sweden packaging accounts for 4-5% only, contrasting with 13-20 for Switzerland and 22% for the USA Evidently, the economic feasibility of using any material for a specific end may vary

Table 8

## Breakup of aluminium usage in a few selected countries and areas

| End-use | USA 1976 /14/ | | Developed countries of Europe, 1973 average /15/ | | Hungary 1976 /16/ | | Brazil 1974 /17/ | | India 1974 /18/ | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1,000 ton | % | 1,000 ton | % | 1,000 ton | % | 1000 ton | % | 1,000 ton | % |
| Transport vehicles | 1,163 | 22 | 1,154 | 28 | 15 | 8 | 41 | 19 | 15 | 12 |
| Mechanical engineering | 375 | 7 | 330 | 8 | 6 | 3 | 7 | 3 | - | - |
| Electrical engineering | 555 | 10 | 454 | 11 | 41 | 22 | 56 | 26 | 65 | 52 |
| Building | 1,331 | 25 | 700 | 16 | 18 | 10 | 39 | 18 | 7 | 6 |
| Packaging | 1,166 | 22 | 454 | 11 | 10 | 6 | 15 | 7 | 5 | 4 |
| Household and other fabricated items | 408 | 7 | 330 | 8 | 13 | 7 | 45 | 20 | 25 | 20 |
| Miscellaneous, including export of semi-manufactures | 402 | 7 | 700 | 15 | 81 | 44 | 14 | 7 | 8 | 6 |
| Total | 5,400 | 100 | 4,123 | 100 | 184 | 100 | 217 | 100 | 125 | 100 |

significantly from country to country by a combination of circumstances /tradition, fashion, technological standards of certain industries, experience, etc/.

To show how the pattern of aluminium consumption may change in the course of time, let us cite once again Hungary's example. A breakup of 1966-1978 end-uses there in terms of volumes is demonstrated in Table 8. The same breakup in percentages is to be found in Table 9.

What are now the prospects of aluminium world consumption in the medium and long term? In the following, an attempt in made to outline principal trends.

In industrial countries, where power economy has become a crucial issue, a further upswing of aluminium may be anticipated in transport vehicle manufacture, electrical engineering, the manufacture of heat-exchangers, containers and components for the mechanical engineering industry, as well as in camping and sports items. This will be accompanied with a downward trend in the growth rate of aluminium usage in building and packaging.

In developing countries, at first electrical engineering is to make great headway in aluminium usage, with packaging for specific ends following suit. /e.g. for new fisheries, dairies and food-canning facilities/. Household appliances, too, will be a fast expanding outlet. At some later time also other end-uses will enter into the picture depending on the economic pattern, geographic situation and other circumstances prevailing in each country.

Table 9

Breakup of aluminium consumption in Hungary by end-uses in percentages [16].

Annual mean growth rate 1966-76: 7.9%

1,000 tons

| End-uses | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A. Transport vehicles | 11.8 | 11.4 | 12.7 | 12.8 | 12.5 | 11.8 | 13.0 | 14.1 | 15.4 | 15.8 | 15.3 |
| B. Mechanical engineering | 2.9 | 2.7 | 3.8 | 4.2 | 4.0 | 5.7 | 4.0 | 5.9 | 6.7 | 4.8 | 5.8 |
| C. Electrical engineering | 24.2 | 26.9 | 30.2 | 28.8 | 30.6 | 33.2 | 33.7 | 31.6 | 36.4 | 38.0 | 40.9 |
| D. Building | 2.9 | 3.1 | 3.6 | 6.2 | 8.7 | 10.9 | 13.2 | 17.2 | 19.4 | 20.3 | 18.4 |
| E. Chemical engineering, food processing, agriculture | 7.3 | 8.6 | 9.9 | 11.2 | 11.0 | 3.8 | 3.6 | 6.2 | 6.9 | 7.1 | 7.0 |
| F. Packaging | | | | | | 7.7 | 7.4 | 7.9 | 9.8 | 9.4 | 10.1 |
| G. Household and office appliances | 8.4 | 8.9 | 8.8 | 9.4 | 16.4 | 5.9 | 3.7 | 5.8 | 6.2 | 6.2 | 6.1 |
| H. Powder | 3.2 | 3.1 | 5.0 | 5.2 | 5.5 | 5.5 | 6.9 | 4.0 | 4.0 | 4.0 | 3.5 |
| I. Steel industry | | | | | | | | | | | |
| J. Other fabricated items /excluding A - I/ | | | | | | 10.8 | 9.1 | 8.8 | 12.0 | 16.1 | 15.7 |
| K. Miscellaneous | 4.6 | 4.4 | 8.6 | 8.5 | 12.6 | 7.6 | 7.5 | 8.0 | 12.6 | 14.6 | 14.4 |
| L. Exports of semi-manufactures, foils and powder | 5.6 | 4.7 | 3.8 | 2.8 | 5.5 | 12.1 | 18.1 | 22.1 | 28.9 | 46.8 | 46.8 |
| Total | 70.9 | 73.8 | 86.4 | 89.1 | 106.8 | 117.1 | 120.5 | 131.6 | 158.3 | 183.2 | 184.0 |

Table 10

Breakup of aluminium consumption in Hungary by end-uses in percentages [16].

Per cent

| End-uses | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A. Transport vehicles | 16.8 | 15.7 | 14.7 | 14.2 | 11.7 | 11.8 | 10.8 | 10.7 | 9.7 | 8.6 | 8.3 |
| B. Mechanical engineering | 4.0 | 3.7 | 4.4 | 4.7 | 3.7 | 4.8 | 3.3 | 4.5 | 4.2 | 2.6 | 3.2 |
| C. Electrical engineering | 34.3 | 36.5 | 35.0 | 32.4 | 28.6 | 28.3 | 28.0 | 24.0 | 23.9 | 20.7 | 22.2 |
| D. Building | 4.0 | 4.1 | 4.1 | 7.0 | 8.1 | 9.3 | 10.9 | 13.1 | 12.3 | 11.1 | 10.0 |
| E. Chemical engineering, food processing, agriculture | 10.4 | 11.6 | 11.5 | 12.5 | 10.89 | 3.7 | 2.0 | 9.4 | 3.5 | 3.9 | 3.8 |
| F. Packaging | | | | | | 6.5 | 6.4 | 6.0 | 6.2 | 5.1 | 5.5 |
| G. Household and office appliances | 11.8 | 12.0 | 10.1 | 10.6 | 15.5 | 5.0 | 3.1 | 4.4 | 3.9 | 3.4 | 3.3 |
| H. Powder | 4.4 | 4.1 | 5.8 | 5.9 | 5.2 | 4.6 | 6.7 | 3.0 | 2.5 | 2.2 | 1.9 |
| I. Steel industry | | | | | | | | | | | |
| J. Other fabricated items /excluding /A-I/ | | | | | | 9.2 | 7.5 | 6.7 | 7.6 | 8.8 | 8.5 |
| K. Miscellaneous | 6.5 | 6.0 | 9.9 | 9.6 | 11.8 | 6.5 | 6.2 | 6.1 | 7.9 | 8.0 | 7.9 |
| L. Export of semi-manufactures, foil and powder | 7.8 | 6.3 | 4.5 | 3.1 | 5.1 | 10.3 | 15.1 | 16.8 | 18.3 | 25.6 | 25.4 |
| Total | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |

Modern agriculture will call for up-to-date cold-storage rooms, irrigation systems, submarine desalinating facilities and building structures, all featuring aluminium. In the transport vehicle and mechanical engineering field, operations will be at first confined to assembly work followed at some later time by the manufacture of special components and products /e.g. high-standard castings/. It is desirable that upon installing new fabricating capacities effective arrangements be made forthwith as to the collecting and recycling of scrap arisings, which are usually in the order of 21-26% of aluminium input.

More details of aluminium usage /possibilities of replacing other materials by it, fresh outlets, etc./, as well as of sources of know-how and its application in actual practice /technologies and products/, are discussed at full length under chapters 5 and 6, respectively.

## 1.3 The pricing of structural materials; forecasts as to future pricing trends

The world market prices of the principal structural materials and their pricing in relation to aluminium over the 1935-1977 period are summed up in Tables 11 and 12, respectively.

An analysis of the pricing trends in Table 11 will clearly demonstrate that as from the end of the Second World War a marked shift in favour of aluminium has taken place to the detriment of copper and steel. The 1973 rise of oil prices did not significantly affect the relative pricing of metals. /Fluctuations in aluminium and copper prices were largely due to market speculation/.

Table 11

## Mean world prices of some selected structural materials

/Based on annual average quotations in current prices/

U.S. $/t

| Material | 1935 | 1950 | 1955 | 1960 | 1965 | 1970 | 1975 | 1976 | 1977 |
|---|---|---|---|---|---|---|---|---|---|
| Aluminium/1/ | 482 | 370 | 500 | 577 | 545 | 614 | 860 | 969 | 1.108 |
| Copper/2/ | 172 | 472 | 500 | 712 | 780 | 1.393 | 1.205 | 1.381 | 1.293 |
| Lead | 69 | 300 | 332 | 265 | 260 | 304 | 412 | 446 | 617 |
| Zinc | 68 | 210 | 273 | 287 | 320 | 296 | 745 | 711 | 589 |
| Tin | 1.090 | n.a. | n.a. | n.a. | 3.428 | 3.673 | 6.870 | 7.583 | 10.798 |
| Steel billets | 34 | 65 | n.a. | n.a. | n.a. | ko. 93 | 173 | 168 | 154 |
| Plastics /PVC//3/ | n.a. | n.a. | n.a. | 350 | 351 | 359 | 642 | 566 | 619 |
| Cement | n.a. | 6 | n.a. | 7 | 8 | 10 | 20 | n.a. | 25 |

/1/ Mean price, ex smelter

/2/ Cathode copper

/3/ Mean price in Federal Republic of Germany

Forecasts published in the world press unanimously agree that the 1970 level of relative pricing of structural materials will persist in the long term, though in absolute terms they predict rising prices throughout the coming years [19]. Such price hikes are considered to be necessary to ensure the economical operation of new capacities coming on stream, although their actual magnitude is suggested to be less than that of oil [9]. Prognostications forecast an annual rise of 3-5% in aluminium prices, by 1980 reaching a 60-63 USA cent/lb. official Canadian price [20]. These predictions seem to be based on the fact that with costs of capital investment steadily rising, by 1977-1978 a price of 55 U.S. cent/lb. or U.S. $ 1.22 per kilogramme may be the lowest limit, at which the operation of an aluminium smelter may still be cost-effective. The installation of a new smelter calls for capital investment of U.S. $ 2,000-2,500 per ton [15]. A steeper average price rise is improbable, because by then new smelters in developing countries would be operative using inexpensive power, and a higher upward trend in aluminium prices would seriously endanger the competibility of aluminium usage. Under these circumstances it is believed that the major share of growth in consumption will be accounted for by some end-using sectors, where unequivocal, direct and significant benefits may be derived from aluminium usage [19]. Cases in point are electrical engineering, transport vehicle manufacture and certain areas of packaging.

Before concluding this part of our analysis, a comparison of average annual pricing trends of some raw materials, sources of power and labour costs involved in aluminium and steel production are tabulated below [21].

Table 12.

### Relative pricing of some structural materials by volume

/Aluminium mean price taken as 100/

| Material | 1935 | 1950 | 1955 | 1960 | 1965 | 1970 | 1975 | 1976 | 1977 |
|---|---|---|---|---|---|---|---|---|---|
| Aluminium | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Copper | 35 | 127 | 100 | 123 | 143 | 227 | 140 | 142 | 117 |
| Lead | 14 | 81 | 66 | 45 | 48 | 50 | 48 | 46 | 56 |
| Zinc | 14 | 57 | 55 | 50 | 59 | 48 | 86 | 73 | 53 |
| Tin | 226 | - | - | - | 629 | 598 | 799 | 782 | 975 |
| Steel billet | 7 | 17 | - | - | - | 15 | 20 | 17 | 14 |
| Plastics | - | - | - | 61 | 64 | 57 | 76 | 58 | 54 |
| Cement | - | 2 | - | 1.2 | 1.5 | 1.6 | 2.3 | - | 2.2 |

Table 13

### Estimated annual mean growth of some raw materials and other pricing factors in Europe

/After CRU/ [21]

Per cent

| Raw material | 1976-1981 | 1981-1986 | 1986-1991 |
|---|---|---|---|
| Bauxite | + 0.55 | + 0.65 | + 1.0 |
| Iron ore | + 1.1 | + 1.3 | + 2.0 |
| Power | | | |
| Electric power | + 1.6 | + 2.2 | + 1.4 |
| Coke | + 4.6 | + 2.0 | + 1.4 |
| Natural gas | + 3.0 | + 2.0 | + 3.5 |
| Labour costs | + 4.1 | + 4.3 | + 4.0 |

In view of the trends outlined above, there is a strong probability that in the years ahead the pricing of aluminium will be competitive with that of steel. While over the 1976-1991 period e.g. the price of steel castings is believed to grow at an annual rate of 8-8.5%, the corresponding rise of aluminium prices is estimated to be in the order of 5% only. The rise of relative pricing will first of all affect the transport vehicle industry, but its effects are to be felt also in the building trade and packaging field as well.

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## 2. SUITABILITY OF ALUMINIUM FROM A TECHNOLOGICAL AND FINANCIAL POINT OF VIEW FOR NEW APPLICATIONS AND TO REPLACE OTHER STRUCTURAL MATERIALS

Any effort of replacing a structural material by an other is aimed to take utmost advantage of the latter's most useful properties. In assessing such prospective benefits in respect of a given country or area - next to the availability of raw material and power on site - the following circumstances have to be taken into account:

- Economic structure and the distribution pattern of capital. /Prevalence of many independent small and medium-sized enterprises; industry and agriculture controlled by large concerns or public corporations/;
- The volume of experience of local manpower;
- The pattern of the domestic market, and how far the latter may be influenced by intervention on the part of government agencies.

Applying these considerations to aluminium, a combination of favourable and detrimental factors emerge, which may be dealt with in detail as below.

### 2.1 Favourable factors

#### 2.11 The raw material situation

90% of the world's alumina output is won from bauxite by the traditional Bayer process or its modifications. Calculated at a 5% annual average growth rate of consumption, the world's total bauxite ore reserves are sufficient for 150 years of alumina production [1]. Next to commercial grade bauxite ores, there are also supplementary resources of poor grade bauxites and other substances of low $Al_2O_3$ content, such as clay, ash, etc. Throughout the world successful efforts are undertaken to process alumina from these economically on an industrial scale. Considering this vast potential, raw material to feed aluminium smelters seems to last for an almost unlimited length of time. With the exception of Australia, at present practically all high-grade bauxite reserves of the world are now located in the tropical areas of developing countries.

Another indispensable prerequisite of running an aluminium industry economically is inexpensive electric power. In industrial countries - where until 1970 the bulk of the world's aluminium smelters was located - a further large-scale expansion of power-intensive aluminium smelter facilities appears hardly to be feasible. The operation of new smelters in such areas could only be based on an additional supply of nuclear power. A case in point is the United Kingdom, where the aluminium smelters erected in the 70's are connected to a grid, where 60% of all electric power transmitted is being generated by nuclear energy. By contrast, there is still a vast unharnessed hydro-electric power potential in the developing countries as tabulated below [2].

| Continent | Untapped share of hydro-power per cent | Megawatt |
|---|---|---|
| Africa | 98 | 429,000 |
| South America | 93 | 269,000 |
| Asia /excluding the Soviet Union/ | 93 | 637,000 |

In addition to hydro-power, the oil producing countries, too, represent a vast power potential with their significant volumes of natural gas still burned away on site without being put to any practical use.

The operation of a 100,000 t.p.a. aluminium smelter calls for a steady power supply of 180 megawatts.

Another important material in operating an aluminium smelter is petrol coke, likely to be in short supply by the end of the century [1].

Thus, from a raw material point of view, possibilities of expanding aluminium smelter operations appear to be practically unlimited.

With regard to fabricated products, the situation is somewhat different. In developing finished product manufacturing facilities, a firm aluminium ingot market, however desirable in itself, may not solve all problems. An equally essential consideration is to have sufficient and effective semi-fabricating capacities installed, capable of taking care of the full impact of demand forthcoming from the aluminium end-using sectors. The installation of semi-manufacturing facilities for producing a fair selection of basic semi-fabricated items for use by the finished product manufacturers may be feasible from a technological and economic point of view even if operations are kept at a more modest scale. Metal won in the smelter may be processed to semi-manufactures in the molten state forthwith by continuous cast equipment directly sited at the smelter, producing 10-20,000 tons of aluminium strip or rod wire coils anually. The manufacture of extruded shapes, profiles and tubes, by contrast, is done in premises elsewhere, using cast aluminium billets dispatched from the smelter. The installation of such smaller semi-manufacturing capacities, while designed to produce a multiplicity of items /except wide strips/, does not call for substantial capital investment and may also be expanded subsequently, if justified by demand.

## 2.12 Relatively stable price levels.

Until the end of the 1970's some 70-75% of total aluminium production by developed countries could be accounted for by six major aluminium concerns: ALCAN, ALCOA, Reynolds, Kaiser, Alusuisse and Pechiney. The market price of aluminium until then too had at all times been governed by the joint business policy of the six majors. With a view to expanding aluminium consumption and penetrating into fresh areas of aluminium usage, they tended to keep aluminium prices at as stable a levels as possible. This is how the so-called "official" market price of aluminium has come into being, based on the 99.6% purity ingot quotation of Alcan, d/d all seaports except those of the USA, Canada, the U.K., and as from 1974 also those of South America. The official aluminium price has remained practically unchanged over longer periods /sometimes for up to 2-3 years/. From 1965 to 1973 it has risen by 10% only, corresponding to an annual average of 1.3% [4]. In principle, 90% of all aluminium market transactions are based on this official quotation. However, in view of growing integration in the aluminium industry, a considerable part of such aluminium is dispatched to the own subsidiaries and affiliated companies of the majors with special confidential discounts granted to protect them against market fluctuations. When there is a recession, such confidential discounts are frequently granted to independent producers as well. Next to the official market price, the London Metal Exchange used to quote in an unofficial capacity also so-called "free market prices", at which, however, only marginal volumes of business were transacted. When demand and supply were balanced, there was no significant difference between the two prices. As from October 1978, the London Metal Exchange has been quoting an official aluminium price as well. At the moment it is still early to say how this may affect the general trend of pricing.

This stable system of pricing has undoubtedly contributed to the annual 9-11% growth of aluminium consumption throughout the 1960's. It has vigorously intensified aluminium usage in various fields, e.g. in the building trade, in packaging and in the manufacture of transport haulage equipment. However, certain drawbacks of the artificially stable aluminium prices became manifest upon the 1973 oil price rise when profits derived from aluminium operations began to decline sharply. By then, too, smelter capacities of the six major concerns have dropped to 44% of world market capacity, after new and partly government-backed aluminium projects have gone on stream in developing countries [3]. To make up for such losses, the majors thereupon decided to raise aluminium prices. The rise has been 62% over the 1973-76 period [4]. Aluminium operations have thereby become more economical, with no significant changes in the pricing of aluminium in relation to most other structural materials. /The 1977-78 record low of copper price was just a passing episode/. Although following the critical time when oil prices rose considerably, some of the structural materials did display marked price fluctuations, aluminium has revealed a more conservative trend of rising prices. Fig.6 is a comparison of aluminium conductor and extrusion prices with those of rolled steel products on the French market [5].

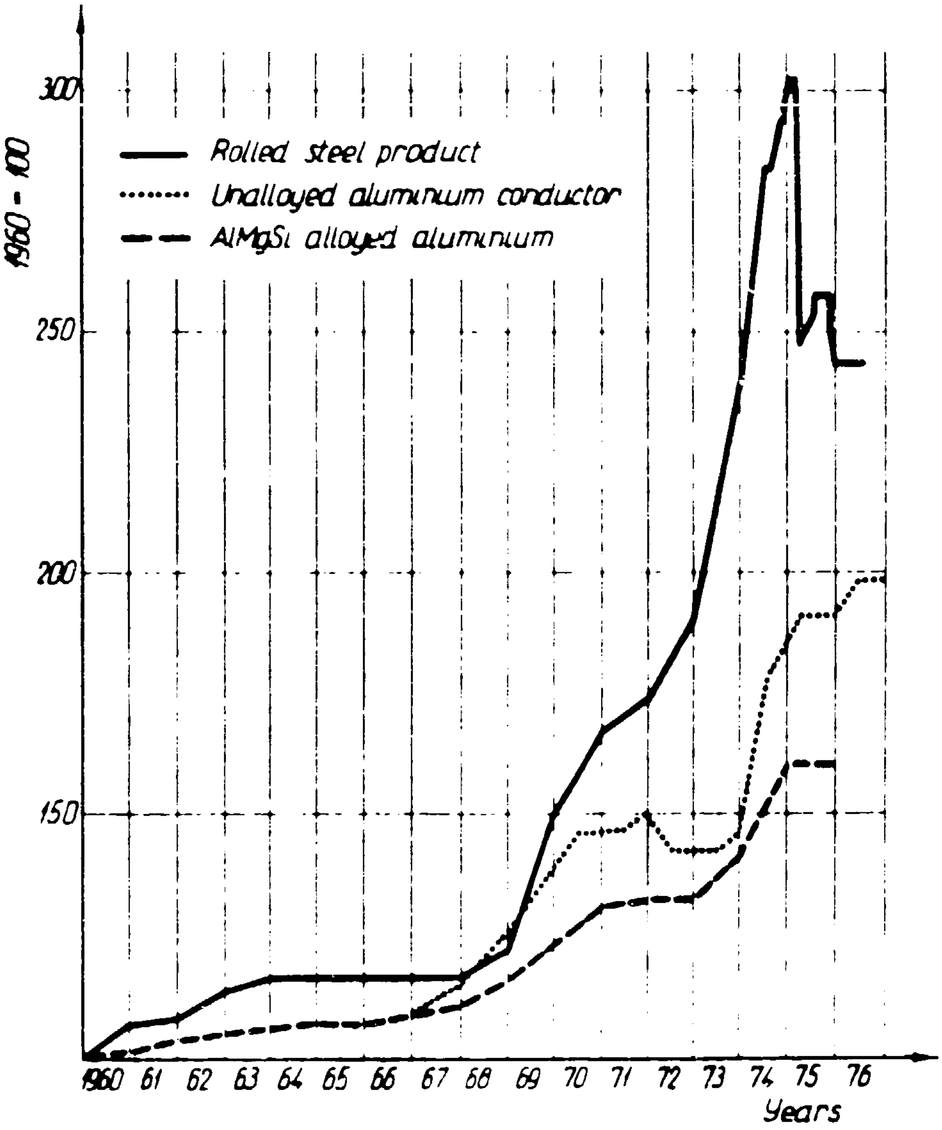

Fig.6 - Changing prices of some aluminium semi-manufactures and steel products on the French market [5]

## 2.13 Competitiveness in price with regard to other materials; comparative calculations

Recent widespread aluminium usage may only be partly attributed to shifts in the pricing of structural materials and the relatively stable pricing pattern of aluminium as outlined under sub-chapters 1.3 and 2.12, respectively. The real crux of the matter are certain unique physicotechnical properties of aluminium having a great impact on aluminium usage in a variety of end-using sectors. Cases in point are several fields of aviation and space research, where lightness coupled with relatively high mechanical strength and good corrosion-resistance are distinctive features rendering the metal highly competitive.

From a standpoint of technological and economic feasibility, aluminium usages may be classed into two major categories, viz.:

- where in view of shifts in pricing the economic feasibility of aluminium usage may be readily demonstrated. Under this heading come first of all direct substitutions of heavy non-ferrous metals by aluminium. Expertly designed, manufactured and assembled aluminium structures may not only be equivalent to but also more useful than those of traditional design; their price, too, is considerably lower. Typical examples are aluminium conductors replacing copper ones, aluminium collapsible tubes and foils used instead of tin ones, or screw bottle closures /pilfer-proof caps/ to substitute cork. According to an inquiry made in the Federal Republic of Germany in 1970, the average cost price of cork bottle closures was 0.045-0.10 DM per piece, in contradistinction with 0.02 DM per piece for aluminium screw bottle closures. The position in similar in substituting zinc rainwater hardware by aluminium or the use of aluminium coolers instead of heat-exchangers made from stainless steel or tin-coated copper.

- The second category embraces aluminium usages, where costs compared to traiditional designs may be higher, but the technical features of aluminium may be put to better advantage. If properly used in itself or in combination with other materials over a longer space of time, such aluminium applications may eventually become a paying proposition, despite higher purchase costs involved at the outset. Cases in point are various aluminium constructions used by the building trade, window and door frames or aluminium components used by other industries to enhance operational efficiency /e.g. pistons, machine accessories for textile mills, heat exchangers etc./ involving no or only slight maintainance costs.

In using aluminium, the following positive features are of special interest:

- Economies in power
- Environmental protection
- Extra benefits from scrap recycling
- Savings in labour both on the production and consumption side /e.g. smaller maintainance costs/
- More comfort for the population /facilitation of household work, light camping and sports items, etc./.

In feasibility studies it is not enough to examine whether or not aluminium is an equivalent alternative to the material to be replaced; it is very important that from its usage the consumer should benefit. For this end

- The relative pricing of raw materials involved in the production process has to be carefully examined, along with the amount, value and usefulness of scrap arisings. In comparing e.g. aluminium and tinplate bottle closure manufacture, next to relating aluminium price with that of tinplate, allowance has to be made for 30% scrap, arising upon cutting the aluminium discs to shape. While the resultant recoverable aluminium scrap represents 9% of the value of the aluminium sheet used, the corresponding figure for tinplate is only 0.6% [6].

- The design of the aluminium structure has to be such as to permit optimal utilization of the metal's inherent favourable properties. The simple application of aluminium in designs originally prepared for other materials is uneconomical and from the outset doomed to failure. A good example of how aluminium may be used economically are the latest metro carriages designed by Alusuisse, featuring large aluminium extrusions for framings. Such carriages are 30% cheaper than those of conventional design with steel framing [7].

- A detailed analysis has to be made of all operations involved in manufacture and assembly, with special regard to savings in time and labour. Several examples of this may be cited in the building trade and metalworking industry. Costs of erecting conventional premises for agriculture and livestock farming are 17% smaller than those of light aluminium panel construction, but labour and time in putting up the latter are 30% less, the two figures more or less outbalancing each other. Moreover, aluminium light constructions lend themselves well for serial manufacture and the siting of major agricultural facilities in more remote areas, such as cold-storage rooms, complex poultry farms etc. in developing countries.

- In addition to the foregoing, special attention has to be devoted to the changing pattern of power resources and the sustained trend of rising power costs. Throughout the world great strives are made to save power, in the wake of which there is now a universal demand for reducing the weight of transport vehicles and transport haulage equipment. The relative pricing of structural materials used in the manufacture of such products /with special regard to steel versus aluminium/ is a crucial factor in determining the viability of aluminium usage. On computing economic feasibility, the surplus interest involved in employing aluminium structures of higher costs, too, has to be allowed for. As to how fast such increased capital expenditure may be recycled to the investor will at all times primarily depend on the magnitude of power prices and operational costs affected by it.

- Thanks to the good corrosion-resisting properties of aluminium, considerable savings may be arrived at in maintainance costs. In case of a steel structure over a period of 30 years some 30-70% of its cost price, plus 0.6-1.0 manhour per square metre and year has to be spent on maintainance. Relating this to the higher purchase costs of an aluminium structure, and once again calculating a higher amount of interest, it appears that e.g. the use of aluminium wire fencing may after 6-8 years become more economical than that made from steel [8].

= From an environmental protection point of view, aluminium presents great advantages. While the destruction of plastic scrap is a tough problem and the handling of steel scrap in view of its weight and volume cumbersome, the collection of aluminium scrap and its recycling into production is a relatively simple and inexpensive procedure. Moreover, by remelting aluminium scrap, considerable power economies may be arrived at [9] /see also sub-chapter 2.15/. In the USA a recent drive of collecting and remelting hitherto throwaway aluminium beer cans has resulted in a rising turnover of aluminium-canned drinks /see sub-chapter 4.24/.

As emphasized in the foregoing, keen competition is going on between aluminium and other structural materials in conquering new fields. Who is to win in this strife, always depends on the technological and economic merits of each solution. In making realistic evaluations, however, no longer does it suffice to approach each issue from a micro-economic angle as viewed by the producer or consumer, but the overall effect of such developments on the macro-economy of the country or area concerned, too, has to be taken into account. /E.G. power savings, aspects of environmental protection, balance of payment, etc./ A more detailed analysis of aluminium end-uses in this context is to be found in Chapter [4].

## 2.14 Favourable technical features

It always depends on the nature of end-use whether low specific weight, good electrical conductivity, susceptibility to plastic deformation, thermal conductivity or corrosion resistance are the principal properties sought for in selecting aluminium as a structural material. Of course, it would be an ideal state of affairs, if all these superior properties could be readily made use of for every application. This, however, is not the case, there being marked interactions between some of these properties, necessitating to focus on such properties as are most desirable in meeting some specific end. E.g. the corrosion-resistance and susceptibility to plastic deformation of high-strength alloys are inferior to those of medium-strength ones.

An important consideration in choosing aluminium to replace another structural material is its corrosion-resistance, which is especially marked is an industrial environment polluted by $SO_2$. Table14 is a comparison of what inroads sulfur dioxide may make on steel, zinc and aluminium surfaces with time [10 11]. The rate of corrosion observed in aluminium, copper and zinc exposed over a long period to different types of corrosive environment, has been the subject of a special study. Some of its findings are summed up in Fig 7. demonstrating that over a period of 10 and 20 years the rate of corrosion has been smallest with aluminium [12].

Table 15 displays the prices of various structural materials related to their mechanical strength [13]. Related to tensile strength, pricing for expanded concrete, high-tensile steel, cast iron and some plastics is lower than that of aluminium. With the other materials listed, however, aluminium compares favourably, a fact to be ascribed to its low specific weight.

Table 14

## Corrosion after 10 and 20 years in different climates and atmospheric conditions [12]

millimetre/annum

| Climate or atmospheric conditions | Aluminium, 99.2% | | Copper, 99.9% | | Zinc, 98.9% | |
|---|---|---|---|---|---|---|
| | 10 years | 20 years | 10 years | 20 years | 10 years | 20 years |
| Phoenix, Arizona, desert climate | $1.10^{-5}$ | $7.6.10^{-5}$ | $1.3.10^{-4}$ | $1.3.10^{-4}$ | $2.5.10^{-4}$ | $1.8.10^{-4}$ |
| State College, Pasadena, continental climate | $2,5.10^{-5}$ | $7.5.10^{-5}$ | $5.8.10^{-4}$ | $4.3.10^{-4}$ | $1.1.10^{-3}$ | $1.1-10^{-3}$ |
| La Jolla, California, maritime climate | $7.1.10^{-4}$ | $6.3.10^{-4}$ | $1.3.10^{-3}$ | $1.3-10^{-3}$ | $1.7.10^{-3}$ | $1.7.10^{-3}$ |
| New York, industrial atmosphere | $7.9-10^{-4}$ | $7.4.10^{-4}$ | $1.2.10^{-3}$ | $1.4.10^{-3}$ | $4.8.10^{-3}$ | $5.6.10^{-3}$ |

Table 15.

## Prices related to mechanical strength [31]

| Material | Tensile strength /MN/m$^2$/ | Modulus of elasticity /MN/m$^2$/ | Fatigue /MN/m$^2$/ | Specific weight /Mp/m$^3$/ | Price /£/Mp/ | Prices in £ related to MNm | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Tensile strength | Modulus of elasticity | Fatigue |
| Cast iron | 400 | 35,000 | 105.0 | 7.30 | 135 | 2.46 | 0.03 | 9.4 |
| Cu-Zn alloys | 400 | 37,300 | 140.0 | 8,36 | 515 | 10.75 | 0.12 | 30.7 |
| Carbon steel | 250 | 77,000 | 193.0 | 7.85 | 140 | 4.4 | 0.01 | 5.7 |
| Alloyed steel | 800 | 77,000 | 495.0 | 7.83 | 212 | 2.1 | 0.02 | 3.4 |
| Titanium alloys | 960 | 45,000 | 310.0 | 4.51 | 6,500 | 30.5 | 0.65 | 94.5 |
| Aluminium alloys | 300 | 26,000 | 90,0 | 2,70 | 800 | 7,2 | 0,08 | 24,0 |
| Mg alloys | 190 | 17,500 | 95.0 | 1.70 | 2,500 | 22.0 | 0,24 | 44,7 |
| Oak | 14 | 4,500 | 6.0 | 0.67 | 895 | 43.0 | 0.13 | 100,0 |
| Polyprotylene | 30 | 0 | 7.5 | 0.90 | 325 | 9.7 | 0 | 39.0 |
| Nylon 66 | 80 | 0 | 24.0 | 1.36 | 925 | 15,7 | 0 | 63.0 |
| PVC | 50 | 0 | 12.0 | 1.40 | 240 | 6.7 | 0 | 27.0 |
| Expanded concrete | 38 | 10,000 | 23.0 | 2.50 | 23 | 1.5 | 0.01 | 2.4 |

How the favourable technical features of aluminium have affected the consumption pattern of some end-using sectors, is discoussed at length in Chapter 4. The same chapter also reveals more details as to how aluminium may be used effectively to replace other structural materials.

## 2.15 Remelting of scrap

In developed countries remelted aluminium scrap accounts for some 25% of total aluminium consumption. Collected, sorted and cleaned aluminium scrap is remelted by various metallurgical processes, in the course of which it disposes of its non-metallic impurities. While earlier some 10-15% of the scrap was irretrievably lost in the remelting process, this figure has now dropped to a few per cent upon the emergence of new remelting techniques. Also, thanks to fresh advances in such metallurgical processes, traces of oxidic and non-metallic impurities remaining in secondary metal won from scrap could be recently reduced by 1-2 orders of magnitude. Power involved in the remelting process too has declined sharply from an earlier 2-3,000 kilowatt-hours to 800 kilowatt-hours per ton [9]. Secondary ingots remelted from carefully handled scrap, with an addition of a proper percentage of alloys, are in every respect equivalent to casting ingots won in the aluminium smelters.

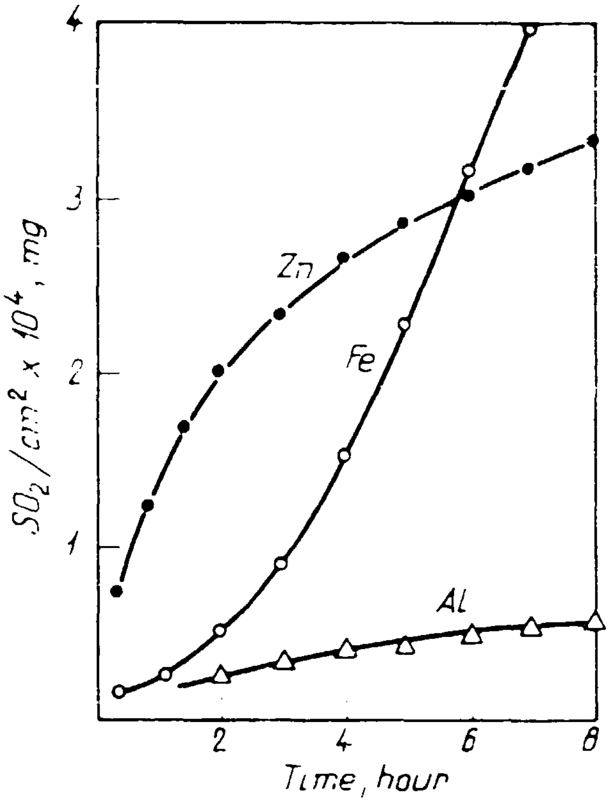

Fig.7 - Changes of sulfur dioxide adsorption on metal surfaces with time at 90% relative humidity. $SO_2$ content of atmosphere: 0.1 ppm /After Sydberger and Vannerberg/ [11]

A breakup of scrap recovered in Hungary is given below:

| | |
|---|---|
| New industrial scrap | 40% |
| Old scrap, discarded by the population | 40% |
| Turnings | 20% |
| Total | 100% |

About two-thirds of collected scrap is remelted to casting-ingots. One-third is added to slab and billet charges at the mills or used as a deoxidant in steel metallurgy.

A fairly elaborate organization is required to collect and sort scrap arisings in an effective manner before having them remelted to secondary ingots. Mixed scrap is difficult and costly to refine by metallurgical methods. It seems therefore expedient that upon the installation of any aluminium fabricating facility the effective collection, sorting, storage, handling and remelting of scrap be taken care of, together with arrangements for the marketing of the resultant secondary metal.

## 2.2 Difficulties

### 2.21 Large amount of power and capital involved in primary aluminium production

The two basic considerations in installing an aluminium smelter are abundance of cheap power and the availability of large capital, the latter far exceeding that required for setting up other raw material production facilities. Bauxite and alumina operations on site or in the region are not an absolute prerequisite, alumina lending itself well for transport over larger distances.

Until the 1960s, generally, only developed countries and centrally planned economies could afford to erect aluminium smelters. This is the reason why the bulk of such facilities are located in Europe, North America and the Soviet Union, where large amounts of hydroelectric of thermal power are available. In earlier days, the proximity of the consumer markets, too, had been a consideration of some portent.

The siting of new smelter projects is nowadays almost exclusively governed by the high power demand of smelting operations. The power resources of developed countries have no longer free capacities to supply abundant amounts of cheap energy. Hence, in siting a new smelter, only such areas may come into consideration, where a sufficiently large potential of cheap power, too, exists. The tapping of new power resources, however, invariably calls for further capital investment in implementing such projects. It should be remembered in this connection that electric energy is at present the largest and most significant cost factor in the electrolytic extraction of aluminium.

The magnitude of power involved in aluminium production is demonstrated in Table 16., where a comparison of power consumed at each successive step of production from the raw material up to the semi-fabricating stage is presented in respect of steel, copper and aluminium [14].

From this tabulation the huge energy demand of aluminium production stands out most strikingly. The difference will remain even after allowance has been made both for the lower specific weight of aluminium and the fact that by adding suitable alloys a composition may be brought about, whose mechanical properties approximate those of mild steel. In calculating this, the power demand of aluminium will be no longer eight times, but only 2.7-3 times that of steel. By the same reasoning, power involved in the manufacture of copper and aluminium conductors will be practically identic after allowance has been made for the difference in specific weights.

Table 16.

Breakup and total of energy consumption involved in steel, copper and aluminium production [13]

GJ per ton

| | Steel rounds 30 mm. dia. | Rolled copper wire | Aluminium sheet |
|---|---|---|---|
| Mining, quarrying | ? | 51.9 | 4.2 |
| Coking | 20.1 | - | - |
| Concentration | 5.9 | - | - |
| Crushing | - | 20.9 | 5.9 |
| Flotation | - | 7.5 | - |
| Alumina manufacture | - | - | 41.9 |
| Smelting | 0.3 | 14.2 | 218.6 |
| Steel manufacture | 6.6 | - | - |
| Electrolyitic refining | - | 12.6 | - |
| Rolling | 5.4 | 18.4 | 28.1 |
| Total GJ/ton | 37.7 | 125.5 | 298.7 |
| Total GJ/cu.m. | 293.1 | 1,130.0 | 795.6 |

Surplus costs of energy incurred in manufacturing an aluminium product, however, may under circumstances be recovered in the course of subsequent usage. In this context reference is made to Heading 4.41, where power economies to be derived from using transport vehicles with aluminium components are discussed.

Not only are aluminium operations compared to the metallurgy of other metals /especially steel and copper/ significantly more power-intensive, but the implementation of fully integrated aluminium projects will also call for a large amount of capital expenditure. This is exemplified by a model calculation summarized in Table 17, wherein capital required for the installation of a 100,000 t.p.a. imaginary aluminium complex is set out in detail. In this connection it is emphasized that

- The production pattern in the last stage of verticality /finished products/ has been randomly chosen;
- Estimated capital costs nowhere include infrastructure and social welfare facilities;
- Though the aluminium smelter itself is calculated to operate at a firm power of 200 MW, the investment cost estimate does not include the installation of a power plant;
- Capital investment at each successive stage of integration may in actual practice greatly vary with the magnitude of capacities involved and the actual technologies used, therefore throughout the model fair medium figures have been taken into account;
- Capacities at each successive stages suggest realistic figures from an economic feasibility point of view; they are, moreover, coordinated to meet demand at the next stage of verticality;
- To facilitate matters, exports of raw material and semi-manufactures have not been calculated.

According to Table 17 the total investment costs of this imaginary 100,000 t.p.a. integrated aluminium complex may be in the order of 670 million U.S. dollars. /At 1977 U.S. dollar prices/.

Table 17.

## Model of investment costs involved in a fully intergrated 100,000 t.p.a. aluminium project

/At 1977 U.S. dollar prices/

| Stage | Embracing | Investment costs per ton and annum U.S. $ | Products or Capacities 1,000 tons | Breakup and total of investment costs million U.S. $ |
|---|---|---|---|---|
| Stage I.<br>Raw material | Bauxite operations | 45-65 | 600 | 40.0 |
| | Alumina manufacture | 500 | 200 | 100.0 |
| | Aluminium smelting /excluding power works/ | 2000 | 100 | 200.0 |
| Raw material stage, total | | | | 340.0 |
| Stage II.<br>Semi-manufactures | Continuous strip casting | 2180 | 55 | 120.0 |
| | Continuous wire rod casting | 250 | 20 | 5.0 |
| | Extrusion | 2700 | 20 | 54.0 |
| | Foil manufacture and finish | 4000 | 5 | 20.0 |
| | Casting /by machine/ | 4440 | 7.5 | 33.0 |
| | Casting /sand and gravity die, sited on an industrial scale/* | 4000 | 2.5 | 10.0 |
| | Scrap remelting | 200 | 20 | 4.0 |
| Semi-manufacturing total | | | | 246.0 |
| Stage III.<br>Semi-manufacturing finish** | Anodization of sections | 670 | 3 | 2.0 |
| | Disc cutting | 20 | 10 | 0.2 |
| | Tube welding | 230 | 3 | 0.7 |
| | Corrugation of sheet | 60 | 10 | 0.6 |
| | Prepainting of sheet | 700 | 10 | 7.0 |
| Semi-manufacturing finish, total | | | | 10.5 |
| Stage IV.<br>Finished products<br>/Manufactured items in the next column/ | Uninsulated conductor /drawing and stranding/ | 470 | 10 | 4.7 |
| | Insulated conductor and cable | 1220 | 10 | 12.2 |
| | Collapsible tubes and aerosol bottles | 2560 | 5 | 12.8 |
| | Building structures | 500 | 15 | 7.5 |
| | Heat-exchangers | 1000 | 5 | 5.0 |
| | Holloware and thick-walled packaging items | 800 | 5 | 4.0 |
| | Equipment for foil packaging | 300 | 3 | 0.9 |
| | Components of mechanical engineering | 800 | 7 | 5.6 |
| | Sundry structural components | 300 | 5 | 1.5 |
| | Other metalworking items | 500 | 20 | 10.0 |
| | Household products | 600 | 10 | 6.0 |
| Finished product stage, total | | | | 70.2 |

* Investment costs of a less complex gravity die casting foundry are about $ 2,000-2,500

** Only equipment, without premises. To avoid overlapping, tonnages are not summarised.

The first stage of integration includes raw material operations /the mining or quarrying of bauxite, alumina manufacture and aluminium smelting/, accounting for 50% of the above sum.

The second stage of integration refers to semi--fabrication. Its share in term of total investment costs is 38%. Two items under this heading, the continuous casting of strip and that of rod wire, represent 50% of the investment costs calculated under semi-manufacturing. The operation of continuous casting, however, is geographically located at the smelter. Allowance made for this, the share of investment costs for raw material operations in the first stage will thereby rise to 70% and that of the remaining semi-manufacturing facilities /extrusion, foil manufacture, casting and scrap remelting/ drop to 18%.

The third stage encompasses certain operations of finish applied to semi-manufactures, whereby the workpiece reaches an intermediate state of finish between semi-fabrication and the finished product /e.g. the surface treatment of cut sections used in prefabricated motor vehicle bodies/. For technological and financial reasons, it is desirable to have such equipment directly sited at the mill. The share of investment for this stage is 2%.

In the fourth stage of integration finished products are manufactured. The installation of capacities to this end accounts for 10% of the integrated project's total suggested investment costs. The siting of such facilities has always to be governed by practical considerations. The manufacture of finished products may begin first in a small way and be expanded subsequently, if called for by demand.

A prerequisite of setting up an aluminium finished product industry in the availability of sufficient raw material, supplied either by domestic producers or from outside sources. If local circumstances do not permit the installation of domestic raw material manufacturing facilities /lack of power or sufficient capital, poor domestic market demand, there are always various ways of obtaining semi-manufactures or ingots under long-term agreements of international division of labour. Should a 100,000 t.p.a. aluminium finished product industry such as demonstrated in our model entirely be based on raw material imports, the investment costs involved in the project - including also operations specified under Stage III - may be estimated at 80 million U.S. dollars. /see Table 17. Stage III, IV./ If, however, semi-manufacturing facilities too are installed for making extrusions, foils or castings - which may always be fed by imported ingots -, investment costs shown for Stage IV may rise by another 100 million U.S. dollars. As a rule, the latter may be at first smaller units to be expanded later, if necessary.

## 2.22 Higher standards of engineering techniques

The chemical, physical and mechanical properties of aluminium differ in many ways from those of other metals. In view of this, the handling and processing of aluminium calls for technologies which may often be regarded as a departure from conventional methods of metallurgy. Even the transport and storage of aluminium require particular care. In case of defective packaging, rough handling en route or poor storage, the vapour repeatedly precipitating and evaporating on its surface may leave behind ugly stains or give rise to corrosion. The surface of aluminium may also be damaged by metal turnings, iron scale, and coke or sand particles. The occurrence of this may be avoided by keeping the aluminium in well aired and tidy storerooms and workshops. In default of this, there may be trouble in the successive processing of aluminium.

Almost aseptic cleanliness is also called for in shops where technological operations are to take place. In processing aluminium, it would be entirely wrong to use, without further ado, any equipment, machinery or die, on which other materials have been previously handled. If this is inevitable, before feeding aluminium into such equipment all components, dies and even the premises themselves have to be carefully cleaned.

The machining of aluminium in some ways resembles to that of timber rather than steel. Such similarity is enhanced by the use of high-speed cutting machines, in which operation, however, tools suitable for aluminium have to be used. In processing aluminium, though it is a malleable metal lending itself well to plastic deformation, dies of special design and quality are required. Aluminium is highly sensitive to the surface smoothness of the die. The deep-drawing of soft aluminium e.g. calls for dies of a harder surface than those used for less deformable and more robust steel. Also, in processing aluminium certain technological instructions to do with some inherent properties of the metal have to be strictly adhered to /e.g. a more marked rounding off of edges, the conicity of the deep-drawing stub, etc./. For the same reason, the economical fabrication of aluminium calls for technologies entirely different from those of steel. A point in case is the manufacture of collapsible tubes and thin-walled hollow cylindrical items, where either the so-called injection pressure die extrusion technique or impact extrusion is used, the latter ensuring highly accurate size combined with suitable strength.

The welding and surface treatment of aluminium, too, is fundamentally different from those of other metals. Notably, upon exposure to air, a firm oxide film is fast depositing on the aluminium surface. Because of this, traditional welding and surface treatment /painting/ methods applied to steel are of no avail in case of aluminium. In view of the high thermal conductivity of aluminium and the oxide film formed on its surface, conventional welding technologies had to be replaced by the highly effective method of shielded-arc welding. Under circumstances, various modifications of electric spot-welding and seam-welding too may be used with advantage, though these latter call for higher power ratings and automatic control. The cold-welding of aluminium requires a strong specific pressure to break the oxide film. /See the clamping of electrical fittings on assembly, as referred to under Heading 4.12./ At present, reliable brazing or soldering of aluminium still calls for very elaborate techniques; modifications of conventional soft soldering methods have produced rather unstable joints susceptible to corrosion. The use of adhesives in joining aluminium parts poses serious problems when done on an industrial scale, because of severe technological standards and a demand for a high degree of cleanliness in the workshops. In view of this and similar difficulties, a novel technique of joining components of aluminium structures is gaining ground, where the extruded sections to be assembled are slipped into one another to become firmly interlocked. While the extrusions to be joined in this manner have to be highly accurate to size, the operation itself may be performed by unskilled labour of some experience.

An effective way of improving the surface properties of aluminium is the strengthening of its oxide film by means of anodic oxidation. The resultant anodized oxide film will be either corrosion-resistant or form a porous surface onto which a priming may be applied forthwith. Unless this is done, aluminium surfaces are unsuitable to be painted or provided with a firm layer of plastics-coating. Therefore, regardless of whether corrosion resistance or preparing the surface for priming is aimed at, the use of an effective method of surface treatment is essential. As for adding a paint coating, the appliances are generally the same as the ones used with other metals.

Notwithstanding techniques as outlined above, the selection of semi-manufactures best suited for a given purpose is of utmost importance. The possibility of some compromise in this respect may, however, not be excluded. E.g. a great deal may depend whether or not the plant is furnished with facilities to anneal or age-harden workpieces within a small temperature range in the course of the production process.

The foregoing will have also convinced the reader that next to the important task of selecting suitable material and optimum technology, specialists engaged in siting and organizing such a plant will have to acquire a thorough familiarity with facts and features eseential in running an up-to-date aluminium industry as well /see sub-chapter 6.2/.

## 2.23 Resistance to new solutions

Most aluminium end-use is such that it has to compete with other working materials. Moreover, whenever a new aluminium outlet emerges, it has to prove in a clearcut manner its technological and economic feasibility in relation to traditional usages. This is by no means easy, the conservative attitude of the market being often governed by

- habit
- old-standing experience in mass-manufacture
- conventional assembly, maintainance and repair methods
- many years of deep-rooted operational practice and
- standing regulations by the authorities /health, operational safety/.

To convince the consumer that a prototype is useful to him, is only a first step. A lot of extra painstaking work is still ahead. A prototype or contract product is always costlier and as a rule not as perfect as a mass-manufactured one, calling at an early time for technical assistance in assembly and maintainance. There is also an ingrained wariness by the consumer of accepting something new, a feeling of reluctance hard to overcome. And finally, regulations by the authorities have to be altered or new ones to be enforced. This process, as outlined, is long, wearisome and costly.

In the following chapter some concrete examples are cited of how such initial difficulties may be surmounted with fair prospects of success.

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## 3. TECHNICAL ADVICE AND RESEARCH TO BOOST ALUMINIUM CONSUMPTION

### 3.1 A chain of technical advising agencies throughout the world

The processing of aluminium and possibilities of expanding its effective usage to various fields had called early for a certain reshaping of traditional technical thinking. This was the case in the late 1920's, when the big aluminium producers of the world, at the time still engaged in smelting only, began to take up research in semi-fabricating and fabricating techniques, reporting back findings to their customers, so as to boost aluminium consumption for a multiplicity of ends.

The fact that aluminium in the meantime has become the fastest growing metal commodity of the century, may be partly ascribed to this early pioneering in research and development. From the very outset, an integral part of this work had been technical information, advice and assistance to the customer. This trend was sutained even when the smelting firms themselves entered the semi-fabricating and fabricating field. With growing integration, the advisory activities of the large aluminium producers became more differentiated.

In some cases - especially when a major aluminium concern had been the sole producer in a country or area - special information and advising agencies were set up under its auspices. They were to a certain extent independent bodies, from an organizational point of view not tied to the research and technical development divisions of the aluminium companies. Their principal task was to promote commercially the findings of the latter. For this end, they were called upon to keep in contact with designers, manufacturers and consumers, and to take the initiative in various ventures aiming to boost aluminium usage.

Even if in the same area or country several large aluminium companies operate, the setting up of such an advising agency in participation with the smelters, semi-manufacturing mills and representatives from the principal end-using sectors appears to be indispensable.

In both cases the ultimate end is identical, viz.

- to boost the economical usage of aluminium in as wide a field as possible;
- to explore and promote new aluminium outlets;
- to help producers and consumers with technical advice, documentation and the organization of training schemes for technical management and skilled staff, and
- to provide local authorities and international organizations with relevant statistical information on aluminium end-use and other developments.

The fundamental difference between the two types of advising agencies is the business policy they pursue. The first type is established with a view to promoting the interests of the sponsoring concern or company. If the sponsor is a public corporation, whether operating only as a smelter or as a more integrated complex, it will be usually called upon to promote aluminium development programmes launched by central government agencies by coordinating the sponsor's interests with those of the prospective consumers. In doing this, the advising agency is counting on the fruitful cooperation of the fabricators and consumers. Its activities are largely governed by achievements of research and development arrived at by the sponsor, which the advisory body will have to promote thereupon in an effective manner. Such and similar organizations are to be found in countries, where essentially only one major integrated aluminium concern is operating.

The names and addresses of some are given below:

- In France: Centre Technique de l'Aluminium /Technical Centre of Aluminium/, 87 Boulevard de Grenelle, F-75015 Paris. /Attached to the Pechiney concern/.
- In Switzerland: Information Service of the Central technical Division of ALUSUISSE, Feldeggstrasse 4, CH-8034 Zurich;
- In Italy: Instituto Sperimentale dei Metalli Leggeri /Experimental Institute for Light Metals/ Via G. Fauser 4, I-28100 Novara, Italy. /Attached to the ALUMETAL concern/;
- In Austria: Vereinigte Metallwerke Ranshofen--Berndorf /United Metal Works Ranshofen-Berndorf/, A 5282 Ranshofen-Braunau, Austria;
- In the German Democratic Republic: Leichtmetall Technischer Beratungsdienst /Technical Advisory Service for Light Metals/, attached to VEB Metallindustrie, Eisleben, GDR. /It also deals with the allocation of light metal quotes in the German Democratic Republic/;

- As for Hungary, see the following pages.

Among the second type of advising agencies the Aluminium Zentrale /Aluminium Centre/ of Federal Germany, Königsallee 30, D-4000 Düsseldorf, is the most renown. A corporate body financed by its member enterprises, it is also editing books and a journal. Of its 50 members 18 are primary aluminium producers, 12 semi-manufacturing mills and 20 aluminium foundries and other fabricators. Registered in Federal Germany, it is a non-profit organization established with a view to promoting aluminium usage and effective manufacturing techniques. Technical advice as well as the use of its documentation service and training schemes are free of charge. It centrally coordinates aluminium propaganda and represents the aluminium industry as an exhibitor at fairs and other shows, besides providing statistical information asked for by various organizations. It runs training workshops and showrooms of its own, but has no research and development divisions.

Similar organizations are to be found also in other parts of the world, amongst others, in

- Norway: Skanaluminium, Rosenkrantzgate 21, Vika,
  Oslo 1, Norway;

- USA: The Aluminium Association Inc., 818
  Connecticut Avenue, N.W. Washington, D.C. 20006

- Japan: Japan Light Metal Association, Nihonbashi
  2-Chome, Chou-Ku Tokyo 103, and

- Australia: The Aluminium Development Council of
  Australia Limited, 56 Pitt Street, Sydney, N.S.W.
  2000.

In Hungary, to emphasize the significance of the aluminium industry to the country's national economy, a special advisory organization was established combining the advantages of both systems. Long-term aluminium activities of the Hungarian aluminium industry are governed by a central development programme approved by the country's government, setting and coordinating medium and long-range targets covering every stage of aluminium integration /see subchapter 6.3/. Its provisions affect all industrial activities by the Hungarian Aluminium Corporation /bauxite and alumina operations, aluminium smelting, semi-manufacture and the manufacture of some finished items/, as well by other aluminium fabricators of the country. All these enterprises are state-owned, operating under the auspices of different government departments. The Hungarian Aluminium Corporation, furthermore, runs a separate research and designing institute as well, acting also as the general contractor of major aluminium development projects, besides providing a scientific background for development also in the finished product field.

In the wake of the world-wide aluminium boom of the 1960s, and more particularly after the conclusion of a long-term alumina/aluminium agreement with the Soviet Union, large stocks of aluminium became available in Hungary, opening up great perspectives for expanding the country's aluminium fabricating capacities. In order to create fresh markets, it seemed then expedient to set up a special agency to deal with the promotion of aluminium usage. This is how the Development Centre for Aluminium Applications of the Hungarian Aluminium Corporation has come into being under the auspices of the latter, but operating as a separate organization. Its activities have been defined by the government agencies sponsoring it as follows:

- Technical advice, information and propaganda to facilitate cooperation between semi-manufacturing mills and finished product manufacturers by coordinating current and prospective aluminium demand. Also, in coordinating certain particular aspects of finished product manufacture, vested rights of decision making on behalf of the National Technical Development Board;

- Monitoring of new advances arrived at in technology and research both in Hungary and other countries; the promotion of schemes, technical and financial, for updating and expanding the production programmes of semi-manufacturing mills and finished item producers;

- In concert with end-using sectors, the boosting and testing of prototype designs and their implementation if appearing feasible from a technological and economic point of view;

- Active participation in such prototype work, if desired by the prospective manufacturer;

- Evaluation of experiences relating to aluminium usage, with special regard to technological and economic feasibility;

- Domestic and world market research, collection, compilation and evaluation of statistical data relevant to aluminium production and consumption; publication of such information;

- Editing of leaflets, brochures and other publications /e.g. Magyar Aluminium, a monthly aluminium engineering journal/;
- Organization of lectures, training courses and demonstration of various techniques in the Centre's own workshop for the benefit of engineers, technicians and skilled workers, and
- Organization of exhibitions and shows in Hungary and elsewhere.

In its activities the Centre used to rely on moral and financial support from the National Technical Development Board, the experience of the research and designing institute of the Hungarian Aluminium Corporation, as well as on suggestions and recommendations forthcoming from different working committees dealing with particular problems, and last but not least on its cooperation with the major fabricators.

The Centre used to have a staff of 50, of whom 20 were engineers and technicians and 10 skilled workman, the latter employed at the Centre's training workshop. Its budget was jointly financed by the Hungarian Aluminium Corporation and the National Technical Development Board, contributing in a proportion of 60% and 40%, respectively. The major part of available funds was devoted to prototype work, to subsidizing some of the extra costs incurred by the introduction of new products, and to technical propaganda /exhibitions, publications, training courses, etc./. Thanks to this arrangement risks involved in innovations could be shared among the aluminium industry, the finished product manufacturer concerned and the government agencies responsible for running industry. Annual action programmes governing the Centre's activities were from year to year jointly approved by the president of the National Technical Development Board, the general manager of the Hungarian Aluminium Corporation and the Minister of Metallurgy and the Engineering Industries, under whose auspices the major finished product manufacturers were operating.

In 1976 the Centre was merged into the Engineering and Development Institute of the Hungarian Aluminium Corporation /ALUTERV-FKI/.

In addition to the various advising agencies and centres discussed above, there are also several other international organizations of the same function as well, but most of them have been set up in pursuit of certain business interests. The most prominent of these is CIDA /International Centre of Aluminium Development/, its membership being composed of the eight largest aluminium concerns of Europe. By mutual consent, CIDA deals with various aluminium development and standardization issues /e.g. the dimensions of aluminium joints, new methods of corrosion abatement, etc./. Its findings are in the first place accessible to its members only.

Some of the developing countries have already earlier realized the necessity of setting up some sort of an aluminium development promotion agency and many more may follow suit shortly. How this is done and under what organizational framework, will always depend on local conditions prevailing on site. However, regardless of whether one, two or more producers are operating in a country or area, it seems desirable that such an organization be set up in concert with all interested parties /raw material producers, semi-fabricating mills, finished product manufacturers and consumers/ as an independent body. New solutions nowadays are no longer confined to some narrow field of engineering, a fact necessitating the cooperation and goodwill of specialists from other walks of life as well. /E.g. light constructions are a complex matter, where next to aluminium specialists, a great deal depends on the experience of the designing architect, the building contractor and even the customer; in aluminium packaging for the food industry, the aluminium industry has to seek cooperation with the food processing industry, the retail trade and the consumers as well/. In addition to obvious technological advantages, such active cooperation with all interested parties may greatly facilitate the medium and long-range planning of production and consumption of a country. /See also sub-chapter 6.3/.

## 3.2 The necessity of setting up research and development bodies to boost new technical advances

In the foregoing it has been shown how advisory facilities may boost aluminium usage. Such efforts, however, may never be really effective, unless aided by a firm background of organized research on one hand, and designing expertise on the other hand. The proliferation of aluminium end-uses and the multiplicity of technologies involved in the manufacture of items meeting such demand, call for a carefully conceived development policy covering the entire field of integration from the raw material up to the finished product stage. With the major aluminium concerns of the world, this arduous, costly and often hazardous task is undertaken by a network of research, development and designing institutes. A typical example is ALCOA, spending about 1.5-2% of its turnover /at 1976 prices some 60 million U.S. dollars/ for this end. It runs and continually updates ALCOA Laboratories, the world's largest light metal research complex. But large amounts are spent on research by the world's other major aluminium producers as well, with even the aluminium industries of smaller countries following suit. A case in point is Hungary, where a research, technical development and designing institute is operating under the auspices of the Hungarian Aluminium Corporation, financed by funds amounting to 4-4.5% of the Corporation's total turnover. Other aluminium producers of the country, too, devote about one per cent of their finished product turnover to research and technical development.

Even in countries just entering the aluminium fabricating field, technical development work is indispensable. Its scope in research and technical designing has to be such that it may be capable of adapting aluminium applications practised with success elsewhere; furthermore, it has to deal with the exploring and testing of completely new outlets likely to be of local market appeal.

Here too the brunt of work and costs has to be born by the aluminium industry. Initially, such technical development is to include

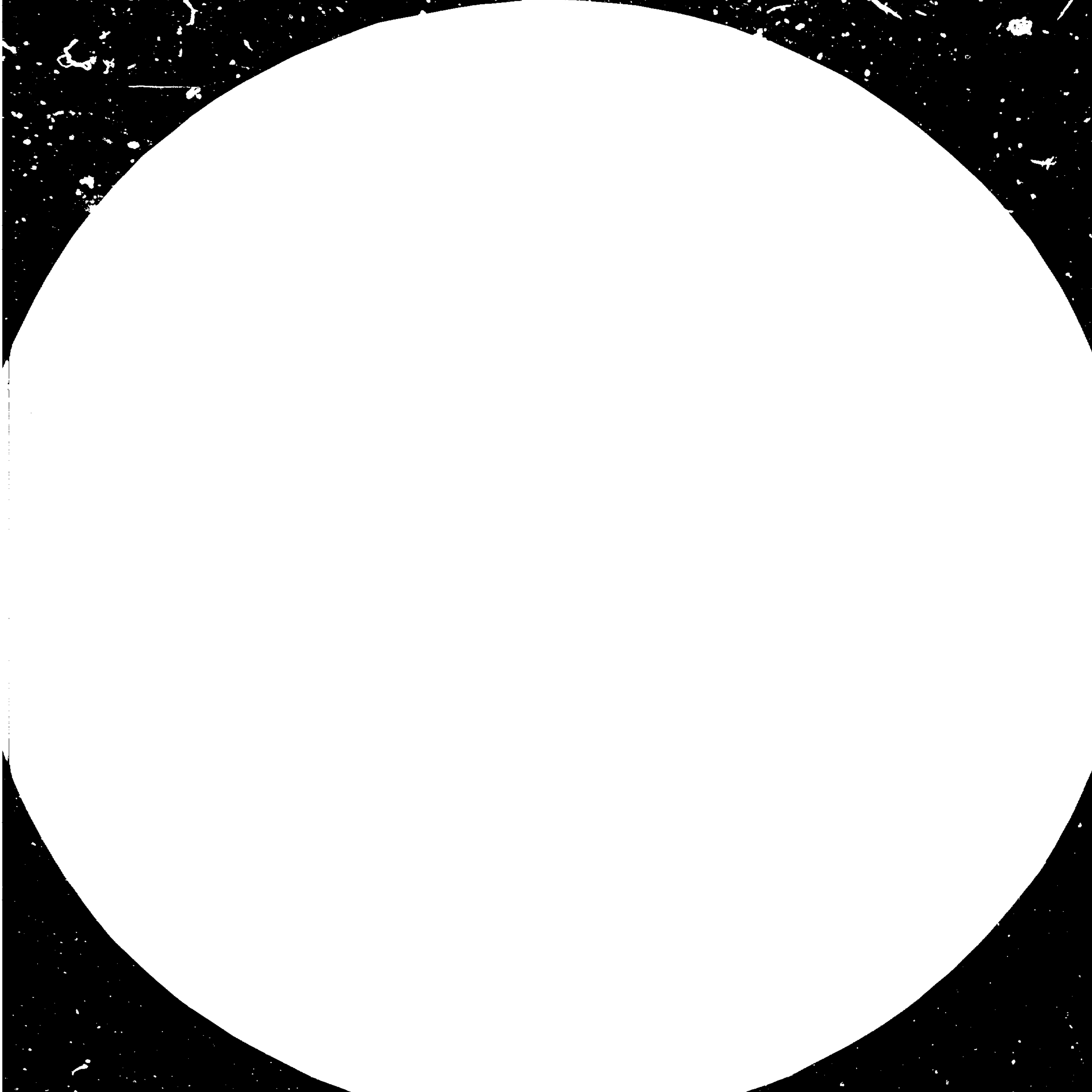
- the elaboration or adaption of alloys best suited for certain ends under local conditions;

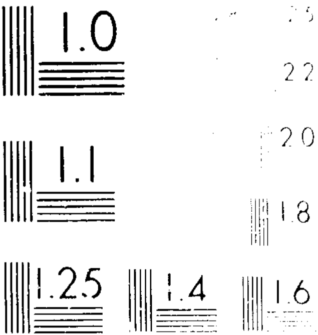
- the introduction of an up-to-date scrap remelting technology essential in supplying a suitable selection of ingots to the light metal foundries;
- the introduction of optimum joining techniques /welding training courses, application of cold joining techniques/;
- the adaptation and if necessary modification of surface treatment methods in line with conditions prevailing on site;
- the study and practical application of plastic deformation technologies, including die-making;
- the use of machine tools for various ends and the local manufacture of their tools, and
- the design and manufacture of prototypes of diverse aluminium items and structures, as well as technical advice to prospective customers before beginning serial manufacture.

It is desirable that local researchers and engineering specialists at this stage seek the assistance of qualified experts and academic lecturers from various disciplines, so as to lay down the foundations of a sound scientific background for further technical development work ahead. /See also sub-chapter 6.2/.

## 3.3 Product development effectivity

Testing the effectivity of product innovation /research, designing, adaptation, licenses and technial advice/ is a hard and complex task. One /but not the only/ indication of its effectiveness is the rate at which the consumption of semi-manufactures

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and the profits of mills grow. But several other factors too exist from which suitable conclusions in this connection may be reached. Some of them are enumerated below:

- The gaining ground of certain typical aluminium applications enhancing the profitability and streamlining the operations of the end-user. /E.g. the replacing of copper by aluminium in the manufacture of electric conductors, reducing the installation costs of power transmission systems; the use of aluminium heat-exchangers: aluminium foil packaging, facilitating the marketing of processed food/.

- The use of aluminium components with significant benefits to the consumer. /E.g. the lightness of aluminium permitting considerable power economies in running transport vehicles; aluminium accessories doing fast alternating movement to and fro in textile mills and printing presses etc., improving technological standards and cost-effectiveness/.

- Savings in maintainance costs, especially marked in light constructions used by the building trade.

A method has recently been devised to evaluate the intensity of innovatory activities in the aluminium field by relating, over periods of 5-10 years, the average annual share of new products to the annual mean growth rate of aluminium consumption. A tabulation to this effect was presented by Kumar at the 1978 Symposium of Aluminium Transformation Technology and Applications in Argentina [1].

Table 18

**The share of new products in some selected countries related to total aluminium consumption over longer periods** [1]

| Country | Period | Annual growth rate per cent | |
|---|---|---|---|
| | | Total growth of consumption | Share of new products |
| United States | 1963-66 | 12,4 | 6,9 |
| Norway | 1958-64 | 12,0 | 6,1 |
| United Kingdom | 1958-65 | 6,1 | 2,3 |
| Federal Republic of Germany | 1958-65 | 9,5 | 4,0 |
| Italy | 1958-65 | 9,8 | 5,8 |
| Japan | 1958-65 | 14,4 | 6,5 |
| Argentina | 1965-74 | 15,5 | 2,3 |
| Hungary | 1965-70 | 9,8 | 6,3 |

Figures for the U.K. and Argentina clearly point to the necessity of effective technical development work, in the absence of which growth of consumption in the successive periods may tend to decline sharply. And indeed, over the 1966-76 period, the average annual growth rate of aluminium consumption in the U.K. has dropped to 1.9% [2].

However, the evaluation of product effectivity is further complicated by the fact that the utility curve of some aluminium applications is highly differentiated. Therefore each product ought to be dealt with separately according its merits. Moreover, the development, testing and final introduction of an aluminium application on an industrial scale may frequently take up a longer time than the actual cycle of its utility /e.g. the extruded aluminium sheathing of underground cables/.

Hungary's 6.5% share of new aluminium applications against an annual average 9.2% growth rate of domestic consumption over a six-year period compares favourably with the other figures listed in Table 18. Evidently, credit for this is due to the effective work of technical development agencies referred to in sub-chapters 3.1 and 3.2. The sustained overall growth of Hungary's aluminium consumption on one hand, and the gradual decline or total discontinuance of certain aluminium usages on the other hand, are always governed by the exigencies of the country's changing industrial pattern.

A few instances where owing to this some aluminium applications in Hungary have by now reached their final phase are enumerated below:

- Water transport vehicles /small dinghies and medium-sized passenger river craft/;
- Aluminium alloy overhead telephone conductors /with phone cables gaining ground/;
- Aluminium doors, windows and roofing of railway trucks /because of the reorganisation of domestic rolling stock manufacture/;

  The cold-extruded aluminium shell of thermos bottles /replaced by plastics/;

- Aluminium soda water bottle heads /also replaced by plastics/.

By contrast, some typical aluminium innovations introduced over the same period include

- aluminium-sheathed underground power transmission cables with solid aluminium conductors
- aerosol bottles
- liquid gas bottles
- pressure cookers
- new types of composite aluminium foil for packaging ends and household foil
- new series of window frames and roofing, and
- radiators.

The advising agencies dealt with in sub-chapter 3.1, besides watching domestic and world market trends, have also to be aware of what may be anticipated over the long term in the way of industrial development at home and abroad. This is a key question in exploring promising outlets effectively and going ahead with prototype work successfully. Hence, whenever industrial trends change, the advising agencies have to react seismographically and induce, in turn, the producer to change or shelve technical development concepts no longer realistic. It also follows from the foregoing that not all efforts of boosting new aluminium applications are bound to be equally successful. In fact, some may bring about gratifying results, others may be too much ahead of time and a great many may even end in a complete failure.

In Hungarian practice some concrete achievements may be exemplified below:

- The development and financing of light construction prototypes 4-5 years ahead of their application on an industrial scale, together with a full evaluation of experiences in this connection. Thanks to this, first-hand information could be obtained on the technological and economic feasibility on one hand, and the limitations on the other hand, of stationary /and in some cases mobile/ aluminium supporting structures. Some applications that have appeared promising and technologically feasible at the prototype stage, did not come up to expectations in actual practice /e.g. supporting structures in electric power transmission [3]. Experiences have also demonstrated that on developing aluminium structures of larger size, special attention has to be devoted to certain considerations which, however minor they may appear at the designing and prototype stage, may influence the behaviour of the structure in actual practice. /E.g. stress caused by stronger thermal expansion, the siting of welding seams at points less exposed to mechanical loads, etc./;

- The boosting of household foil manufacture and usage, by market research and helping the producer select and install manufacturing equipment for this purpose;

- The launching of the manufacture of aluminium fasteners /nails, screws, bolts etc./;

- Cooperation in developing and financing the prototype of a 27-cu. metre aluminium superstructure of a large motor lorry; technical advice in eliminating certain shortcomings in the initial phases of serial manufacture;

- The introduction of aluminium framings for agricultural and gardening foil tents.

On the other hand, some innovation efforts proved to be ineffective. /E.g. the prototype of an aluminium-framed wind power plant, some types of aluminium furniture, irrigation systems from extruded aluminium tubes, etc./.

Roughly, some 30-40% of the funds devoted by the advising centre to innovations could be put to immediate use; some 20-25% were spent on paving the way for some future aluminium applications within the next 5-10 years, and 40% on schemes which eventually turned out to be unfeasible for various reasons. The relatively large share of negative experiences, however, had at least one advantage in common: it did point to certain areas where aluminium can definitely not be used to replace other structural materials.

The above examples will have amply illustrated that the work of advising agencies may significantly contribute to product development effectivity. The advising agencies, moreover, are a useful instrument in sharing with all interested parties hazards involved in every new aluminium application venture. The form and extent of sharing such risks, of course, will always vary with the economic system and industrial pattern of each country, as well as with conditions prevailing in the presence or absence of local raw material manufacturing facilities.

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/Chapter 3./

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[2] European Aluminium Statistics, 1976. Aluminium Zentrale, Düsseldorf

[3] Mankher, E., Miklós, F., Zachár, I.: Fresh developments in overhead power transmission installations. Magyar Aluminium /Budapest/ 8:8:236-38. 1971.

## 4. PRINCIPAL OUTLETS OF ECONOMICAL ALUMINIUM USAGE

The great strides aluminium is making throughout the world and the efforts of its promoters to keep its position intact are taking place in an atmosphere of keen competition with other structural materials. The outcome of this strife, with all of its technological and economic implications, may seriously affect the relative position of aluminium, either accelerating or slowing down the momentum of its usage in different end-using fields. There are, however, certain areas where its position seems to be firm and uncontested, not likely to change in the long term because of the world's raw material situation.

A case in point is the electrical engineering industry, where aluminium conductors for the transmission of heavy and medium voltage energy have in actual practice irreversibly displaced copper.

A similar process is now taking place in the manufacture and use of heat exchangers.

In transport vehicle manufacture, however, aluminium trends are somewhat paradoxical. Here, despite its favourable technological and economic aspects, aluminium is faced with heavy competition from steel and more recently from plastics.

In other end-using sectors, competition is even more marked, with most items lending themselves equally well to manufacture from aluminium and other materials. An interesting comparison in this respect is made by Altenpohl, whose utility curves plotted for different aluminium kitchenware used in some developed countries of Europe are demonstrated in Fig.8 [1]. It will be observed that traditional aluminium kitchenware could keep its position more or less firmly throughout the period under survey. By contrast, stainless steel kitchenware combined with aluminium, after some headway for about 2-3 years, has soon disappeared from the market for reasons of price and lack of response. Costs of developing it could have hardly been recycled into production within such short space of time. Following this, plastics-coated and enamelled aluminium kitchenware, too, appeared on the market. After a three years' trial period, this innovation has become popular and there was a great upsurge in its sales. How long this trend is to continue will a great deal depend on future market demand and fashion. /E.g. stainless steel kitchenware with ornamental enamel coating/. Anyway, in spite of heavy expenditure involved in developing it, this item seems to promise fast financial returns.

The following is a detailed analysis of a few typical aluminium end-uses. They have been expressly selected for the purpose of this study to demonstrate how necessary it is to pursue technical development work with utmost vigour and to be at all times on the lookout for finding new viable market outlets and for keeping the integrity of old ones. Several cases too will be presented, where, apparently, the merits of an idea or scheme were from the very outset not assessed with sufficient circumspection or where later on, competition by other structural materials has made such inroads on certain aluminium usages that the manufacture of such items had to be temporarily suspended or completely abandoned.

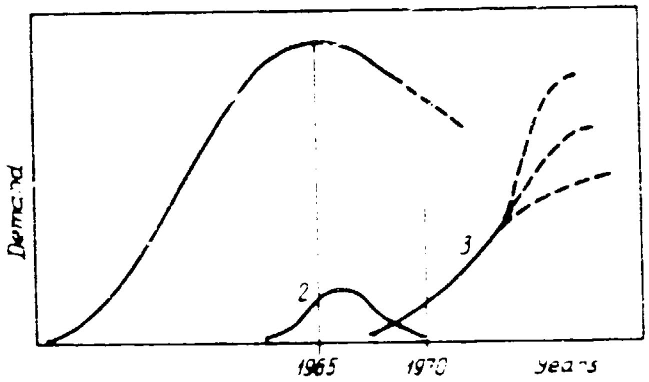


Fig.8 - Cycles of aluminium kitchenware demand in some developed countries of Europe

1. Traditional kitchenware
2. Aluminium/stainless steel kitchenware
3. Enamelled and/or plastic-coated aluminium kitchenware

While the present chapter is to deal in the first place with technological aspects, chapter 5 will contain useful information on sources of know-how, together with the names and addresses of institutions and industrial firms, from where further relevant information or assistance may be forthcoming.

## 4.1 Electrical engineering

### 4.11 General observations

In 1976 world aluminium consumption for electrical engineering ends had been in the order of 2 million tons, accounting for 15% of total world aluminium consumption [2]. The magnitude of tonnages used by the electrical engineering industry, however, greatly varies with countries and regions as examplified in Table 19 below.

Table 19

## Aluminium consumption by the electrical engineering industries of some selected countries or regions /1973-1977 averages/

| Country or region | Consumption kilogramme per capita |
|---|---|
| United States | 3.7 |
| Average of West-European developed countries | 0.7 - 1.8<br>/weighted average 1.4/ |
| Hungary | 3.5 |
| South African Union | 1.0 |
| Brazil | 1.2 |
| India | 0.15 |

The outlook for further expansion is bright both in industrially developed and developing countries.

According to information furnished by the British Post Office Administration, 25% of its telephone cable network is made from aluminium. Within 10 years, it appears, aluminium telephone cables will completely displace copper ones [2]. According to another forecast, electrical engineering in the USA - despite its present high per capita consumption - is to be fastest growing aluminium outlet in that country [3]. By the turn of the century, electrical engineering is expected to account for 20% of total world aluminium consumption [4].

In the overall aluminium consumption figure of Hungary there is a heavy concentration of aluminium usage in the electric engineering field. Historically, this may be attributed to the country's chronic dearth of and continued drive for savings in heavy non-ferrous metals throughout the pre- and post-war period, coupled with the changing pattern of copper pricing /see also caption 1.3/. In the wake of this, the use of aluminium began to gain ground rapidly in the manufacture of overhead power transmission cables, medium and low voltage conductors, as well as motor and transformer windings. In 1951 a document entitled "The Use of Aluminium and Aluminium Alloys in Electrical Engineering" was published and enforced as a Hungarian Standard Specification. Dealing with the technologically and economically feasible application of aluminium for a multiplicity of electrical ends, it concretely classifies each possibility as "desirable", "practicable" or"not practicable". Prompted by fresh advances in technology, this first standard specification has been subsequently revised and newly published.

Hungarian electrical conductor manufacture is now strongly aluminium-oriented, the share of aluminium conductors manufactured being 76% against 24% of copper. In most centrally planned economies aluminium accounts for 50-60% of total conductor manufacture, whereas in the Federal Republic of Germany 70% of all conductors are still made from copper and only 30% from aluminium. Hungarian aluminium conductor and cable manufacturers have in the meantime acquired great experience in turning out products of high technological standards.

The remarkable advance of aluminium consumption in the conductor field was also precipitated by the early specialization of Hungarian engineering and working personnel in aluminium installation techniques and the application of aluminium in electrical equipment and gear. In view of this, Hungarian engineering firms engaged in such operations today prefer using aluminium to copper.

Conductors are made either from copper or aluminium; for some particular ends copper, and for others aluminium is given preference. However, with aluminium encroaching on more and more novel electrical fields, the outlook of aluminium usage in this sector seems to be promising.

To determine whether for a given end aluminium or copper should be used, will depend on three factors: the production costs of aluminium conductors, the economics of their usage and their reliability.

Related to copper, there is from year to year, and over the long term even more so, a marked downward trend in the pricing of aluminium conductors.

In actual usage, their low specific weight and high specific conductivity/small energy losses/, coupled with their corrosion-resistance /savings in maintainance costs/ present extra advantages.

Reliability is ensured by their high mechanical strength and their susceptibility to plastic deformation, casting, welding and soldering. Under the same load, the rate at which their transient temperature tends to rise is identical with that of copper.

Thanks to these properties, the endurance of an aluminium conductor, too, is equivalent to that made from copper.

In electrical engineering aluminium is used either as a conductor /unalloyed or alloyed/ or as a rolled, extruded or cast structural material.

In future evaluations the $\sqrt{\rho p \gamma}$ formula may be used with advantage to compare its economic feasibility, wherein $\rho$ represents its specific resistivity, p its price per volume unit and $\gamma$ its density [6]. Calculated at 1974 prices and using 1 for aluminium as a basis, the corresponding indices for copper, magnesium and sodium will be 2, 1.14 and 0.55 respectively. /In the long term these seem to be the most promising conductors/. It will be observed that from an economic feasibility point of view magnesium and sodium are the two nearest approaches to aluminium. However, in large quantities both are hard to come by, and compared to aluminium, at present awkward to handle and difficult to process. Therefore it is believed that the significance of aluminium as a conductor is likely to grow in the two decades ahead.

## 4.12 Overhead lines and aerial cables

In Hungary the use of overhead conductors in transmitting and distributing power is of fairly old standing. Many years ahead of similar developments elsewhere, Hungary was one of the pioneers in installing complete aluminium power transmission and telecommunication grids. Experiences over the past have amply demonstrated that from an operational point of view aluminium is equivalent and from an economic point of view even superior to the copper and cadmium-bronze conductors previously used. Hence, practically throughout the world, power grids have gone over completely to using aluminium even in highest voltages /e.g. Hungary's 750 kV power transmission line/.

### 4.12.1 High-voltage overhead lines

The cost-effectiveness of cables used in high-voltage power systems is compared in Table 20.

Table 20

Comparison of resistance and pricing of electrical conductors
/Aluminium = 100/

| Per 1 kilogramme of conductor | Cadmium bronze | E AlMgSi | Aluminium conductor steel reinforced /ACSR/ /1:6/ |
|---|---|---|---|
| Resistance | 228 | 100 | 108.7 |
| 1976 world market price | 150 | 100 | 70 |

From the comparison in Table 20 it will be observed that in terms of the same weight unit the conductivity of an aluminium-based conductor is more than twice that of a copper-based one and its pricing compared to copper /allowing for some fluctuation in the world market price of the latter/ is about 1.5-2 times lower than that of copper.

Same applies also to low-voltage networks, where owing to the frequent branching off of distribution mains and the proximity of towers holding them the tensile strength of aluminium is not fully utilized.

Overhead power transmission grids and networks are usually made from cables as specified in Table 21 below.

Table 21

## Properties of conductors predominantly used in overhead lines

| Material | Specific resistivity $/\rho\ mm^2/m/$ | Tensile strength $/N/mm^2/$ | Permissible temperature /C°/ | |
|---|---|---|---|---|
| | | | normally | in case of short-circuit |
| Aluminium /hard/ | 0.0282 | 170–200 | 70 | 130 |
| Aluminium alloy /E AlMgSi/ | 0.0325 | 295 | 80 | 155 |
| ACSR | | | | |
| Steel | 0.240 | 1,530 | - | - |
| Aluminium | 0.0282 | 163–197 | - | - |

High-voltage overhead lines have to resist safely all thermal and mechanical loads, as well as the corrosive effects of outdoor usage. Moreover, they have to be so designed as to allow for some excess load that may arise in the course of their installation.

Because of their smaller mechanical strength, unalloyed aluminium conductors are as a rule used in low voltage networks, where mechanical loads are smaller. For medium and high voltage networks, in the first place steel-cored aluminium cables

/ACSR/, and to a lesser extent aluminium alloy cables are used [7]. For some specific ends steel-cored aluminium alloy cables, too, are available.

The addition of a zinc coating to protect the steel core against corrosion is usual, but lately, as an alternative, a so-called alumoweld coating too has come into use [8].

Aluminium and steel-cored aluminium conductors /ACSR/ are both suitable to be used either as phase or grounding conductors. In electrical networks it is of paramount importance to determine the maximum power rating of a conductor correctly.

Its magnitude will depend, next to environmental and climatic factors, on the composition, design and the stranding parameters of the conductor. In selecting a specification, particular attention has to be devoted to aspects of operational safety throughout the projected life of the cable. During this time, no major damage may occur to it, and under no circumstances may its mechanical strength fall below 5% of its original values.

The performance and reliability of cables are permanently checked, and even now in many parts of the world efforts are under way to develop new and more effective types of aluminium overhead conductors.

Table 22

### Maximum power ratings of high-voltage overhead conductors made in Hungary

| Material | Cross-section /mm$^2$/ | Maximum power rating | |
|---|---|---|---|
| | | Normally /A/ | In case of short-circuit /kA/ |
| Aluminium | 300 | 680 | 27 |
| | 643 | 1,120 | 58 |
| Aluminium alloy /E AlMgSi/ | 95 | 350 | 9 |
| | 240 | 625 | 24 |
| | 300 | 785 | 28 |
| Aluminium conductor steel reinforced /ACSR/ | 110/120 | 430 | 12 |
| | 250/40 | 710 | 24 |
| | 500/65 | 1,120 | 60 |

The above values are valid for the worst environmental conditions /solar radiation, + 30 $^0$C ambient temperature, one m/sec wind velocity/.

### 4.12.2 Aerial cables

Aluminium aerial cables are used as phase and neutral conductors in low voltage distribution systems, service mains, outdoor and provisional installations /Fig 9/.

They have won fast acceptance because of the increased ease, with which faults occurring in low voltage distribution systems caused by conventional outdoor service mains may be eliminated /about 80%/. Their salient features are

- simple disposition and easy installation
- aesthetic considerations, and
- fewer faults.

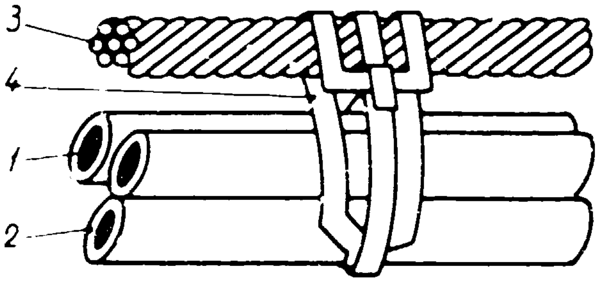


Fig.9 - Disposition of aerial cables

1. Solid or stranded conductor
2. Plastics insulation
3. Stranded suspension rope
4. Suspension shackles

Aerial cables are made from 99.5% aluminium in cross-sections of 6-300 square millimetres, with a tensile strength of 70-110 N/mm$^2$.

Maximum power rating e.g. of a 240 mm$^2$ cross-section cable: under normal operation at a 25 °C ambient temperature 410 A; in case of shorts temperature may not rise beyond 150 °C.

The dielectric strength of the plastics insulation is 40 KV/cm. The stranded suspension rope is made from aluminium or an aluminium alloy /E AlMgSi/. Securely attached to the service mains, it will meet all technical and electrical requirements acting as the carrier of the insulated phase conductor on one hand, and as a neutral on the other hand.

The installation of aerial cables has to be done in strict conformity with standing standard specifications. Quick and up-to-date technologies of assembly are greatly facilitated by prefabricated fittings.

### 4.12.3 Aluminium fittings

In electrical power transmission they are used as conductor-, suspending- and protecting fittings.

Conductor fittings are designed to link two or more conductors of a transmission line; suspending fittings are used to hold overhead cables, aerial conductors and insulators in position or to connect them with one another; and protecting fittings are installed to enhance the operational safety of the transmission line.

To fasten conductor ends, pressure clamping is the usual technology. Fittings employed to this end are reliable, economical and easy to handle.

These fittings embody latest advances in installation technology. In Hungary they are used from 0.4 kV low-voltage networks up to the largest 750 kV high-voltage transmission system [10] [13] [14].

### 4.12.4 Aluminium load-bearing structures of power transmission lines

Throughout the world there is a growing shortage of skilled labour accompanied by a universal pressure for updating conductor installation techniques. Prompted by this demand, several aluminium structures have been recently developed by which maintainance costs of power transmission lines may be saved. In

Hungary, too, several such aluminium structures have been designed and tested, e.g. prototypes of low and medium voltage tower heads and towers.

Although erected ten years ago in an industrial area where chemicals are liberally used, annual checkups of an aluminium transmission line tower prototype have so far revealed no trace of change or any damage This and similar prototypes have aroused great international interest [15].

### 4.12.5 Overhead telecommunication networks

For several decades past, aerial cables used in Hungary as carrier frequency basic circuits of trunk calls over more or less long distances have been composed from age-hardened E AlMgSi aluminium alloy wires. Statistical returns for the past 30 years have demonstrated that faults occurring in the course of their usage had been only one half or two-thirds of the ones recorded in respect of earlier bronze conductors [12]. This was largely due, besides the inherent properties of aluminium, to the effective fastening and jointing techniques applied.

### 4.13 High-power underground cables

The use of aluminium conductors in cable manufacture is dating back to the 1930s. However, it was not before the post-war years that different technologies for the sheathing of underground cables by aluminium were devised and introduced on an industrial scale. A major breakthrough in underground cable design occurred recently with the emergence of the solid aluminium conductor in low voltage solid dielectric cables. The pioneer of this innovation had been ALCAN, being the first to release in detail the technical features of its SOLIDAL type low voltage solid aluminium conductor cables 16 . Since then, the Hungarian industry, too, is manufacturing such cables.

The production costs of solid dielectric 0.6/1 kV cables may only compete with those of impregnated paper insulated cables made from three stranded aluminium phase conductors with an aluminium sheathing acting as neutral, if all four conductors are made from aluminium. The standard specifications of some countries /e.g. VDE 0271/3.69 of the Federal Republic of Germany/ explicitly forbid the use of aluminium as a neutral conductor placed concentrically around the three other conductors, insisting on copper to be used for this end. Despite its technological merits, such a design seriously jeopardizes the cost-effectiveness of such a cable. However, with suitable protection against corrosion, in some countries the use of a concentrically placed fourth aluminium conductor is permissible. Cases in point are the WAVECONAL-type cables of the U.K. or the TRINEUTRAL cables developed in Hungary and reproduced in Figs 10 and 11 [17] [18] [19].

In Hungary TRINEUTRAL cables have so far been laid over a distance of 50 kilometres giving full satisfaction.

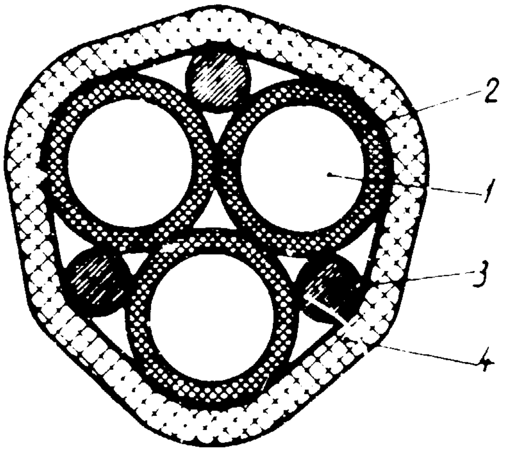


Fig.10 - Section of TRINEUTRAL cable

1 - Round solid aluminium conductor
2 - PVC insulation
3 - Neutral: three round aluminium wires and an aluminium tape
4 - Black PVC sheathing

The 95-150-240 $mm^2$ section aluminium conductors extruded from 99.5% aluminium have a tensile strength of 60-70 $N/mm^2$. They are sufficiently soft and pliable to permit easy handling upon installation. Their use has confirmed that no longer need high voltage underground cables be composed of stranded conductors but up to a 240 $mm^2$ section solid conductors may be applied with advantage.

On joining cable terminals, by flattening and punching the solid conductor ends with the aid of a special tool, suitable cable shoes may be formed. Cold pressure technologies in fastening stranded conductors have now been effectively adapted to solid conductors as well. Moreover, traditional methods of welding may, according to experience, safely be applied to solid conductors in making firm and reliable joints.

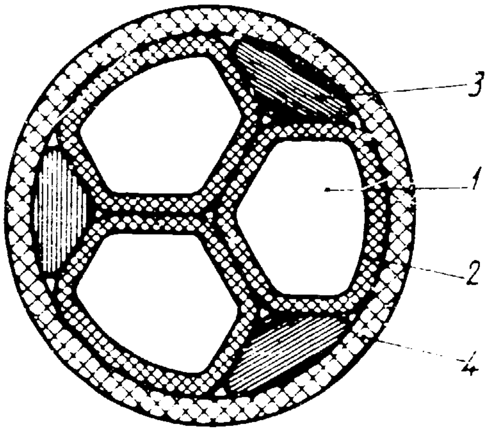


Fig.11 - Section of 0.6/1 kV 3x70 - 3x240/240 $mm^2$ cable

1 - Solid aluminium conductor of arched five-angled section
2 - PVC insulation
3 - Neutral: three aluminium wires of arched triangular section and an aluminium tape
4 - Black PVC sheathing

In view of these gratifying results, Hungary has been using for the last ten years solid conductors also in manufacturing 6-35 kV high-voltage underground cables as shown in Fig.12 [19]. The laying of such cable poses no problem and its insulation too is facilitated by the fact that a smooth-surfaced semi-conductor plastics layer may be more easily added to a solid conductor than to a stranded one. Under a new Hungarian technology, even this semi-conductor layer may be dispensed with, provided the surface of the solid conductor is absolutely smooth and flawless.

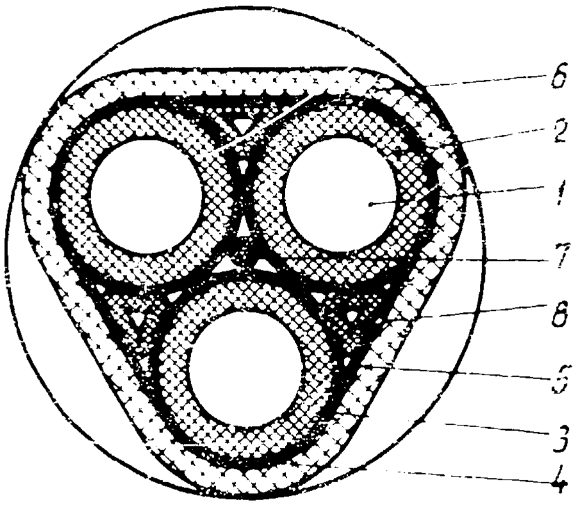


Fig.12 - Section of ROUNDAL high-voltage cable

6 - Blue PVC sheathing
2 - Plastic insulation with graphite-coated outer surface
1 - Round solid aluminium conductor
7 - Aluminium guard wire
8 - PVC filling
5 - Double layer steel strip
3 - Semi-conductor paper tape
4 - Double layer aluminium strip

If this condition cannot be complied with, a layer for smoothing the conductor surface - like the one used with stranded conductors - has to be added. In this case, however, stringent requirements as to the surface smoothness of the solid conductor no longer apply, and the latter may be used forthwith as received from the extrusion mill.

As mentioned before, some international standard specifications do not permit the use of concentric neutral and guard conductors made from aluminium. By contrast, in Hungary even the metal part of the insulation screening is made from an aluminium band [19]. Earlier, it used to be wound round the conductor, but the new 6/10 kV cable now features an aluminium band screening fixed longitudinally onto the conductor.

Favourable experiences have demonstrated that low and high voltage solid dielectric cables composed of aluminium phase conductors, screenings and neutral or guard conductors may be manufactured and used with advantage permitting fair economies in material and labour costs [19]. Their application may be especially welcome in countries where the setting up of a cable industry is envisaged or under way.

## 4.14 Telephone and telecommunication cables

Owing to copper shortage, during the second world war Hungary used to manufacture symmetrical carrier frequency long-distance and local telephone cables from aluminium with paper insulation and lead sheathing [16]. In the post-war period when copper prices began to rise steeply, there was a similar trend elsewhere as well, but such schemes did not gain ground to a larger extent except in Australia [3] [17].

However, the emergence of fully-filled cables has fundamentally changed the situation. These cables are usually manufactured with cellular polyethylene insulation, the gaps between the wires being filled with a water-repellent petroleum jelly to protect the cable against corrosion. Their sheathing consists of a polyethylene-coated aluminium band and polyethylene 18 . Some firms have developed a special AlMgFe alloy as a conductor, approximating the mechanical properties of copper conductors permitting higher productivity in manufacture and easier techniques of joining upon installation [19]. Aluminium and aluminium alloy fully-filled cables have especially in the U.K. won wide acceptance [18] [19].

## 4.15 Service mains and installations

Service mains are used to feed the interior electrical installations of buildings, households, industrial undertakings and agricultural consumers.

With fresh advances in manufacture and installation techniques, aluminium for a good many ends in this field has become an equivalent conductor to copper. For general installation purposes aluminium is nowadays universally accepted. Copper is only used where increased operational safety is a special consideration /e.g. warning signals, interior wiring of equipment, etc./ [20].

Items discussed under this heading comprise

- Insulated conductors [21]
- Busbar channels [22] [24]
- Joints and fittings [24] [25]

### 4.15.1 Insulated conductors

The conductivity of aluminium depends on a great many factors. Technical features in this connection are so varied and permitting so many combinations that in many countries - including Hungary - conductors for installation ends have been standardized. They are usually made from 99.5% aluminium, either in solid form or by stranding several wires.

To enhance their flexibility, the 99.5% aluminium is sometimes slightly alloyed with other metals, especially iron [26]. Some of these are known as Triple E and Super T conductor material /see also sub-chapter 5.1/.

Their ratings are embodied in the relevant standard specifications, depending also on where they are to be installed /under plaster, extramurally armour--clad etc./.

In many countries predominantly or exclusively insulated conductors composed of several aluminium wires may be used for purposes of lighting or the operation of equipment in households, industrial undertakings, schools and other institutions.

In Hungary aluminium conductor installation techniques may look back to 30 years of experience. The technologies developed and practised since then have greatly contributed to the viability of aluminium for such end-use in its competition with copper.

In the laying of joints, connections and fittings, some peculiarities of aluminium have to be allowed for, in order to avoid the fracture of wires as well as the strong creep causing excess temperatures and possible shorts with extra danger of fire.

Where stiff safety regulations are imposed or over a short distance many joints and connections are to be made /e.g. in hospitals, distribution boxes, etc./ it is preferable to use copper conductors, so as to avoid creep.

### 4.15.2 Conductor bar channels

Conventional building methods are no longer adequate to keep pace with the pressure of latest technological advances. Thus, the emergence of light constructions gave also rise to various new designs of corductor bar channels. These, as well as the perforated assembly plates and the plastic-coated tubular uprising aluminium conductor bar systems themselves, now greatly facilitate the work of installation, improving its productivity and permitting labour savings.

In selecting a suitable material for conductor bar channels, aluminium is now considered preferable to plastics, in order to present the possible fires from spreading.

### 4.15.3 Joints and fittings

Aluminium conductors are susceptible to creep and sensitive to incisions. It is therefore of particular importance that effective technologies of fastening, joining, stretching and connecting conductors be applied and fittings of suitable design be selected in carrying out such work [24] [25].

In Hungary, earlier, the conventional way of connecting conductors had been the simple twisting together of wire ends. This method, however, did not prove to be sufficiently reliable, hence the use of special fittings for this end has become compulsory. An example of this is shown in Fig.13.

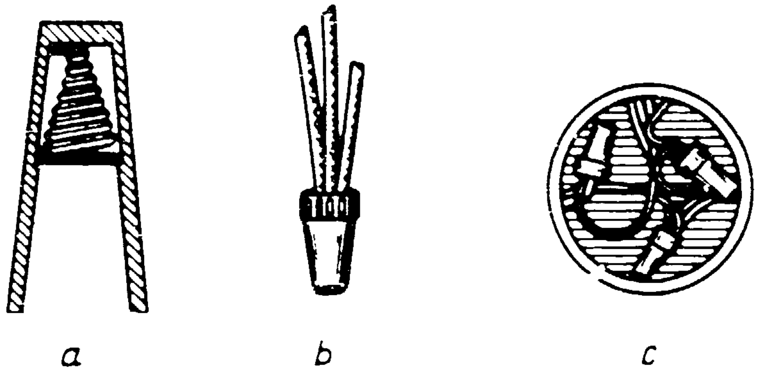


Fig.13 - Plastics-capped self-cutting, twisting and uninsulated fitting for connecting conductor ends

a - Sectional view
b - The joints
c - The position of joints in the connection box

Next to the one illustrated in Fig.13, there are also other effective technologies of joining, e.g. by soldering, welding or pressure clamping.

In recent times a large variety of joints and fittings have been devised to ensure the reliable and cost-effective operation of service conductors. Handled by sufficiently trained and skilled personnel, they may greatly enhance the efficiency and operational safety of such installations.

## 4.16 Transformers and capacitors

### 4.16.1 Transformers

Hungary has 40 years of experience in the manufacture and operation of transformers with aluminium windings. Used in the first place in distribution transformers, they are usually designed with ratings of up to 2.5 MVA and voltages ranging from 3.6 to 36 kV. Some of them are oil, and others dry transformers. Aluminium-wound transformers are also available for very small /several VA/ and higher /25-63 MVA/ ratings as well. In recent designs of high-power transformers several structural parts too are made from aluminium, so as to reduce additional transformation losses. Such aluminium components include clamps, containers, lids and electromagnetic screening surfaces.

The economics of aluminium usage in transformer windings is governed by the pricing of aluminium winding related to that of copper. If the copper windings of a transformer are replaced by aluminium windings of the same size, at a temperature of 75 °C the ratio of their windings may be expressed as

$$P_{al} = P_{cu} \quad \frac{\rho_{cu}}{\rho_{al}} = 0.79\ P_{cu}$$

where $P_{al}$ and $P_{cu}$ are the ratings of transformers with aluminium and copper windings, and $\rho_{cu}$ and $\rho_{al}$ their corresponding resistivity. If the price of a copper-wound transformer of $p_{cu}$ rating is $p'_{cu}$, and for the sake of comparison its rating is reduced to that of the aluminium-wound one, its price will become $p'_{cu}$ ; and since prices change with the 3/4th power of ratings, we thus obtain

$$P'_{cu} = P_{cu} \left( \sqrt{\frac{\rho_{cu}}{\rho_{al}}} \right)^{3/4} = 0.84\ P_{cu}$$

From a point of view of production costs, aluminium usage will be more economical, if the reduced production costs brought about by the reduction of rating in a copper-wound transformer $p_{cu} = 0.84\ p_{cu}$ are higher than those of a transformer with aluminium windings of the same rating.

A transformer is economical, when both its production and operating costs may be kept at a minimum. When a transformer is designed in this manner, its aluminium wildings are even less utilized than would be the case if the same thermic load were to be striven for as applied to the copper-wound transformer. While with copper windings the most economical current densities are in the 2.5 - 3.5 $A/mm^2$ range, with aluminium the corresponding figures are 1.5 - 2 $A/mm^2$.

In Fig.14 the ratio for total production and operating costs between aluminium-wound and copper-wound 25 MVA and 4 MVA transformers $S_{al}/S_{cu}$ is plotted against the relative aluminium/copper pricing $K_{al}/K_{cu}$ based on 1974 metal prices in Hungary. It will be observed that in case of the high-output transformer the use of aluminium windings, and in case of the smaller output one or where the aluminium/copper ratio falls to or below 0.85, the use of copper-windings is more cost-effective [3] [28].

Metal and power prices may vary with each country, but it may be accepted as a general rule that below a 2.5 MVA rating aluminium-windings are more economical than copper-windings. The recognition of this is the more important, bacause 90% of the world's transformer production may be accounted for by ratings smaller than this. As for ratings beyond 25 MVA, for reasons of size, the use of aluminium windings is not practicable.

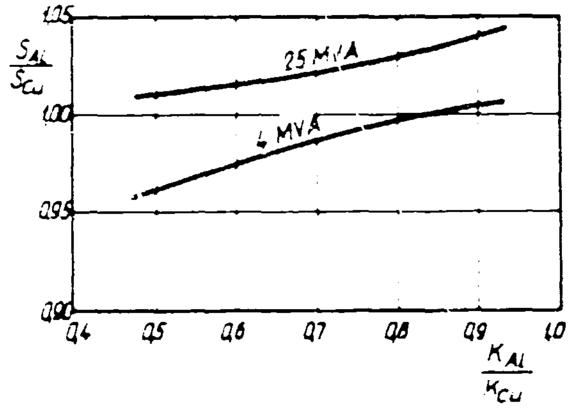


Fig.14 - Relative total production and operating costs of aluminium-wound and copper-wound transformers plotted against aluminium/copper pricing

Special mention has to be made of dry transformers. Here the windings take up most of the transformer space, therefore the application of aluminium windings is throughout economical and production costs too are lower.

In view of the loads and sizes involved, the best aluminium winding material is half-hard wire with a conductance of 35 $\frac{Sm}{mm^2}$ , a tensile strength of 110 N/mm$^2$, an elongation at rupture of 12% and a Brinell hardness ≥ 200 N/mm$^2$.

Lately, up to 4 MVA ratings, aluminium foil windings too are used both in dry and oil-insulated transformers [29] [30]. Their advantages may be summed up as follows:

- Better heat dissipation in the windings
- Increased resistance to short currents
- Improved voltage distribution caused by impulse voltages

- Windings leading themselves well to automation.

The gauge of 99.5% purity aluminium foil used in oil- and plastics-insulated transformers is ranging from 0.01 to 0.4 millimetres; above this gauge aluminium strips are used. Hungary is manufacturing at present up-to-date plastics--insulated aluminium foil dry transformers under a special AEG licence.

### 4.16.2 Capacitors

The rising growth rate of electrical power consumption calls also in the wattless power field for the setting up of more capacitor sub-stations. Up-to-date liquid-dielectric high voltage and dry low voltage capacitors are made almost exclusively with aluminium foild windings. The minimum 99.9% purity aluminium foil necessary for this end is of 0.005-0.120 mm gauge and 60-400 mm width. The foil surface has to be clean, even and oilless. Fluctuations of more than 10% in foil gauge and unsuitable heat-treatment detrimentally affect capacity and production costs.

## 4.17 Road vehicle accessories

In designing road vehicles, there is nowadays a marked trend towards weight reduction and energy savings. In view of this, at various research institutes of the world efforts are under way to test the substitution of traditional copper conductors and coils in motorcars by aluminium ones. According to latest prognostications there is a fair chance for aluminium to replace in the long run copper usage in this field, provided suitable methods may be devised for connecting and fixing aluminium conductors in a reliable and economical manner involving the least possible voltage drop.

At present, the development of a flexible creep-resistant aluminium alloy and efficient low-voltage /12 V/ contacts are under way. The application of these on a commercial scale is anticipated in the near future.

## 4.18 Lighting gear

The use of aluminium in this field is determined by its following properties: low specific gravity, corrosion-resistance, attractiveness and good reflectance. Accordingly, aluminium under this heading is predominantly used as lamp casings and mirrors.

Low specific gravity is an important consideration at points where economies are striven for not so much by the lightness of lamp fittings but by the gear holding them. This is especially the case at sites where numerous lamps are installed in closed groups, as e.g. in sports stadiums where often 60-80 spotlights are to be held by each pole.

Corrosion-resistance is an important prerequisite in all lighting gear used outdoors, whether it is a reflector of sports grounds, a factory yard or an ordinary street lamp. Outdoor lighting gear has to last at least ten years or more. The surface of aluminium mirrors has to be provided with anodic oxidation. Although such a surface tends to reduce somewhat its reflectance, the increased hardness and resistance to wear thus arrived at may permit the cleaning of such gear at regular intervals.

Attractive appearance of lighting gear is especially desirable if used indoors. For this end the aluminium surface has to be provided with bright polish or dye-anodization.

Reflectance is a fundamental requirement in case of reflectors, street lamps and indoor illumination.

To enhance reflectance, 99.99% high-purity aluminium is used with 0.5 - 1% magnesium added. The brilliance of the aluminium surface may be arrived at by chemical, electrolytic or mechanical polishing or a combination of these.

Hungary is an exporter of lighting gear to a great many countries. The mass-manufacture of such items calls for automation. A recent technology uses steam pressure in applying aluminium onto plastics surfaces. However, the heat resistance of such mirrors is still limited. In using light sources where elevated temperatures are involved /mercury, halogen and sodium lamps/ the use of aluminium mirrors is more feasible from a technological and economic point of view.

## 4.19 Electric motors

The windings of electric motors is usually made from copper. The reason for this is the higher specific resistivity of aluminium.

Aluminium windings for this end are as yet not too widespread and are more or less limited to small motors. But even in small motors they are not gaining ground, for most of the latter are of the commutator type, where aluminium may not be readily used because of the oxide film formed on its surface.

By contrast, in case of rotor coils of synchronous motors, aluminium with its one-third of specific gravity considerably reduces centrifugal force. In turn, the coil grips too are exposed to smaller load and may be reduced in size, leaving more space for mounting the coils. Thanks to this arrangement, aluminium in such cases may be used with advantage.

Some engineering firms specialising in transformer winding material have also taken up the manufacture of insulated aluminium wires for rotor coils as well. Such wire is round or flat, furnished with enamel or glass-fibre etc. insulation.

At present, in each country the relative pricing of aluminium and copper will determine which of the two alternatives is more economical. Many motor manufacturers have gone over to using aluminium rotor coilings, deriving considerable technological and financial benefits from applying specifications of wire and insulation best suited for their particular technologies.

## 4.20 Up-to-date installation equipment

The electrical engineering industry is using large quantities of aluminium in switch equipment as a conductor or structural material.

### 4.20.1 Aluminium conductors

For the transmission of heavier power aluminium conductor bars are now widely used. In designing and installing them three parameters have to be taken into account: their specific gravity, electrical conductivity and mechanical strength.

From a specific gravity point of view, aluminium is obviously superior to any other conductor material. As far as conductivity is concerned, in theory it would be best to use aluminium of as high purity as possible. However, in applying an aluminium conductor, certain requirements as to mechanical strength have to be complied with. Therefore, in actual practice, such aluminium alloys have to be given preference /AlMgSi0.5/ which may relatively best meet both of these requirements. In the installation of conductor bars, the greatest attention has to be devoted to the expert handling of contact surfaces in joining, connecting and fastening them.

Releasable joints may best be made by screwing the conductor ends together. In case of extra thin conductors, the looping of conductor-ends too is possible. The contact resistance of screwed joints will always depend on how they were made [32]. Contacts may never be really effective, unless from the conductor terminals to be fitted together, the oxide film formed on the aluminium surface - which is a poor conductor -, had been removed or the conductor ends had been coated with a metal of good contact properties. Good contacts may be arrived at by cleaning the terminal surfaces under a layer of vaseline by applying zinc particles suspended in vaseline /Desox paste/, by electroplating the contact surfaces /e.g. by silver, copper or tin/ or by metal-spraying them by a metal of superior conductivity to that of aluminium /e.g. copper, silver, etc./ [33]. The EXCONAL type of bars developed by ASEA of Sweden combine the useful features of aluminium and copper by a copper foil being pressed onto the aluminium conductor /see also sub-chapter 5.1/. Of the volume of EXCONAL bars 85% consists of aluminium and 15% of the copper-coating. Such conductor bars may be joined as if they were pure copper ones.

Permanent joints are made either by welding or pressure [34]. Welded joints are better conductors than releasable ones, being not susceptible to transient resistance rise. Their welding, however, is unwieldy, calling for care in selecting a suitable method and technology [35] [36].

Permanent joints by pressure are made e.g. in case of stranded cables, or by cold-extrusion in case of connecting foil conductors [37] [39] [34]. The joining of cable wire ends is done either by cold-extrusion or pressure clamping /see also sub-chapter 4.13/.

### 4.20.2 Metal-clad bars

To increase operational safety at the consumers' end several armour-clad distribution systems have been developed.

Such systems are spread out throughout the works area, permitting individual service lines to be linked on swiftly. Owing to certain difficulties in installation techniques, often preference is give to using copper for this purpose. However, VBEM of Hungary has developed an effective technology of connecting such branch lines to aluminium conductor bars either permanently or with the aid of suitable plugs /see also sub-chapter 5.1/.

Metal-clad bars are used in power works and distribution systems to connect generators and transformers [38]. Each phase of the bars is separately metal-clad, this arrangement practically excluding the possibility of busbar short-circuits.

### 4.20.3 Metal-clad equipment

Calculations have demonstrated that structural steel in equipment handling heavier than 1,000 A power tends to give rise to considerable secondary currents and losses, which at around 3,000 A no longer permit the use of such designs. Hence, in installing equipment for heavy curents steel is not a sufficiently safe structural material and has to be replaced by an aluminium alloy [40].

Aluminium as a structural material is also gaining ground is outdoor switchgear, where corrosion and maintainance costs may thereby be reduced to a reasonable minimum [40]

Into such metal-clad aluminium switchgear only electrical equipment destined for indoor use may be mounted. The erection of sub-stations housing them does not involve considerable building capacities [40]. This is an important point especially in case of exports, where sufficient building capacities are usually hard to obtain.

Hungarian industry has so far furnished such switchgear for some 50 gas turbine power works exported abroad [41].

The use of aluminium in outdoor transformer sub-stations too present similar advantages [41].

An interesting example of aluminium usage is sulfur-hexafluoride gas protected high-voltage metal-clad switchgear, where both the conductor bars and equipment are mounted into an aluminium alloy body.

### 4.20.4 Outdoor switch equipment

Sub-stations within the 35-750 kV range are as a rule of outdoor design. Same applies also to most of the busbars used nowadays, made from an aluminium alloy in the form of a stranded conductor or tube.

In industrial countries there is a marked trend of building outdoor sub-stations with metal-clad switchgear insulated by sulfur-hexafluoride gas, permitting considerable space economies. Under a licence from BBC of Switzerland, their manufacture was taken up by the Ganz Electrical Works of Hungary, building 120 kV and 400 kV transformer stations of this type.

Sulfur-hexafluoride gas insulated metal-clad electrical gear /circuit breakers, measuring switches etc./ are also used effectively in traditional busbar sub-stations.

## 4.2 Chemical engineering and food processing

Early in the history of aluminium had the chemical engineering and food industries entered the field as major buyers of equipment where this material is applied for structural purposes or where they are using it for different packaging and storage ends. The progress of aluminium in these sectors may be largely attributed to its corrosion resistance, its anti-toxic properties, its workability, small specific gravity and last but not least to the fact that in most cases it lends itself well to replacing tin. The momentum of this growth, however, has recently slowed down somewhat owing to certain new developments in modern technology. The emergence of stainless steel and plastics, with subsequent price reductions of items made from them, has within the last ten years made certain inroads on the aluminium market. To keep pace with such competition, serious efforts were undertaken to find new aluminium outlets, to update old ones and to develop new technologies permitting large volumes of such items to be manufactured with utmost cost-effectiviness. Accordingly, the selection of aluminium items in this field is rapidly changing, with utility cycles tending to become shorter and shorter. The risks of introducing such innovations are great; this necessitates a very thorough appraisal of the market situation in each case, with special regard to circumstances prevailing on site.

### 4.21 The use of aluminium in chemical engineering

The great headway recently made by the inorganic and organic chemical engineering industries calls for more sophisticated designs of storage tanks and transport containers. In many instances tinned copper, tinplate or lead-coated steel used earlier as a structural material, could no longer meet new and increasingly stringent requirements. In view of this, aluminium with its good corrosion-resisting properties and lightness has in due course gained ground for such usage /e.g. oxigen, nitric acid, acetic acid manufacture/. At first, the high price of stainless steel has favourably affected such trends. Meanwhile, stainless steel prices have fallen and operating experiences in aluminium usage have become more widespread. At present, these two underlying factors determine a great deal where and how aluminium may be used with advantage in chemical engineering.

The present study is not destined to deal with prototype or customized work. What is aimed at is to point to some specific areas where large quantities of aluminium are used by the chemical engineering industry as a structural material in making silos, tanks, transport containers and auxiliary equipment. Each of these groups is to be discussed according to its merits and in relation to other structural materials as potential competitors. Concrete examples will be given as to the manufacture and use of

- storage silos
- tanks, transport containers,
- air engineering equipment and tubing and
- cladding of insulated tubes.

Storage silos have grown in importance since plastics manufacturing and processing capacities are throughout the world expanding. They are especially in demand in PVC and polypropylene factories. Their sizes range from 150 cu. metres to 500 cu. metres. There are also smaller units of 50-150-cu. metre size, used for intermediate storage at different stages of the manufacturing process.

Stationary and mobile containers are predominantly used in the manufacture of light chemicals, pharmaceuticals and paints. The mobile variety is also used in the transport of concentrated nitric acid, acetic acid and some products of the oil industry /e.g. petrol, liquid gas/. The manufacture of liquid gas transport containers calls for great experience. In Hungary for more than 20 years 0.5 - 25-litre aluminium liquid gas bottles and cylinders have been used with advantage, made by wall-reducing deep-drawing. In case of the 25-litre cylinders, a weight saving of 3 kilogrammes per piece could be arrived at, compared to their steel counterpart. Moreover, aluminium ones need not be re-painted every three years /see also sub-chapter 5.2/.

Air-coolers in chemical engineering usually consist of ribbed aluminium tubes or aluminium ribbing embracing a steel, acid-proof steel or copper tube core. Such tubes with pleated transversal ribbing are as a rule made at the semi-manufacturing mills, featuring a special technology. /For know-how see sub-chapter 5.2/. The largest customers of aluminium ribbed tubes are oil refineries and chemical engineering works, where such coolers form part of complete heat-exchanging systems.

As for air conduits of the chemical engineering industry, the use of flexible aluminium tubes made by continuous edge-rolling of aluminium strips is steadily gaining ground. In square-section sheet tube design the zinc-coated steel variety is still widespread, but aluminium tubes - with special regard to their flexibility - are also expected to make good headway for use inside works premises or employed as flue stacks.

In chemical engineering most insulated tubes have to be provided with an extra protective coating. For this end, usually aluminium strips are used, being corrosion-resistant and easy to handle. Zinc-coated steel strips have by now almost completely been replaced by aluminium ones.

### 4.22 Aluminium usage by breweries and dairies

Brewing of beer and processing of milk are age-old pursuits of mankind. For several centuries past, for this purpose equipment manufactured exclusively from tinned copper, wood and later tinplate had been used. The use of aluminium in this field may be dated back to the 1930's. Experiences over several decades have amply demonstrated that designs of aluminium manufacturing and storage equipment in breweries and dairies are not only more economical in use, but also present numerous technological advantages in view of certain properties of aluminium. Though these advantages have been referred to in sub-chapter 2.14, let us briefly recapitulate them, as far as this part of the present study is concerned:

- Aluminium in the processing and storage of beer and dairy products is never attacked by any substance it gets into contact with, except for sour milk, which has a slightly aggressive effect;

- In contrast with equipment and transport containers /e.g. milk cans/ made from tinned copper or tinplate, aluminium ones require no maintainance whatever;

- With aluminium lending itself well to plastic deformation and welding, it is ideally fit for the cost-effective mass-production of containers and other items /beer casks, milk cans etc./.

In using aluminium in breweries and dairies, the following considerations too have to be taken into account:

- As a raw material only copper-free smelter aluminium /with a maximum copper content of 0.1% according to DIN, and 0.2-0.3% according to some U.S. standards/ may be used either in unalloyed form or alloyed with maximum 3% of magnesium or a combination of maximum 1% magnesium, 1.2% silicon and 1% manganese;

- Preference is to be given to one-piece deep-drawn designs. Accessories - as far as possible made from the same material as the deep-drawn body - may only be joined by shielded-arc welding;

- Special attention has to be devoted to the cleanliness and fresh air supply of workshops and storerooms; after finishing pressure tests, the equipment has to be dried, so as to avoid the detrimental effects of condense vapour. Also, in the layout of equipment it should be remembered that an aluminium one calls for increased space;

- Inner surfaces getting into direct contact with beer or milk have to be smoothed out by a suitable technology /e.g. mechanical polishing/;

- Organic coating may only be added onto primings approved by the health-authorities. E.g. the inner resin-coating of beer casks may only be applied to an electroformed anodic oxidation-based priming such as developed by the Refrigerator Works of Hungary [42]. /See also sub-chapter 5.3/.

- All equipment and transport containers have to be kept scrupulously clean. According to experience in Hungary, dairy equipment may best be sterilized with the aid of a water glass inhibited solution of formol; scale forming on the inner surface of beer tanks may best be removed by using silicon earth soaked in a dextrin solution, to which 10% nitric acid had been added previously. The latter has to be flushed out by hot water 24 hours after it had been applied to the surface [43]. Soda and as inhibitors certain solutions containing sodium metasilicate or trimetallic sodium orthophosphate, too, may be used with advantage. As to how an aluminium equipment containing steel components may best be cleaned, Du Pont's No. 2,948,392 U.S. patent is giving a detailed answer [44].

However, despite its many useful properties in this field, aluminium had been faced in the last few decades with serious and not unsuccessful competition by stainless steel. The position of aluminium became precarious when the relative pricing of stainless steel decreased and when fast but aggressively reacting detergents came into use [45]. The present situation and future outlook for the next ten years in this context may be summed up as follows:

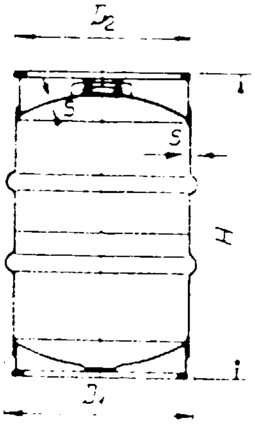
- In both industries aluminium is to keep its position in case of mass-produced transport vessels and containers /beer casks, new types of cold-storage milk transport containers and milk cans/, large stationary or mobile containers, as well as storage tanks where good thermal conductivity is a special requirement;

- Stainless steel is to win general acceptance for more sophisticated equipment where frequent cleaning is necessary /e.g.thickeners, milk separators, etc./.

### 4.22.1 Aluminium usage by breweries

Today the major part of equipment used by modern breweries is made from aluminium, completely displacing earlier wood and tinned copper usage. For storage, fermentation and transport, large unalloyed aluminium tanks of 5-10 millimetre thickness are employed. The cooling of the large underground fermenting and storage caves too is preferably done by aluminium heat exchangers and piping. Aluminium apparatus may also be used with advantage for the saturation of beer with carbon dioxide. Boiling vessels have in several instances too been made from aluminium, replacing tinned copper. Recent shifts in the relative pricing of aluminium and stainless steel, as well as the greater ease of cleaning equipment made from the latter, have caused a setback in aluminium usage. However, for the next ten years or so, the position of aluminium as a structural material of small beer casks /25-100 litres/ seems to be firm and uncontested. In weight, an aluminium cask is only one-third or one-fourth that of a wooden cask. As a further advantage, it needs no maintainance. Aluminium beer casks are usually made from an age-hardened AlMgSi1 alloy by joining two deep-drawn halves of their body into one by means of shielded-arc welding. For reasons of protection and hygiene, the inner surface of the cask is either plated with a 99.8% pure aluminium layer, or after being given a proper priming, coated with a synthetic-resin film burned onto the inner cask wall. The second alternative enhances the chemical resistance of the inside of the cask against aggressive agents, permitting its use also for other purposes as well. In Hungary, at present 100,000 such beer casks are manufactured annually /see sub-chapter 5.3/. Recently, after a British design, 30 and 50-litre so-called "Keg"-type beer casks have come into use, which are easier to manufacture [45] Fig.15.

As for aluminium beer cans, this subject is dealt with under sub-chapter 4.23.



| Volume | $D_1\ ^{+14}_{-1}$ | $D_2\ ^{+0}_{-3}$ | $H\ ^{+0}_{-3}$ | S | ~ kg |
|---|---|---|---|---|---|
| 30l | 381 | 366 | 400 | 2,8 | 5,5 |
| 50l | 381 | 366 | 600 | 2,8 | 6,0 |

Fig.15 - "Keg"-type beer cask with three circular seams and welded tap-hole

### 4.22.2 Aluminium usage by the dairy industry

In dairies operating on an industrial scale the situation as to equipment and apparatuses /containers, coolers, pasteurizers, etc./ is similar to that of the breweries. In double-walled coolers and heaters a combination of two metals is gaining ground, their outer hull being made from aluminium and their inner body in direct contact with milk or milk products from stainless steel, so as to permit easier cleaning. In coolers and heaters the use of integral tubes in aluminium sheets /e.g. so-called "roll bond" sheets/ is widespread. Easy to manufacture, in actual practice they are of high thermal efficiency.

In collecting and distributing milk, aluminium transport milk cans have completely displaced earlier designs made from tinned steel. With tinning every 3-4 years no longer necessary, deep-drawn aluminium cans manufactured in large series with high productivity have won universal acceptance. For reasons of mechanical strength and economies in material, in their manufacture the use of $AlMn_1$ and age-hardened AlMgSi alloys are steadily gaining ground. A new wall-reducing deep-drawing technology is highly effective in manufacturing large series of 100,000 cans annually /see sub-chapter 5.2/.

In up-to-date technology the chain of operations from collecting milk up to its storage has recently undergone great changes. Milk has to be kept cool even in smaller quantities at the farmer's end until called for by larger transport vehicles fitted with coolers. Hence both the storage tanks and transport containers have to be constructed with double walls. Their outher hull and the heat exchangers /pipe coils and others/ are made from aluminium. As for their inner body in direct contact with milk, the use of stainless steel [illegible] [illegible] on, in order [illegible] [illegible] [illegible] [illegible] [illegible] effective cleaning.

For packaging milk and milk products see sub-chapters 4.23 and 4.24.

### 4.23 Aluminium cans, boxes, lids, bottle closures and collapsible tubes; substitution of tinplate

Tinplate used to be a traditional material of packaging in making cans, lids, bottle closures and sundry other items for the food industry. In up-to-date practice, however, aluminium is more and more displacing tinplate for such and similar ends. One reason for this is to be found in the world market price of tin.

World tinplate production, though growing at an annual average rate of 9-10 per cent, is insufficient to meet actual world demand. In 1976 world tin production /excluding the Soviet Union, China and other centrally planned economies/ totalled 178,000 tons, devoted to the following end-uses:

| | |
|---|---|
| Tinplate | 40% |
| Soldering | 25% |
| Bearings | 10% |
| Chemical engineering | 8% |
| Surface coatings | 5% |
| Other ends | 12% |

As will be observed tinplate manufacture ranks first in tin consumption.

Perhaps nowhere is competition between aluminium and other materials so keen as in the packaging field, espacially in relation to tinplate. A reason for this is to be found in the production costs of modern packaging items, which are often higher than those of the substances they hold /e.g. cosmetics, some foodstuffs/. The selection of an economically and technologically feasible means of packaging may therefore considerably reduce overall production costs.

Some 75% of aluminium packaging is used by the food industry. Demand by this sector is therefore of paramount importance in dealing with development trends.

At present, competition is keenest in the packaging of canned food and beverages. A typical example of what benefits may be derived from selecting a suitable packaging material, is the aluminium/plastics combination can developed by Reynolds Metals of USA under the trade name of "FLEX-CAN" for preserving meat and fruit; it weighs 6 kilogrammes per batch of 1,000, whereas the same number of tinplate cans of comparable size weigh 50 kilogrammes [46]. /See also sub-chapter 5.2/.

Analyses conducted on an international scale have revealed a marked relationship between GDP and modern aluminium packaging. In countries with GDP higher than 1,000 U.S. dollars per capita, the use of beer and soft drink cans as well as of aerosol bottles - predominantly made from aluminium - is rising at a dramatic rate. However, the realization that such a correlation does exist, is in itself not enough to swing the pendulum of competition in this or that direction. To make a realistic assessment, circumstances prevailing on site, too, must be taken into account, notably, whether or not suitable can-charging machines, equipment for making tear-off closures and other similar machinery are available or obtainable to develop a modern food industry.

The advantages of aluminium in this connection may be summed up as follows:

- Flexibility, high degree of workability. /Its mechanical strength in the unalloyed state, however, is smaller than that of tinplate; it would be uneconomical to use; even in a 0.30-0.35-millimetre gauge it may not ensure sufficient mechanical strength; therefore a suitable alloy has to be employed under all circumstances/.

- Higher corrosion-resistance. /The annual amount of aluminium ions dissolving into food owing to corrosion is under 6 - 70-milligramme per kilogramme of food/.

- Whether or not furnished with a resin-coated inner surface, no toxic metal ions are being released. /This finally solves the tin-lead issue frequently encounterd with in using tinplate cans; in packing meat or processed meat the inner surface of the can never darkens; foodstuffs containing amino-acids of sulfur content /e.g. fish, peas, cauliflower, etc./ do not enter into sulfide reaction with the can upon heating;

- Small specific gravity,permitting great economies in weight as exemplified by the following comparison of a 240 ml box:

| | |
|---|---|
| - Made from tinplate | 77 g |
| - Made from aluminium | 27 g |
| - Made from aluminium foil | 15 g |

- Up-to-date production lines, permitting great productivity /800 - 1,000 pieces per minute/.

The annual amount of metal cans manufactured throughout the world is in the order of 200-210,000 million pieces. Their manufacture requires some 8,500 million sq. metres of thin metal sheet per annum; of this about 10% is aluminium, with an annual growth rate of 2-5% [47].

In developed countries the share of aluminium cans related to total can manufacture in 1973 was as follows:

| | |
|---|---|
| USA | 15.0% |
| France | 10.1% |
| Italy | 9.4% |
| Federal Republic of Germany | 9.3% |
| Norway | 9.0% |
| United Kingdom | 7.0% |

From 1965 to 1971 the amount of aluminium used in the USA in box manufacture has grown four-fold against 1.3-times that of tinplate. Over the same period, the relative share of aluminium has risen from 1.9% to 5.9% [48].

An analysis of can production figures in the USA as revealed in Tables 23 and 24 is yielding interesting results. Over the 1968-72 period, although the total turnover of fruit and fruit juice cans has at 5,800-6,000 million pieces remained practically constant and the number of vegetable and vegetable juice cans too has been stagnating, the number of aluminium cans manufactured has risen substantially. While the total number of beer cans has risen from 17,200 million in 1968 to 21,800 in

1972, the share of aluminium cans has grown from 24.6% to 33.9%.

Table 23.

Tinplate and aluminium usage in the USA can manufacture compared [48]
/1965 = 100/

| Year | Tinplate | | Aluminium | | Aluminium related to tin | |
|---|---|---|---|---|---|---|
| | 1,000 tons | Per cent | 1,000 ton | Per cent | Per cent | Index |
| 1965 | 4,407 | 100 | 85 | 100 | 1.9 | 100 |
| 1966 | 5,591 | 126 | 113 | 133 | 2.5 | 127 |
| 1967 | 4,671 | 106 | 158 | 187 | 4.4 | 175 |
| 1968 | 4,997 | 112 | 189 | 222 | 3.7 | 196 |
| 1969 | 5,149 | 116 | 246 | 290 | 4.5 | 238 |
| 1970 | 5,407* | 122 | 295* | 348 | 5.2* | 275 |
| 1971 | 5,715* | 129 | 345* | 405 | 5.9 | 312 |

* Estimate

As for soft drinks, while the total turnover has grown from 10,700 million pieces in 1966 to 15,400 million pieces in 1972, the share of aluminium has grown from 4.8% to 11.7% [46].

Aluminium cans are usually made from cold-rolled anodized and then synthetic resin-coated or plastics-laminated strip or sheet made therefrom. The synthetic resin film considerably improves the corrosion-resistance of the aluminium surface. For this end, an epoxide-, phenol- or vinil-based synthetic resin is used, which at 250-350 °C temperature will dry quickly /within 30-40 seconds/.

Table 24

## Can turnover in the USA [46]
/Estimate/

| | 1968 | 1969 | 1970 | 1971 | 1972 |
|---|---|---|---|---|---|
| | 1,000 million pieces | | | | |
| Tinplate | | | | | |
| Fruits and fruit juices | 5,9 | 6,4 | 5,6 | 5,5 | 5,8 |
| Vegetables and vegetable juices | 10,2 | 9,7 | 10,0 | 9,6 | 9,1 |
| Beer | 13,8 | 14,5 | 15,5 | 14,6 | 14,4 |
| Soft drinks | 10,2 | 11,6 | 12,5 | 13,1 | 13,6 |
| Miscellaneous | 22,7 | 22,6 | 23,5 | 23,1 | 23,6 |
| Tinplate, total | 62,8 | 64,8 | 67,1 | 65,9 | 66,5 |
| Aluminium | | | | | |
| Beer | 3,4 | 4,2 | 4,7 | 5,9 | 7,4 |
| Soft drinks | 0,5 | 0,7 | 1,0 | 1,3 | 1,8 |
| Alumirium, total | 3,9 | 4,9 | 5,7 | 7,2 | 9,2 |
| Grand total | 66,7 | 69,7 | 72,8 | 73,1 | 75,7 |

In developed countries, 70% of aluminium boxes are used for the bottling of beer, fruit juices and other soft drinks.

For packaging ends in the food industry, as a rule, the following aluminium alloys are used:

| | | |
|---|---|---|
| Food canning | $AlMg_{2.5}$ | /U.S. Standard Specification No. 5052/ |
| Drink canning | $AlMg_1Mn_1$ | /U.S. Standard Specification No. 3004/ |
| Easy-opening closures | AlMgMn | /U.S. Standard Specification No. 5182 and 5082/ |

Although the manufacture of strip from such special alloys calls for higher production costs than those of the unalloyed variety, such difference in costs is offset by economies in material derived from its higher mechanical strength. Compared e.g. to 0.6-millimetre 99.5% aluminium strip, savings as specified in Table 25 may be arrived at [[illegible]].

Table 25

Savings derived from using aluminium alloys

| Alloy | Price ratio | Material savings due to higher mechanical strength Per cent |
|---|---|---|
| $AlMn_1$ | 1.04 | 23 |
| $AlMg_1$ | 1.16 | 20 |
| $AlMg_3$ | 1.38 | 31 |

Thin-walled packaging material is manufactured throughout the world from rolled semi-manufactures, i.e. sheets, strips and foil or circular or differently-shaped discs cut from therefrom.

Up-to-date packaging material has for reasons of corrosion-resistance to be inside resin-coated, and lacquered and printed outside.

They are manufactured by either of the following two technologies:

- cold extrusion from slugs, with the resultant boxes or collapsible tubes being lacquered and printed afterwards, or

- Using lacquered and printed semi-manufactures formed to desired shape successively [50]

### 4.23.1 Aluminium cans and boxes

In producing aluminium cans, the two principal operations involved are the manufacture of their body and that of their lid.

Aluminium cans and boxes made by cold extrusion [51]
Cold extrusion has been the first manufacturing process by which thin aluminium boxes of taller hulls than their diameter could be produced from one piece. For this end, 2-4-millimetre thick slugs are used which on being given a strong impact become suddenly malleable, whereupon the soft aluminium flows with great force through the gap between a stationary hollow die and its fast striking rod-like counterpart, forming thereby the hull of the box. Cold extrusion presses used in Europe are usually designed for 50-80 strokes per minute. Owing to the thickness of the box bottoms /1.1-millimetre/ and sidewalls /0.3-0.35-millimetre/, this technology is not economical in view of the relatively large amounts of material involved. The height of the boxes, too, is limited.

Deep-drawn cans and boxes of small height [46]
The sidewalls of cans and boxes produced by this technology are usually shorter than their bottom radius, but may never be taller than 2.5-times the latter. They are manufactured by 30-100-ton eccentric presses.

Deep-drawn cans used [illegible]
[illegible] AlMg$_2$ [illegible]

plastic deformation. Although upon being cold-formed the material considerably hardens, even in its hard state it remains sufficiently pliable. In the process usually a 0.22 - 0.30-millimetre half-hard anodized and lacquered strip is used. The resultant can is cylindrical, square, oval or elliptic. If the cans are manufactured in a plant distant from where they are to be filled, a conical shape may be preferable, permitting savings in space and transport costs. In case of a $6^0$ conicity, such savings in space may amount to 70%.

The sidewalls of the cans are sometimes reinforced by ribs to render them more massive. The 0.25 - 0.30-millimetre alloyed strips are given a continuous lacquer coil-coating.

Such cans are usually available in 100 to 350 ml sizes with inside surfaces lacquered and outside ones lacquered or printed, for packing meat, fish vegetables or preserves.

Recent demand for such deep-drawn cans has been such that the Ministry of Fisheries in the Soviet Union decided to set up a 12,000 t.p.a. aluminium strip lacquer-coating facility at Dmitrovo in combination with a factory, where round and oval deep-drawn low fish cans and tear-off lids are manufactured. The State Sea Fishery Enterprise of the German Democratic Republic too is operating a similar plant at Stralsund. [52] [47].

Small capacity aluminium cans /100-200 ml/ are widely used in Norway, Switzerland and France for packing fish, paste and milk.

World consumption of thin aluminium strip used in making food cans is estimated to be in the order of 200-250,000 tons per annum, replacing some 400,000 tons of tinplate.

Despite the great difference in specific weight between tinplate and aluminium, owing to the poor yield of deep-drawing technology caused by large scrap arisings, only one kilogramme aluminium may replace 2 kilogrammes of tinplate [53] [54]. A large part of the cans is manufactured by the canneries themselves, but big volumes are also purchased from specialized aluminium box producers /e.g. CEBAL of France, BOXAL of Switzerland. See also sub-chapter 5.2/.

Automatic deep-drawing production lines operate with high efficiency. The basic operation of deep-drawing in case of aluminium is simpler than the processing of tinplate /cutting, forming the hull, soldering, flanging, capping etc./. Thanks to this, several high-duty presses may be installed for this end to operate simultaneously with great economies in space. An up-to-date 200-piece per minute production line is fed by aluminium sheets cut to measure as diagrammatically represented in Fig. 16.

The aluminium sheets are first placed on feeder /1/. To facilitate deep-drawing and to prevent the sheets from ripping, sheet surfaces have to be oiled. The PNr-370 type automatic press /2/ punches the sheets, the resultant discs being thereupon deep-drawn to boxes of suitable sizes, with all unnecessary material removed from their edges and blown away as scrap. The boxes are then passed through another feeder /3/ to a receptacle /4/, whence they are moved on by a sledge 5 to a conveyor band /6/, dispatching them to a loading machine /7/ piling them on pallets in regular batches. Collected scrap is crushed and dispatched to be remelted.

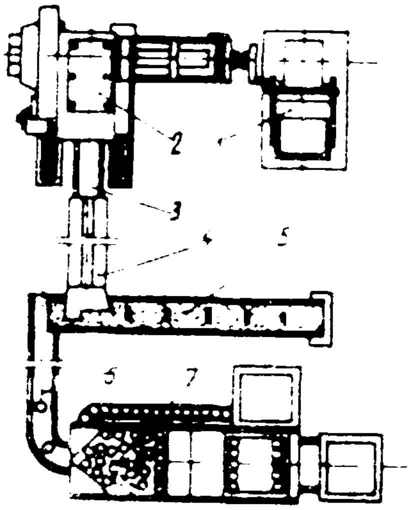


Fig. 16 - Automatic production line manufacturing deep-drawn cans and boxes /Karges-Hammer system/

Cans and boxes with diameters smaller than 90 millimetres have to be deep-drawn by special presses operating with 2-10 heads simultaneously and turning out cans and boxes at a rate of 200-1,000 pieces per minute.

As for wall-reducing deep-drawing /ironing/, by this technology first of all cans of carbonic acid-containing drinks are made in heights of 1.5 - 3-times their diameters.

The original thickness of the $AlMg_{2.5}$ or AlMgMn plain unlacquered strip used for this end is 0.30 - 0.50 millimetre. In the first operation from the strip discs are cut, from which small cups are drawn; in the course of the second operation the cup is deep-drawn to a cylindrical hull in a conventional manner; next comes the operation of wall-reducing deep-drawing, in the course of which the wall of the hull is drawn through 3-5 rings, the bottom is slightly raised and the lower and upper parts of the material become reinforced. In doing this, the diameter of the hull is slightly reduced /2-3%/ and its height stretches to more than threefold /e.g. from 40 millimetres to 120 millimetres/. The production line is operating at a minimum rate of 200 pieces per minute, though up-to-date high-duty ones are known to turn out as many as 600-650 pieces per minute.

The sizes of cans produced by modern wall-reducing technology are very favourable. The bottom of a 12 oz. beer can is 0.34 millimetre and its hull - except for its 0.30-millimetre lower and upper part - 0.125-millimetre thick, weighing 9 grams per piece. Its wall, however, is strong enough to cope with the inside pressure of carbonic acid, its resistance being 70 $N/mm^2$. The weight of a comparable cold-extruded box is 23-32 grams.

The wall-reduced cans are thereupon degreased, their outer hull enamel-primed and passed through rubber rolls for printing. The inside of the can is epoxide resin-coated and both the inside and outside lacquering burned into the hull in a single operation. Finally, the hull is flanged, so as to permit its lid to be firmly secured after packing. This technology is designed to take utmost advantage of the mechanical properties of aluminium in making cans of any size and height holding carbonic acid drinks in a completely sterilized manner [55].

Aluminium strips used in the process need not be coil-coated, but demands as to technological standards are very stringent. This technology is gaining ground especially in developed countries, where the use of wall-reduced deep-drawn cans is growing at an annual average rate of 15-20%. A case in point is their usage in the USA as tabulated below [56]:

| End use | Material | Consumption million pieces | | Growth rates Per cent |
|---|---|---|---|---|
| | | 1973 | 1974 | |
| Carbonic acid drinks | Tinplate | 15,862 | 15,482 | - 2.4 |
| | Aluminium | 1,731 | 2,017 | + 16.5 |
| Beer | Tinplate | 14,999 | 14,017 | - 6.5 |
| | Aluminium | 8,905 | 11,862 | + 33.2 |
| | Total | 41,497 | 43,378 | + 4.5 |

A breakup of drink-packaging in the U.S. is estimated as below:

| | |
|---|---|
| Aluminium cans | 30% |
| Tinplate cans | 30% |
| Glass bottles | 40% |

According to information by the Coors Company of USA, in 1968 investment costs of a 50 million-piece per annum facility amounted to two million dollars.

Aluminium drink cans are manufactured with special easy-opening lids /see sub-chapter 4.23.2/. In the USA at present 770,000 tons of aluminium are used for manufacturing drink cans, accounting for 12% of the country's total aluminium consumption. The fast rate at which aluminium drink cans gain ground may largely be attributed to the economical manner, in which scrap arisings and the material of used cans may be reclaimed. This is done by up-to-date continuous cast wide strip mills, such as the one sited e.g. at the Coors Company itself. This largest brewery of the USA is making under an ALCOA licence 4 million cans and closures per annum, using about 100,000 tons of aluminium. The Caster II type continuous cast wide strip mill installed at the brewery and operated by a technology developed by ALUSUISSE, is reprocessing about one-half /some 50,000 tons/ of the aluminium used by the brewery annually in the manufacture of cans. /See also sub-chapter 2.15/.

In 1977 International Alloys Ltd. of the U.K. too has launched an experimental campaign for the collection of used aluminium cans from 5,000 households. Its evaluation is now under way.

### 4.23.2 Can lids

Their design is similar or more up-to-date than that of tinplate, in that they are easy to open or to be torn off. The latter variety is available in two designs, depending on what the can is to hold. The lids of drink cans /beer, soft drinks/ are designed to be partially torn off, whereas meat, fish and vegetable can tops may be fully opened and removed.

In the middle of partially openable can tops there is a slightly depressed cuneiform notch thinned to 0.09-millimetre gauge, fitted with a small riveted ear. On raising the ear the thinned notch cracks and on pulling its ring the can top opens.

In earlier designs of fully openable can lids there is a 1.5 - 2-turn spiral depression from the top centre towards the edge of the lid, working on the same principle, with a tear-off ear riveted in the middle. This design has the following drawbacks:

- The pressure die necessary for making the lid is complicated and costly;
- The tear-off surface is too long;
- There is danger of hurting one's hands, and
- The spiral design of the thinning impairs the rigidity of the lid.

In newer designs the lid is only thinned along the circumference of its rim. The can is not opened by a riveted ear but by a cutter, acting as a two-armed lever simply removing the lid. Tear-off lids are made from an $AlMg_{4.5}Mn$ alloy /ASTM 5182 H19/; they are of 0.3 to 0.35-millimetre thickness and are epoxide resin-coated on one side; they have a tensile strength of 300–370 $N/mm^2$ and a yield point ranging from 270 to 330 $N/mm^2$.

### 4.23.3 Glass jar tops

In packing preserved food, certain technological problems arise when glass jars have to be sealed with tinplate lids. Notably, upon the heat treatment of some foodstuffs, the released sulfur tends to enter into chemical reaction with the iron content of tinplate, forming unpleasant black sulfide compounds staining the surface of the lid.

To overcome this difficulty, aluminium lids may be used with advantage. They are made in two types known under the trade names of OMNIA and PANO, cut from 0.15 - 0.25-millimetre aluminium strip, lacquered on one side and printed on the other.

In Europe the largest manufacturer of OMNIA lids is Thomas Hunter of the U.K. The three principal brands available are

- "Preserve", for food heat-treated under a temperature of 100 °C,
- "Pickling"
- "Retorting", for food heat-treated at higher temperatures than 100 °C.

In Europe, the aluminium alloy sheets from which the lids are made, are usually lacquered with a dispenser supplied by RATCLIFF of the U.K., printed by a multi-colouring press furnished by MAILAENDER of the Federal Republic of Germany and burned in by an LTG furnace also made in the Federal Republic of Germany; the lacquered and printed sheet is cut by an FMI /Italy/ circular shear to strips, from which - with the aid of an FMI press - the lids are sebsequently formed and flanged. Finally, a sealing compound is applied and stoved by an equipment and furnace supplied by DAREX of the Federal Republic of Germany.

[illegible] lid is sea[illegible]ed with the aid of a [illegible] [illegible] seaming machine of [illegible], [illegible] hour capacity. /See also sub-chapter 5.2/.

PANO lids are all-purpose ones, manufactured by PANO-Verschluss GmbH. of the Federal Republic of Germany. Lids made therefrom are secured by 3, 6 and 9-head machines with performances ranging from 800 to 12,000 pieces per hour.

### 4.23.4 Bottle closures

Traditional tinplate crown closures of soft drink and beer bottles could so far not be replaced by aluminium ones in an economical manner. By contrast, several other special aluminium bottle closures have been developed and introduced on a large scale.

Aluminium screw caps are used for the closure of liquor and apéritif bottles. To keep the bottle contents before their first opening intact, they are fitted with a control ring, breaking when the bottle is first used. Depending on their height, they are manufactured by means of single or several-stage deep-drawing from lacquered and printed strip. The best-known types are known as PILFERPROOF, TOPSIDE and REALPAC-28 closures, the latter suitable also for bottling pressurized drinks.

Such bottle-closures are made from 0.15 - 0.25-millimetre thin 99.5% aluminium strip, lending itself excellently to deep-drawing. Their inside is epoxide resin- and adhesive sealing lacquer-coated, and their outside lacquer-coated and printed. They cost about half or one-third of conventional cork bottle closures.

The so-called ALCA closures are of a simpler tear-off design, fitted with an ear. As a rule, they are used for the closure of smaller /0.05 - 0.1-litre/ glass bottles and are made from 0.18-millimetre plain aluminium narrow strip. In recent times they have also gained ground as the closure of 0.5 -1-litre plastic bottles and in France as that of wine bottles [53].

## 4.23.5 Collapsible tubes

Much of the aluminium used in packaging is in the form of throwaway collapsible tubes. They are hygienic, inexpensive, considerably lighter than other traditional packaging, affording effective protection against the detrimental chemical and physical influences of the enviroment.

Manufactured by cold extrusion from 3.5-millimetre aluminium slugs cut from 99.5-99.7% continuous cast strip, collapsible tubes are available in sizes of 50, 100 and 200 grams; they are 0.11-millimetre thin, airtight, seamless, heat-resisting, unbreakable, flexible and if desired, sterilizable. Their orifice is closed in case of foodstuffs and open in case of cosmetics and household cleansing agents. Should their contents be used for the decoration of food /mayonnaise, sandwich paste, whipped cream/, their orifice may also be formed to be star-shaped. Their outside may be printed with multi-colour designs, texts or publicity slogans; their inner surface is coated with two layers of burned-in epoxide-based synthetic resin film of 6 micron gauge each.

Their usual dimensions are

30 mm by 150 mm to hold 80 grams, and
40 mm by 180 mm to hold 150 grams.

In food processing they may be used for the packaging of a multiplicity of items such as tomato paste, paprika- and tomato-based condiments, mustard, garlic paste, mayonnaise, meat paste, anchovy paste, concentrated milk, cheese, cream, cocoa, gravy, liver paste, jam, marmelade, ice- cream and juice. Food industry accounts for some 10% of total collapsible tube usage [57]. As for Hungary, in the long term this figure may be expected to rise to 20%.

In order to reduce transport costs, designs of developing conical collapsible tubes are under way. Their telescopicity may result in some 30-40% savings in transport space.

There is a dramatic growth of aluminium collapsible tube usage throughout the world both in food processing and in the manufacture of cosmetics or household chemicals. E.g. in Federal Germany the total number of collapsible tubes manufactured in 1976 amounted to 1,230 million pieces, of which 1,100 million were aluminium ones; in the U.S. in 1970 1,120 million collapsible tubes were manufactured for pharmaceutic and cosmetic ends, of which 67% were aluminium ones.

Aluminium/plastics combinations of collapsible tubes.

In view of the fact that the double or more inside resin-coating of conventional aluminium collapsible tubes does not completely seal off porosity and in case of food does not afford full protection against the corrosive effects of aggressive agents, a new type of collapsible tube has been developed, featuring besides aluminium also plastics for enhanced protection [58]. It consists of three superimposed layers, viz.

- a 0.050 - 0.100-millimetre thin inside polyethylene one to increase corrosion-resistance, to keep the quality of food longer intact and to render the collapsible tube suitabe for welding;
- a 0.020 - 0.050-millimetre aluminium middle-layer to permit perfect gas- and vapour-tightness and protection from light, and
- a 0.050 - 0.100-millimetre polyethylene outer coating to afford protection against enviromental influences and to permit welding and priting.

This foil combination is dispatched in coils to the machine, where it is formed to tubes and high-frequency welded hulls; to the top part of the hull a plastics inset of suitable design is welded, on which a cap may be screwed on. After filling, the orifice of the collapsible tube is tightly sealed by welding.

Texts and designs are multi-colour printed on the white pigment-saturated outer plastics foil layer and thereupon provided with a transparent varnish film. The capacity of such a production line is 600 - 1000 pieces per minute.

This process is relatively simple, involving fewer operations than the manufacture of collapsible tubes from conventional slugs.

The properties of collapsible tubes made from different materials and their combinations are summed up in Table 26.

The patentee of combined aluminium/plastics collapsible tubes is the AMERICAN CAN COMPANY, Greenwich, Connecticut, USA. For Europe the licence has been purchased by the TUBMATIC COMPANY of Switzerland /see also sub-chapter 5.2/.

Table 26

Properties of collapsible tubes compared

| Property | Material | | |
|---|---|---|---|
| | Combined | Aluminium | Plastics |
| Light protection | + | + | - |
| Gas- and vapour-tightness | + | + | - |
| Resistance against | | | |
| tooth-paste | + | + | - |
| tooth-paste of F-content | + | 0 | - |
| mustard, tomato paste | + | + | - |
| Permanent deformation on emptying | + | + | - |
| Vulnerability of empty tube | 0 | - | + |
| Possibility of conical forming | + | + | - |
| Possibility of circular printing | - | + | + |

Legend Favourable +
indifferent: 0
unfavourable: -

## 4.24 Aluminium foil used by the food industry

### 4.24.1 Packaging foil

Aluminium foil as a packaging item has achieved a substantial growth, in practice completely displacing tinfoil.

Its average annual growth rate of production is 10 - 12%, but that of high-finish and laminated aluminium foils as well as of aluminium foil/plastics combinations is even ahead of this figure. At present, the food industry accounts for 60-70% of total world consumption.

In order to improve its properties, aluminium foil is often combined with other materials /paper, vellum paper, plastics etc./ and provided with coatings of different protective films /coloured or colourless heat-proof lacquers, hot-melt films/ both plain and printed. By a combination of these materials a great variety of specifications may be brought about for a multiplicity of ends, with the food industry ranking first as a consumer. Such foils and foil combinations are listed in Table 27 with indications of end-use in the food industry.

### 4.24.2 Hard-foil trays

Foil trays for commercial catering are used to hold prepared food, fruits, vegetables as well as bakery and confectionery products. They are formed from plain or slightly pleated hard 0.03 - 0.08-millimetre strip, unlacquered or lacquered only on one side.

Table 27

## Aluminium foil usage by the food industry [59]

| Description of foil | End-use |
|---|---|
| Plain foil | Sweets industry, household foil, prepared-food trays |
| Foil, patterned, with coloured or transparent lacquer-coating | Sweets industry: chocolate, dessert, bonbons; wrapping of wine bottle tops |
| Foil with coloured or transparent hot-melt lacquer coating | Dairy industry: cheese wrapping |
| Hard foil, with hot-melt lacquer coating, printed | Canning industry: lids of jam and marmelade jars |
| Soft foil, with hot-melt lacquer coating, printed | Dairy industry: milk and dairy product cup closures |
| Aluminium foil/vellum paper combination, wet-laminated, printed | Tobacco industry: cigarette wrapping; coffee and spice bags |
| Aluminium foil/wellum paper combination, wax-laminated | Dairy industry: butter, cottage cheese wrapping; vegetable oil industry: margarine wrapping |
| Aluminium foil/paper combination, wet-laminated, with hot-melt coating, printed | Sweets industry: filled wafers, biscuits |
| Aluminium foil/paper/polyethylene film combination, dry and wet-laminated, printed | Soup-powder bags, seasoning bags |
| Aluminium foil/single or double plastics film combination, dry-laminated, printed | Canning industry: fruit juices |

Though sealed with flanging or otherwise, the tray is not airtight.

The greatest attraction of the hard foil tray - besides preserving both food quality and aroma - is the possibility that the prepared meal may be warmed or baked right in it and then be readily eaten from the tray itself. Thanks to its easy and hygienic handling, it has won universal acceptance in competing with plastics. In the USA e.g. in 1970 prepared food was disposed of in 4,500 million such foil trays [60]. The storage and sale of such food in aluminium foil trays for commercial catering, however, calls for a well-organized chain of cold-storage facilities from the producer's end to the supermarket. The emergence of the aluminium foil tray has displaced much of traditional tinplate can usage.

### 4.24.3 Low, thin-walled, sterilizable cups and small containers with hot-melt inside plastics-coating

They are manufactured by a single deep-drawing operation of maximum 30 - 35-millimetre depth from 0.05 - 0.1-millimetre 99.3-98.7% aluminium or AlMn alloy strip, thereupon inside-coated with a 0.05-millimetre polyethylene or polypropylene film. Available in cylindrical, square, oval or elliptic shape, their description and principal end-uses are summed up in Table 28 [47].

Table 28

Sterilizable cups and small containers from combined foil

| Shape | Capacity $cm^3$ | Wall-thickness mm | To hold |
|---|---|---|---|
| Cup | 60-110 | 0.05-0.07 | Ice-cream, cottage cheese |
| Box | 30-130 | 0.10-0.15 | Processed meat and fish, fruit cream, jam, marmelade, honey, cheese |
| Plate | 150-1,300 | 0.07-0.09 | Pasta, fruit-cake, buns, frozen food |

In Europe this type of foil is best known under the trade names of ALUSEAL and STERALCON.

The polyethylene-laminated 0.07 - 0.18-millimetre aluminium foil cups and small containers are semi-rigid and in the empty state susceptible to damage. They are manufactured by one of the two machines described below:

- The Aluseal 151 equipment, developed by HAMAC-HANSELLA of the Federal Republic of Germany; here the operations of forming and filling the body, as well as of making and sealing the lid are done by a single self-contained machine unit /see sub-chapter 5.2/; the sealing of the container is completed at 240-260 °C temperature and 6-8 atm. pressure in two seconds. The output of the machine is
  - 80-120 pieces of 20-50 ml containers per minute or
  - 50-80 pieces of 50-130 ml containers per minute.

The sterilization of the containers may be done in counter-pressure autoclaves.

There is no extra transport of container bodies and lids to site. With the manufacturing process being fully integrated in the same premises, exposure to damage is reduced to a minimum. The annual output of the machine, calculated in 100 $cm^3$ units, is 20 million pieces, corresponding to 120 tons of laminated foil per annum.

Where conditions prevailing on site do not permit the forming and filling of the containers in the same premises, an equipment developed by STERALCON may be used with advantage. Here the container bodies and lids are dispatched on separate pallets to the charging machine, where the container bodies are automatically lifted and charged, the lids added and securely sealed.

Recently, several other foil combinations too have been devised for the packaging of preserved food /see "Flex-can" packaging under sub-chapter 4.23 and the sterilizable aluminium/plastics collapsible tube combinations under sub-chapter 4.23.5/.

Plastics trays with hot-melt aluminium lids are used in food canneries for the packaging of jam and marmelade. By the vacuum-forming of PVC or polystyrene strip, small containers of 50, 100 and 200 ml capacities are made, filled and secured with a printed hot-melt lacquer-coated aluminium lid.

FORMPACK is the trade name given to another wellknown packaging system, featuring a 99.[illegible]% hard aluminium foil of 0.03 - 0.05-millimetre gauge.

The foil is coated outside with a 1 $g/m^2$ lacquer film resisting temperatures up to 180 °C and inside with a 5-8 $g/m^2$ hot-melt lacquer film.

## 4.3 HEAT EXCHANGERS

### 4.31 General considerations

The spheres of aluminium applications so far dealt with may more or less look back upon experiences of several decades. By contrast, the aluminium outlet to be discussed hereunder is relatively new. In thermo-engineering and refrigeration, aluminium usage began about 10 years ago, when the first designs of ribbed tubes for such ends appeared on the market. Aluminium usage in this field was facilitated by the fact that in air-cooled heat exchangers such ribbed aluminium tubes may be used with special advantage. Their general arrangement, notably, is such that within the tubes themselves steam, water or a cooling liquid - that is an agent of favourable heat transfer properties - is circulating, while in a vertical direction to the tubes usually air is flowing. Now, air - like any other gases - is notorious of having poor heat transfer properties, and this is what necessitates the addition of ribs on the air side.

In selecting a suitable material as ribbing, its thermal conductivity $\lambda$, its specific weight $\gamma$ and its relative pricing /a/ have to be taken into account.

Essential features of metals which in this respect may come into consideration are compared in Table 29.

It will be observed that aluminium has the lowest specific weight and the best coefficient of thermal conductivity; however, its price related to steel is high.

Table 29

Essential features of metals used in heat exchangers

| Metal | Specific weight g/cm | Thermal conductivity kcal/m.h °C | Relative pricing /aluminium=1/ |
|---|---|---|---|
| 99.5% aluminium sheet | 2.7 | 182 | 1.0 |
| Aluminium alloy sheet | 2.7 | 142 | 1.3 |
| Copper sheet | 8.3 | 320 | 3.0 |
| Steel sheet | 7.8 | 50 | 0.5 |
| Alloyed steel sheet | 8.0 | 13 | 0.8 |

From an economic point of view, aluminium is obviously the best material to be used as the ribbing of heat- exchangers. It will be seen from Table 30, that copper ribbing, though a good thermal conductor, is by dint of its heavier weight 60% inferior to aluminium in thermal conductivity. The corresponding figure for steel is 85% in favour of aluminium.

It should be noted that the above comparisons refer to the ribbing only, without taking the complete heat exchanger /including tubes, chambers, etc./ into consideration.

Table 30

Specific heat transfer of ribbing made from different metal sheets

| | q | $q/q_{al}$ |
|---|---|---|
| | kcal/h.kg | |
| 99.5% aluminium sheet | 3,400 | - |
| Aluminium alloy sheet | 3,000 | 0.88 |
| Copper sheet | 1,250 | 0.367 |
| Steel sheet | 500 | 0.147 |
| Steel alloy sheet | 250 | 0.074 |

## 4.32 Small-ribbed industrial and household heat exchangers

Aluminium, in view of its properties, is not only suitable to replace other non-ferrous metals in this field, but is also superior to them. It lends itself excellently to plastic deformation and is thus an ideal material in making heat exchangers.

In heat-exchangers where the heating medium is circulating laminarily, all along the flat heating surfaces boundary spaces develop, strongly influencing the heat transfer that is taking place between the flat surfaces and the gases surrounding them. The thicker this boundary space, the less effective will heat transfer be. The thickness of this boundary space increases with the distance from the entering edges of the sheets, gradually impairing thereby the local heat transfer coefficient.

In case of conventional cast iron or steel plate central heating radiators, air is flowing upwards along the long flat surfaces of the radiators; hence the heat transfer coefficient of the radiator surface tends to deteriorate with the growing height of the radiator.

This gradual impairment of the heat transfer coefficient along the long flat radiator surface may be offset by slitting a series of small narrow strips at the radiator sheets and slightly raising them from the plane of the radiator body. In doing this, a small-ribbed radiator is arrived at, featuring a far superior heat transfer coefficient to that of conventional radiators. Though the small ribbing tends to increase the resistance of the structure on the air side, under identic conditions of ventilation the small-ribbed design will transfer more heat than its conventional counterpart.

The so-called RADAL type of radiators manufactured in Hungary is based on this principle.

In power engineering the heat exchangers and cooling components of the wellknown Heller-Forgó air condensation system too are hinging on the same concept. Its special design permits the siting of power works in arid areas - even in deserts -, the condense water necessary for the operation of the steam turbines being circulated in a closed system and air-cooled with the aid of aluminium cooling elements.

Such small-ribbed cooling elements, however, may not only be used in power works with advantage. They may also be employed in a variety of other fields, e.g. in operating oil and natural gas pipelines by using oil, gas or water coolers at compressor stations sited in arid areas. They may also be used for air-cooling by other industries as well, e.g. by chemical engineering.

## 4.33 Motor engine coolers

In the road vehicle industry there is an intensification of aluminium usage in making pistons, engine block castings and other components. The use of aluminium in water and oil cooling, however, is a relatively recent development, although the idea is not new. Towards the end of the second world war and in the early post-war years, light metal heat exchangers and aluminium oil coolers were used by the aircraft indutry. In ground transport, however, such innovations could not catch on, owing to heavy competition by the more durable copper coolers.

In the heat exchangers of transport vehicles aluminium appeared for the first time as the lamellae of water coolers employed in Diesel motor trains and Diesel engines.

Used as a cooler in transport vehicle engines, aluminium is the second best heat conductor after copper.

Recent developments in motorcar cooler design have set a double aim. On one hand, an attempt is made to increase the amount of heat taken care of per cooler volume unit; this is desirable in view of recent trends favouring massive power output in motorcar engines. On the other hand, great efforts are made to reduce the overall weight of motorcars - be it even by only a few grammes in case of a given component -, so as to avoid the increase and, if possible, to permit the reduction of fuel consumption, despite trends of stepping-up engine performance. This, obviously, calls for a weight reduction of the water cooler. With this end in view, the development of new and more economical engine coolers is under way.

## 4.34 Heat-exchangers in air-conditioning and refrigeration

In these fields aluminium is widely used as evaporators and condensers. In condensers it is gradually displacing copper-ribbed heat exchangers, whereas in evaporators nowadays exclusively aluminium is used.

Aluminium evaporation panels are made with integral tubes by a technology known as roll-bonding or Z-bonding. In roll-bonding two aluminium sheets are joined into one by welding; but before this is done, the tracings of the future tube network are painted on the sheets; when the two sheets are rolled into one, the tracings do not fuse; they are thereupon slightly inflated by compressed air and the resultant tubing is provided with suitable fittings.

Z-bonding is similar to roll-bonding, but here the sheets are not joined by rolling but by brazing, with the ducts being eventually melted out.

## 4.35 Solar power collector

The direct utilization of solar energy in generating heat has recently very much been in the focus of public interest. Solar energy lends itself well to transformation into thermal energy, which, in turn, may be employed for heating, cooling or generating electric power.

The principal part of a solar power station is the collector, whose radiation-absorbing surface is fully made from aluminium, because of the high thermal conductivity of this metal. Owing to its good corrosion resistance, aluminium is also used in making the framework and superstructure of the collector.

## 4.4 Miscellaneous fields

So far such aluminium applications have been discussed in this survey, where technological and economic benefits derived from their usage as a substitute for traditional materials is at first sight self-evident. The following is to deal with a few selected aluminium applications, where such financial benefits are only indirect and at prima facie less conspicuous. Such secondary advantages, however, include a wide range of significant issues from fuel economies in running transport vehicles to easy transport and assembly of prefabricated building components or labour savings in agriculture. The chapters to follow do not claim to be a full enumeration but only an exemplification of what vast potential still exists in this connection.

### 4.41 Up-to-date castings for the engineering industries

In 1974-77 an annual average of 20-25% of world aluminium consumption was devoted to the manufacture of castings. Of the 2.5 million tons of castings produced annually some 60-70% were used as components of transport vehicles, especially such of motorcar engines. According to an estimate, in the 1970's some 30 million passenger cars and motorbycicles are turned out annually in the world, using about 1.2 million tons of aluminium castings. Prognostications claim that in the years ahead the pattern of structural materials to be used in passenger car manufacture is to undergo considerable changes [61]. There is a sustained trend for further energy savings; one way of accomplishing this goal in the automotive industries is to reduce the weight of components.

In view of this, in the medium term, a further advance in aluminium castings usage may be anticipated. These aluminium castings are to replace first of all iron and steel, and to a lesser degree copper and zinc ones /fittings, decorations etc./. A forecast as to such changeover is summed up in Table 31.

Table 31

The changing pattern of structural materials used in passenger car manufacture [61]

| Material | 1975<br>kilos | % | 1980<br>kilos | % | 1990<br>kilos | % |
|---|---|---|---|---|---|---|
| Steel and iron castings | 1,210 | 77 | 830 | 67 | 614 | 56 |
| Aluminium alloys | 43 | 3 | 107 | 8.6 | 390 | 35 |
| Plastics | 55 | 4 | 95 | 7.6 | 127 | 11.5 |
| Copper alloys | 15 | 1 | 11 | 0.9 | 7 | 0.6 |
| Zinc alloys | 13 | 1 | 5 | 0.4 | 3.6 | 0.3 |

Aluminium castings employed now and expected to be used in future as well as their technical features and manufacturing methods, were the subject of an enquiry dealt with at the International "Aluminium+Automobile" Conference organized by the Aluminium Zentrale of Federal Germany on March 22-23, 1976 [63].

A rapid upswing in the usage of aluminium castings seems also to be justified by the following circumstances:

- Aluminium castings of great accuracy to size, easy to exchange and requiring no additional machining after casting may be produced by various up-to-date technologies in large series with relatively small labour involved. The most effective mechanized technologies are high pressure, low pressure and counter-pressure die casting as well as die forging. But conventional sand or gravity die casting techniques too may be easily mechanized by installing relatively simple equipment. A rough idea of capital expenditure involved in setting up light metal foundries is given in Table 17 under sub-chapter 2.21. Costs of investment in establishing light metal foundries are considerably lower than those of modern steel foundries. As a rule of the thumb it may be accepted that up to 1,000 pieces sand casting, from 1,000 to 10,000 pieces gravity die casting, and for larger series different pressure die casting technologies are the most economical. In extreme cases /e.g. when stringent demands of gas-proofness have to be complied with or special techniques of machining or surface treatment are called for/ mechanized pressure die casting may be more economical even is case of smaller series. A breakup of the principal casting technologies practised in different parts of the world is to be found in Table 32, whereas some technical features of castings made by these methods are shown in Table 33.

Table 32

## Breakup of principal casting technologies employed in 1970-74

Per cent

| | Sand casting | Manual gravity die casting | Mechanized casting |
|---|---|---|---|
| USA /average/ | 14 | 22 | 64 |
| Developed West-European countries /average/ | 20 | 40 | 40 |
| Moderately industrialized countries /estimated average/ | 35 | 45 | 20 |
| Developing countries /estimated average/ | 45 | 50 | 5 |

Aluminium casting has the distinct advantage that any change-over from one technology to another is a relatively simple procedure. In Hungary e.g. the 110-kilogramme Diesel engine blocks were originally sand-cast; when this had no longer been sufficiently economical, mechanized gravity die casting was introduced in its stead [65]. At present, 10,000 high-standard motor blocks are cast annually in this manner, with comparatively small capital expenditure being involved in the process of change-over, without necessitating the purchase of costly high-pressure casting machinery. The castings may be protected against wear with the aid of a special surface treatment /extra hard anodisation/ permitting castings of light weight to be used, where components are normally exposed to friction and wear. A case in point are different parts and accessories of equipment used by textile mills and other industries to raise output /e.g. textile

Table 33.

## Different casting methods compared [64]

| Technology | Minimum wall-thickness mm | Tolerance of wall-thickness per cent | Productivity per worker Piece/hours | Die endurance, pieces | Economical minimum of workpieces | Relative costs of workpiece | Mechanical strength | Surface smoothness | Acquisability |
|---|---|---|---|---|---|---|---|---|---|
| Sand casting | 3.0 | ± 10 | 2 | 100-300[a] | under 1,000 | 1 | C | C | B |
| Gravity die casting | 2.0 | ± 5 | 30 | 10,000-20,000 | over 1,000 | 0.65 | B | B | A |
| Pressure die casting | 0.8 | ± 2 | 75-250 | 10,000-50,000 | 10,000 | 0.50 | A | A | B |

[a] In case of wooden mould; by using a metal /aluminium/ die endurance improves by one order of magnitude

The lettering A, B and C refers to relative grading; "A" is best, "C" the least satisfactory.

spindles, mobile frames of printing machines, casings and pistons of pneumatic control valves, etc./.

- Apart from the easy mechanization of the casting process, its susceptibility to producing large series and possibilities of fuel economies due to the reduced self-weight of motorcars - roughly one litre petrol per kilogramme weight saved when driving 100,000 kilometres -, the relative pricing of aluminium and cast iron, too, is an important point to be considered upon designing a transport vehicle or similar equipment. A reference to Table 13 under sub-chapter 1.3 will demonstrate that in future a further shift in favour of aluminium pricing may be anticipated. Although in manufacturing one ton of a steel product 38 GJ of energy are involved against a comparable figure of 300 GJ for aluminium, in case of Diesel motor lorries surplus energy costs embodied in aluminium components will be repaid within two years in form of fuel savings. As from that time, subsequent power economies will accrue as net savings [67].

By the same reasoning, similar advantages may be derived from aluminium usage in other industries as well. On planning medium-term production targets, the possibility of setting up aluminium foundries at small cost for the manufacture of castings in relatively small series has many promising implications; this is especially so in case of developing countries. This and the favourable pricing trends referred to, are the principal reasons why in a good many areas light metal castings have become a viable competitor of copper, bronze and zinc castings used earlier. Therefore, on launching new industrialization projects, considerations as outlined above may help developing countries in the responsible task of decision making.

## 4.42 Transport vehicles

### 4.42.1 Window frames and fittings

In road-, rail- and water-transport - except where the complete vehicle body is made from aluminium - the foremost aluminium category used are castings /see sub-chapter 4.41/.

However, aluminium usage for other ends in rolling stock and road transport vehicle manufacture, too, is making great headway in view of the special properties of the light metal. Some of such aluminium usage is by now completely replacing that of other non-ferrous metals.

A case in point are window frames in railway carriages. Originally, they used to be made from wood and later on from bronze. The first aluminium window frame design in rolling stock manufacture appeared some 50 years ago. Since then, for reasons of weight and economies in other non-ferrous metals, such window frames made from anodized aluminium extrusions have completely displaced other structural materials.

As a next step, aluminium was introduced as certain fittings of railway carriages, most of them castings. The principal aim of this was to use a less labour-intensive material both in manufacture and maintainance. The bronze, brass or zinc-alloy luggage racks, door knobs and handles used earlier had to be electroplated by nickel or chromium for reasons of enhanced protection. By contrast, the surfaces of their aluminium counterparts are just polished or in most cases anodized, so as to protect them against corrosion and to prevent them from getting discoloured.

In this context recent competition by plastics has been heavy. Plastics, however, often failed to come up to expectations, because of the heavy loads involved in rail transport.

A novelty finding now widening application is the use of aluminium alloy motorcar fenders. Their high strength coupled with easy automation of their surface treatment, have greatly contributed to their success. In the USA made from an AlZnMgCu /7016-T6/ alloy, they were first used by Chevrolet in the "Vega" and "Camaro" models, with Ford following suit in 1977 applying aluminium alloy fenders in the design of its "Pinto" and "Mercury Bobcat" models. In Europe Volvo has been the pioneer, using now exclusively aluminium for car fenders. Compared to steel, the advantages of aluminium alloy fenders may be summed up as follows: [66]

- In case of collision its shock absorption is more favourable; by using an aluminium alloy fender the stringent requirements set by U.S. standards are easier to comply with;

- Manufacture and surface treatment lend themselves better to automation, involving fewer operations; hence, an aluminium alloy fender is cheaper than a chromium-plated steel one;

- The use of chromium /or nickel/ in coating the steel fender may be completely dispensed with.

### 4.42.2 Bodywork and superstructure

With cold and spot welding as well as adhesion techniques getting more widespread, aluminium components of bodywork find growing acceptance in public transport and commerial vehicle manufacture.

In some cases aluminium does not only replace other non-ferrous metals, but steel as well. Aluminium in this event is used to prevent damage normally caused by the corrosion of steel. An additional advantage is the light weight of certain labour-saving mobile structures in modern rolling stock design, such as room dividers, large sliding doors, tipping or sliding roofs and openable external panelling as well as window frames, covers and gratings of freight cars.

An interesting development is the exchange of steel/wood combined bodywork of motor lorries for aluminium superstructures. By such aluminium usage considerable savings could be arrived at in mainteinance and repair costs [68] [69] [70]. When the aluminium bodywork consists of extruded aluminium sections to be pushed into one another and secured with a catch, thanks to the resultant labour savings its pricing may approximate that of the steel/wood combination, with the extra benefit of easing skilled manpower shortage [72].

The potential of aluminium usage in transport vehicle manufacture is certainly fair and promising. This is also true in respect of motorcar manufacture, where certainly more aluminium is expected to be used in the years ahead than heretofore. Table 34 is a projection by a U.S. producer of how much aluminium is likely to be used in the medium term in the manufacture of a wellknown motorcar make [72].

Table 34.

Forecast of aluminium usage in the manufacture of a wellknown type of motorcar in the USA [72]

| Year | Castings kg | Rolled and extruded parts kg | Total kg |
|---|---|---|---|
| 1965 | 24 | 8 | 32 |
| 1970 | 26 | 9 | 35 |
| 1975 | 27 | 11 | 38 |
| 1977 | 29 | 15 | 44 |
| 1980 | 41-45 | 27-45 | 68-90 |
| 1985 | 57-79 | 34-102 | 91-181 |

### 4.42.3 High-duty components

Die-forging is an important technological process in the plastic deformation of aluminium, ensuring added mechanical strength and longer serviceability. Thanks to this, the resultant product becomes suitable for high-duty performance and the coping with heavy loads frequently encountered with in using transport vehicles.

The technology is also significant in that it permits the manufacture of sturdy passenger car wheels from one piece, to be used over most difficult terrain with utmost safety.

It is a special case in vehicle manufacture when all load-bearing parts of the vehicle, that is, its chassis, body-framing and the cladding of its superstructure, are made from an aluminium alloy. In this event - apart from weight and fuel economies - considerable savings may also be arrived at in manufacturing and maintainance costs. With the aid of the relatively simple technology of extrusion, consoles and supports of such sizes and sections may be produced which - in contrast with rolled or folded welded steel parts - may permit wall-thicknesses at different points to be so distributed as to ensure optimum mechanical strength.

In addition to carrying loads, such parts and components are also designed to perform various additional functions [68]. Owing to this, and in view of the large variety of sectional and longitudinal dimensions involved, the use of such profiles may also save a great deal of labour costs [72].

The lower specific weight of aluminium results in a lower self-weight of the vehicle, implying, in turn, considerable fuel or power economies. Moreover, in the absence of corrosion, the walls of aluminium members remain intact throughout the time the vehicle is serviceable, with no dismounting, surface treatment and re-assembly being necessary from time to time.

The weight reduction may cause minor wear in rolling stock running-gear and underframe. In case of collision, the shock absorption of aluminium is more favourable than that of steel.

A negative factor in aluminium usage at the outset is the relatively higher pricing of aluminium. However, this is offset in the long run by fuel or power economies derived from the lower specific weight of aluminium and the labour-saving design of aluminium sections [69] [71] [72] [73] [74].

No doubt, the aggregate amount of specific energy embodied in an aluminium finished product is higher than that of other structural materials. This in itself, however, taken out of its context, is highly deceptive; for while a transport vehicle is serviceable, usually nine times as much energy may be saved than the surplus energy involved in the manufacture or aluminium parts and components. In case of aluminium underground railway carriages the situation is even better: 1.5-2 years suffice to make up for the aforesaid difference [74].

The realization of this fact, coupled with fresh advances in modern extrusion techniques, have led to the recent purchase of 1,000 aluminium underground motor-carriages by the Paris Metro, which were thus cheaper than their steel counterparts [74]. Encouraged by such developments, the Atlanta subway has now ordered similar underground carriages from Europe [75].

### 4.43 Agricultural consumers

Because of the usual rough handling of outdoor equipment by agriculture and the difficult local circumstances that may prevail on site, quality standards of aluminium items used by this sector are in most cases high and exacting. Corrosion resistance is an important consideration in view of the large amount of chemicals used in and difficulties of maintenance by agriculture.

In agriculture, aluminium is faced with heavy competition from two other structural materials: zinc-coated steel and plastics. Who is to win in the face of such conflicting interests, will always depend on the relative pricing and technical features of these materials.

To illustrate the relative advantages of aluminium usage in the field of agriculture, two concrete examples will be cited, based partly on experiences in Hungary and partly on such reported by literature.

### 4.43.1 Irrigation systems

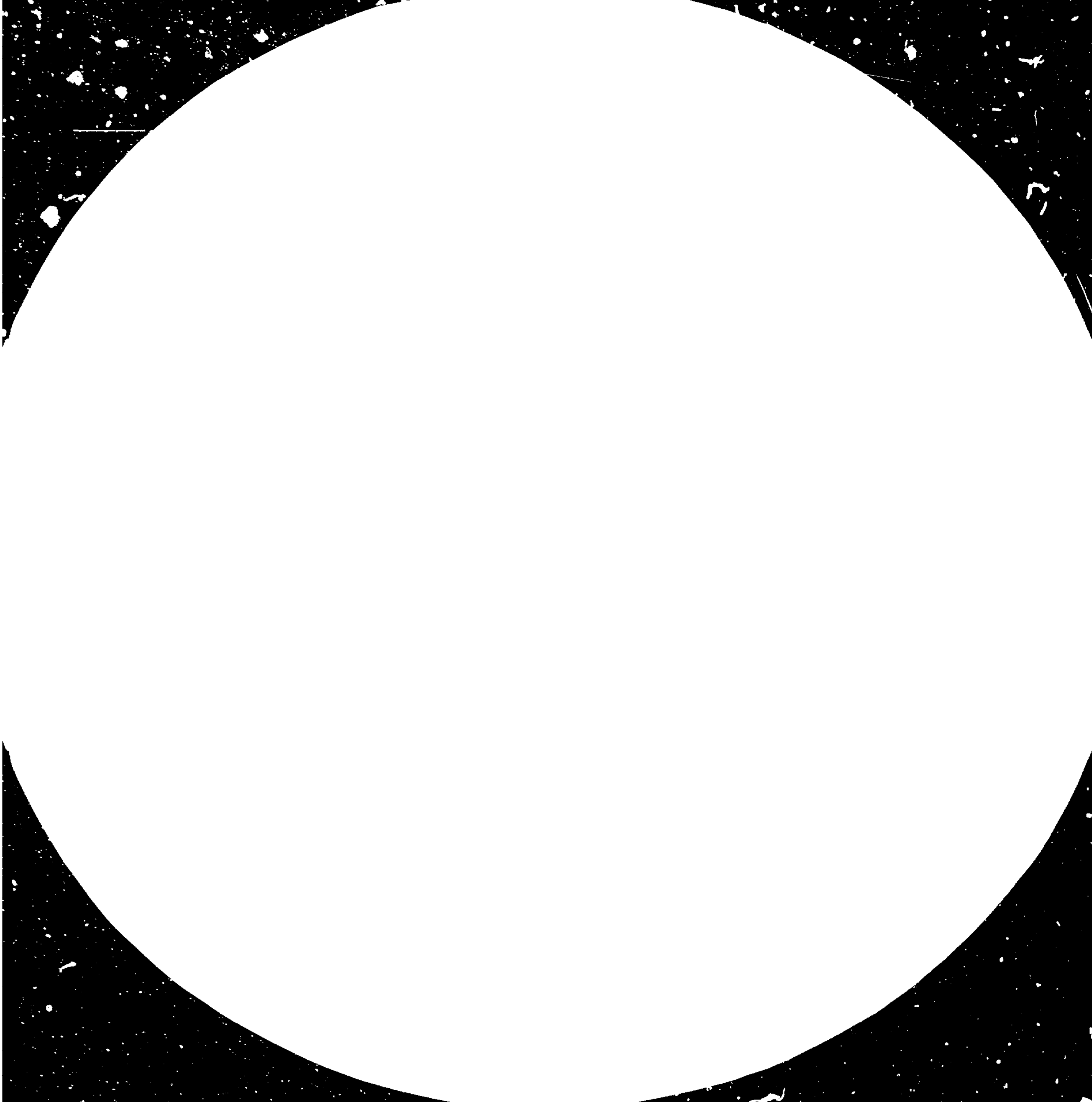
Irrigation systems greatly vary with the site where they are to be installed. They are different in case of arable land from such as are used in gardening. Their design too depends on whether rainers, sprinklers or subsoil irrigation is required.

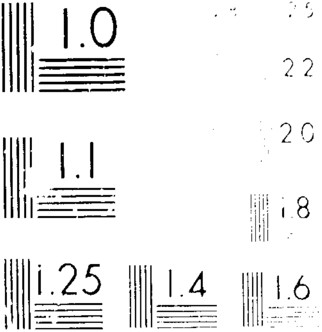
Aluminium irrigation systems are usually installed in arable land using pipelines that are

- easy to re-site
- self-propelling or
- trailable over longer distances.

For whatever purpose used, their common feature is mobility. Hence, next to corrosion resistance, their two other prerequisites are lightness and sufficient mechanical strength. In weight aluminium compares most favourably with zinc-coated steel; as for mechanical strength, it is far superior to plastics.

Re-siteable systems are designed with one main pipeline and three or six secondary pipelines. The length of each component pipe is 6 metres. Their two ends are fitted with fast locking joints. Re-siteable systems differ from the two others by their fast-locking joints. They are either of the

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Perrot or Wright-Rain type; the former are firmly fitting mechanical shackles, whereas the latter use the pressure of irrigation water to tighten the packing rings. Both types allow for a ± 15° deflection from the pipe axis. In Hungary mechanical locking is more widespread.

The principal dimensions of the main pipes are as follows:

| | |
|---|---|
| Inside diameter | 130 millimetres |
| Length | 6 metres |
| Gauge | 1.2 millimetre |
| Weight | 11.15 kg/piece |

As for secondary pipes, the principal dimensions are given below:

| | |
|---|---|
| Inside diameter | 87 millimetres |
| Length | 6 metres |
| Gauge | 1.2 millimetre |
| Weight | 7.8 kg/piece |

Both are welded from an aluminium alloy band. Their test pressure is 160 N/mm$^2$.

The re-siting of self-propelled rain applicators calls for considerably less physical labour, the work being done on rollers by the system's own motor. A standardized rain-applicator system is made up from welded aluminium alloy pipes of 130-millimetre diameter.

A trailable pipeline system is acting as the main pipeline of the self-propelled rain applicators. By its use hard physical labour in re-siting the main pipeline may be dispensed with. Here the welded aluminium pipes are of 159-millimetre diameter and 2-millimetre gauge. The number of wheels is 46 pairs; the sideline piping is resting on 19 rollers.

Re-siteable irrigation systems may be used for any kind of outdoor cultivation in arable lands, fields, large orchards or vegetable gardens, even on uneven or sloping ground. A trailable equipment is only suitable for operation on flat ground, but for any sort of cultivation, whereas self-propelled rain applicators will irrigate only plants not taller than one metre cultivated on flat ground. /For the irrigation of orchards they are thus unsuitable./

### 4.43.2 Gardening

The size of irrigation pipes used by gardening in greenhouses and foil tents are considerably smaller than those normally used in the fields. In earlier years, stable aluminium irrigation pipes too were used for such ends, but by now these have completely disappeared giving way to plastics, especially polyethylene ones.

Same applies also to the sprinklers used outdoors for the irrigation of vineyards and smaller orchards.

Subsoil irrigation is predominantly used in vegetable cultivation. Dug into the soil such pipes are destined to water the roots of plants. Here too, as a rule, plastics piping is laid, aluminium being used in such soils only where upon changing from one culture to the other the desinfection of the soil has to be done by high-temperature heating instead of by chemicals.

Generally speaking, aluminium for irrigation ends may in this field not compete with plastics. It may, however, be used with advantage as the framework of foil tents or as poles and supports in viniculture.

Foil tents are usually available in two sizes; they are either 4.5-metre wide structures dug into the ground, fitted with a framework of aluminium tubing made from 300 mm dia. by 1.5 mm gauge pipes, or are 7.5-metre wide with a framework of 40 mm dia. by 2 mm gauge tubing.

In temperate climates like that of Hungary, such plastics tents have found wide acceptance for growing vegetables, seedlings and firstlings, the costs of erecting them being only 10% that of conventional greenhouses.

The use of aluminium profiles as vine-grape poles and supports, too, is catching on. One of the principal reasons for this is that in contrast with timber and concrete, they lend themselves well to mechanized handling. They are 3-metre tall, made from 2.5 mm by 40 mm by 60 mm folded aluminium channel sections to be driven into the ground in spacings of 8 metres by a hydraulic device mounted on a tractor. The use of grape harvesters too calls for an elimination of timber and concrete for such ends. In facing competition from other metals, its corrosion resistance and easy maintainance present great advantages.

## 4.44 Building and construction

A corollary to economic growth is an intensification of investments. Nowhere is this so much in evidence as [illegible] in construction, where the proliferation of new industrial edifices, storage facilities, agricultural premises and office blocks immediately strikes the eye. With living standards improving, the erection of communal buildings and multi-storey apartment blocks too follow suit, creating a pressure of demand which traditional building methods are no longer able to cope with. This calls for a thorough revision of conventional architectural thinking throughout the world, with more sophisticated building techniques, prefabrication and light constructions emerging in its wake. Where building capacities are inadequate or no building industry is operating at all, this new concept may afford the following advantages:

- Facilities for prefabrication may be conveniently sited in areas where a more or less advanced stage of industrialization already exists and where the necessary infrastructure is available;

- On setting-up multi-purpose industrial undertakings /metal-working, mechanical engineering, etc./ such facilities may also take care of manufacturing prefabricated building components, whereby part of the heavy expenditure usually involved in erecting separate building material plants may be saved;

- In comparison to conventional building methods, light constructions tend to reduce built-in volumes of material to one-fifth or one-tenth, permitting great economies in transport costs;

- Assembly and installation work require a smaller amount of skilled labour;

- The completion of projects may be speeded up, planned capacities may go on stream earlier.

### 4.44.1 Roofing and sidewalls

In light construction it is of paramount importance that prefabricated roofing and sidewall components be currently available in sufficient quantities ready for assembly on site. To this effect, first of all various rolled aluminium products such as corrugated sheets, sandwich panels and other combinations of rolled aluminium may be used with advantage. Such aluminium usage replaces large quantities of zinc-coated steel. This is an important consideration especially in regions where owing to the local climate steel under the zinc-coating soon begins to rust.

In building and construction, the foremost fields where aluminium may be applied with advantage include

- industrial premises and storerooms;
- bays of framed design, featuring large roofing spans; such premises are usually steel-framed. As a cladding corrugated aluminium sheets, aluminium sheet-coated sandwich panels or other combined prefabricated components may be used;
- agricultural premises where livestock is kept, usually designed with a roofing of smaller span. In view of the large number of buildings and the fast changing animal husbandry technologies involved, building costs have to be kept on the modest side. For this reason, frequently aluminium-clad timber framing is employed;
- facilities for the cold-storage of deep-freezing of fruit and meat; in such premises nowadays exclusively aluminium sandwich panels are used;

- for cladding the frames of public edifices and apartment buildings, aluminium sandwich panel walls and partitions may be employed; also, in tropical climates various types of shade-reflecting surfaces and ventilation shells may be made from aluminium;
- an interesting field of application - at present still in an experimental stage - are aluminium-clad sun convectors, with the aid of which some of the heat energy required in buildings /e.g. hot water supply/ may be generated in this natural way /see also sub-chapter 4.3/.

In raising sidewalls or putting up a roofing, as a rule corrugated aluminium sheets are used. They are made from medium-wide /1,000-1,200 mm/ or wide /1,200-1,600 mm/ strip, corrugated longitudinally so as to assume sufficient rigidity. Their usual material is an $AlMn_1$ or $AlMg_{1-3}$ alloy. Being corrugated lengtwise, they are available in any desired length depending on the possibilities of transport. Their width is determined by the technology of their manufacture and the actual width of the strip from which they are rolled. In the finished state they are as a rule 600-1,200 mm wide. The thickness of the sheet will also depend on where and for what ends they are to be used, what loads they are to cope with and how deep the corrugations have to be. The usual thickness of corrugated aluminium sheets varies from 0.45 to 1.2-millimetre.

Weight per surface unit is usually within the 1.2 kg/m$^2$ - 5.4 kg/m$^2$ range, with 3 kg/m$^2$ being a fair economical average. In using corrugated sheets on a commercial scale, various aluminium fasteners and other items of aluminium hardware are necessary. Their local manufacture has to be organized simultaneously with installing sheet corrugating facilities. Such aluminium hardware includes

- rain gutters
- parapets and
- corner joints or such as to be employed for connecting window frames or components made from aluminium or other structural materials; such parts are profiles, cold-formed by folding or by passing them through a set of rollers.

By a suitable design of fasteners, joints and aluminium hardware a great deal of labour and scaffolding costs may be saved. Moreover, if expertly designed, they may counterbalance the effects of slight expansion and contraction aluminium structures are exposed to in the presence of changing climatic conditions, and may protect them from rainwater leakage, prolonging thereby their age of soundness.

With the same end in view, various types of aluminium cladding systems have been developed, differing from one another only is slight detail /e.g. such as designed by Alusuisse, Alfal-Cegedur, etc./.

A single-layer uninsulated corrugated aluminium sheet cladding may be fitted with thermal insulation suspended or placed behind it. A thermally well insulating sidewall or roofing may, furthermore, be arrived at by placing an insulation between two corrugated aluminium sheet claddings. The inside cladding may also be made from wood or some other building material. In such an event, of course, a further set of components have to be added such as

- distance pieces
- adjustable trusses and
- secondary ribbing.

Major aluminium producers have all developed suitable designs of insulated sidewall and roofing systems as well.

One drawback of light constructions is the danger of getting over-heated when exposed to warm sunshine. In tropical regions even with traditional techniques it is difficult to provide a room temperature required to house delicate equipment /e.g. computers/ or to ensure a feeling of comfort to the inmates of such buildings. To reduce the ill-effects of over-heating, special aluminium screening systems have been devised to be sited as members independent from the roofing, permitting thereby effective ventilation between screening and roofing. Surplus costs involved in installing such shading screens are amply repaid by economies in air-conditioning or the complete elimination of the latter.

Another widely accepted prefabricated building component is the sandwich panel, featuring a rigid plastics foam core firmly fixed between two hardwood, plastics, steel or aluminium claddings. The plastics core is usually polyurethane or isocyan-urate, but throughout the world research is under way to develop a more fireproof type of plastics foam. The ready-made panels are usually 8,000-12,000-millimetre long and 600-1,500-millimetre wide. The aluminium cladding is made as a rule from a 0.6-1-millimetre strip of medium width passed through a set of rollers for corrugation. Cladding edges are so shaped as to permit assembly on site forthwith.

While the great majority of sandwich panels is used as sidewalls, there are also some special ones to serve as part of the roofing. In installing them, great attention has to be devoted to effective rainwater sealing.

The overall thickness of panels used in industrial and agricultural premises as well as in public buildings is 35 - 55 millimetres. Such panels contain 5.5 kilogrammes of aluminium and 2 kilogrammes of plastics per square metre of panel.

In the construction of cold-storage rooms thicker panels have to be used: 80-100 millimetres for fruit and 200-300 millimetres for the deep-freezing of other food. Upon assembly they have to be joined with the utmost care and accuracy.

Compared to other designs, aluminium claddings of sandwich panels have the distinct advantage that owing to their corrosion-resistance no extra surface treatment is necessary on installation, nor is there any maintainance work to be done later. The surplus expenditure involved in erecting such premises is amply repaid in the form of cost savings within 5 - 8 years. Following this, the application of aluminium in cold-storage room construction is not only technologically useful, but also financially a sound proposition.

Recently, a special type of prefabricated roofing has been put on the market by the Hungarian Aluminium Corporation under the trade name of ALU-DONGA. It is of an arched shell design where two corrugated aluminium sheet layers are connected by rigid metal ribs with a suitable insulation placed in and between. The roofing is available in 12-14-metre long spans which are held in position without extra trusses or supports. Being fully prefabricated, their installation is both time-saving and highly economical. Over longer distances, however, they are difficult to transport owing to the poor utilization of shipping space.

### Substitution of other materials by aluminium

By using aluminium in building and construction, first of all traditional silicate-based building materials may be replaçed. But aluminium in this field has also a great potential in substituting zinc- or plastic-coated steel for reasons demonstrated below.

By using one ton aluminium sheet 2.4 - 2.6-ton steel plate and 0.2 - 0.25-ton zinc-coating may be replaced. Moreover, the age of soundness of an aluminium sheet is several times that of a steel-plated one without extra maintainance, whereas zinc-coated steel has to be surface-treated every 2 - 4 years.

## 4.44.2 Rain gutters

An effective rainwater disposal system is essential in any aluminium light construction design. Its lack, poor design or damage may cause indirect financial loss and depreciate the value of the building.

The traditional material of rain gutters is zinc, though earlier, in some cases, also copper had been used. However, the relative pricing of zinc kept on rising throughout the last decades, therefore as from the 1910's zinc-coated steel came into general use. But the thin and often not continous zinc-coating is not a fully-fledged substitute of zinc-plate, which normally remains serviceable for 30-40 years. As a rule, after 2 - 3 years of use, on the surface of zinc-coating specks of rust become visible and after 5 - 6 years the rain gutters become defective at several points and have to be replaced.

Attepts were made to prolong their age by adding a paint coat successively. However, what with the extra labour and paint costs involved, this did not prove a paying proposition and has never been practised on a larger scale except for small houses in private ownership. The prepainting of the zinc-coated steel plate by using an effective priming and high quality paint coating proved to be more useful; this costly operation did actually prolong the serviceability of the rain gutter by 10-15 years, but this in itself was but a fraction of how long a genuine zinc-plate may last. Experiments were also conducted to use plastics rain gutters /PVC or shatterproof polysteryne/. Such usage, however, fell short of expectations, because of its poor cost-effectiveness.

The obvious answer to the problem had appeared to be aluminium. Notwithstanding some random attempts made earlier, it was not until 1966 that organized research in this context could be started in Hungary. While in 1970 only 2-3% of the rain gutters had been made from aluminium, in 1976 this figure rose to 30%. By now facilities for the manufacture of fasteners, fittings and other auxiliary components, too, are available.

According to experience so far, rain gutters for general use should be manufactured from 0.8-millimetre aluminium sheet,

Outdoor corrosion trials with 99.5% half-hard aluminium sheets and such of other specifications have yielded the following experimental results:

- After exposure for six months, a sprinkling of small white removable corrosion spots appeared on the surface of the test pieces;
- Following this, the intensity of corrosion tended to slow down; even after several years, corrosion did not grow substantially, nor have the exposed test pieces become defective at any point;
- The rate at which such white spots develop, as well as their density, was observed to vary with the intensity of ambient air pollution;
- Underneath the impurities depositing on the surface of suspended rain-gutters corrosive inroads were found to be more frequent;
- On undoing unfastenable joints, the insulation placed between two different metals to avoid direct contact was at various points found to be defective: in spite of this, either no or only a slight degree of contact corrosion could be observed;
- The rear and the edges of the claddings are in direct contact with substances prone to alkaline reaction /mortar, cement concrete/. If such aluminium parts are not properly mounted, humidity entering into the resultant gaps may cause corrosive changes;

- Apart from the white spots referred to above, substantial corrosive changes could nowhere be discerned;
- Laboratory tests have demonstrated that the depth of corrosive inroads does not increase proportionately with time, that is, the rate and intensity of corrosion tend to slow down in the long run.

To prevent corrosive damage to suspended aluminium rain gutters by impurities amassing in them, they have to be given a greater tilt upon mounting than that of zinc-coated steel ones. If in raising a new edifice aluminium building hardware is used, all parts have to be aluminium. When in the course of renovation aluminium building hardware is employed, as far as possible all other parts too should be exchanged for aluminium. The use of different metals side by side is harmful and should be avoided.

The principal dimensions of aluminium building hardware are practically identical with those of zinc or zinc-coated steel ones with the following reservations:

- 99.5% half-hard aluminium sheet of 0.8-millimetre thickness has to be used;
- At a maximum distance of 10-metres from points where suspended structures are firmly fixed /e.g. pipe-end joints/ water-tight clearances for expansion have to be provided for.

In view of the properties of aluminium, rain gutters have to be installed with a slope of 3-4%. Moreover, rain gutter brackets have to be mounted at regular distances of 1,000 millimetres with a tolerance of ± 100 millimetres and placed so that they may ensure the desired slope.

No effective technology has so far been devised to solder aluminium building components on a commercial scale. Therefore aluminium members may at present only be joined by riveting or folded joints. Rivets have to be of aluminium or another material compatible with aluminium.

Aluminium and other metals may not be directly joined. To avoid the detrimental effects of corrosion, contact surfaces have to be provided with effective insulation.

## 4.44.3 Window frames and doors

Another aluminium outlet finding wide acceptance by the building trade are aluminium window frames.

Latest advances is technology permit the manufacture of window frame components of highest dimensional accuracy, permitting easy and quick assembly on site. Apart from the pressure of universal demand for more personal comfort, nowadays more and more industrial plants, scientific and medical institutions, too, call for an effective control of temperature, humidity, sterility and dust-proofness in indoor areas.

Such claims may be fully met by applying modern aluminium window frames and doors of practical and aesthetically appealing design.

In the following, first of all aluminium window frames are to be dealt with at some length. Evidently, their design will be determined [illegible] climatic conditions prevailing in the region where they are to be used. In sub-tropical and mediterranean climates /at mean temperature above 18 °C/ in most cases single windows will suffice. For economical considerations, in such regions usually horizontally sliding or vertically moveable window frames made from smaller aluminium sections may be applied with advantage.

In order to ensure the high quality of such frames, the component aluminium sections have to be anodized. To permit a better utilization of available surface treatment capacities, the extruded sections are now usually anodized in full-length batches. The earlier practice of welding the frame corners has therefore been almost completely abandoned and replaced by applying mechanical corner joints.

For this purpose, next to screw fastenings, cast or extruded section insets, driven-in nuts or cold-formed fasteners have come into use.

Depending on size, the weight of a modern single horizontal aluminium sliding window frame varies from 4 kilogrammes to 7 kilogrammes per square metre.

In temperate climates the use of insulated double window panes is justified. Notwithstanding size, the technology of their manufacture is practically the same as that of the single window frames. In order to ensure air-tight sealing, special care has to be devoted to applying effective fittings /e.g. locks/ and packings /e.g. "brushes"/. The weight of an insulated double aluminium window frame is about 4 - 7 kilogrammes per square metre.

In the wake of rising fuel prices, a new aluminium window frame design has emerged, featuring what may be briefly referred to as "thermal bridges". In such window frames, between the outer and inner aluminium section surfaces, usually a plastics layer is added which is a much poorer thermal conductor than aluminium. Thereby the heat loss occurring in the total structure may become considerably smaller and the danger of vapour condensation too may be reduced or completely eliminated. The plastics inset tends to impair the mechanical strength of the window frame; therefore the aluminium frame has to be more robust, its weight usually ranging from 6 kilogrammes to 13 kilogrammes per square metre.

In regions of higher mean temperature where the number of sunny hours is higher, the disposal of indoor surplus heat in summer is more difficult than making up for heat losses in winter. Hence research is now under way to develop new types of window frames, where such surplus heat may be readily reduced without applying a separate screening system.

The first step towards resolving this problem has been the introduction of light-reflecting window panes. However, at present a more effective solution is striven for, featuring a double window where the two frames are placed 10-30 centimetres apart and the natural or artificially incited airflow between the two may drive out the major part of the surplus heat generated.

Cost savings in using aluminium window frames accrue in operational overheads rather than in capital expediture.

According to an inquiry, in buildings of traditional design 60-80% of the heat losses occurring in the winter months is caused by heat transfer through the building construction itself and 20-40% by such as is passing through the window frames. By using securely insulated modern aluminium window frames the latter may be reduced to one-tenth. In a similar manner - though to a lesser degree - may summer heat be reduced effectively by applying window frames of suitable design.

All this has a telling effect on energy consumption, an area where savings are always welcome in the face of steadily rising power and fuel prices.

As far as aluminium doors are concerned, different heat-insulated designs are used in cold-storage rooms; large mechanically operated aluminium doors are installed as the entrance to hangars, factory bays and some public buildings; aluminium doors and gates are also to be found in agricultural and animal farming premises, sheds and silos.

## Manufacture of window frames and doors

The continuous supply of aluminium window frames calls for the availability of aluminium extrusions in sufficient volumes and suitable specifications. Therefore at plants where aluminium window frames are manufactured hydraulic presses for the extrusion of aluminium sections too are often installed.

Investment costs of aluminium window frame plants greatly vary with the extent of mechanization and automation applied in technology and with the rate of productivity striven for. The installation of an automated 5,000 t.p.a. /80,000-square metre/ facility employing a maximum labour force of 20 may call for capital expenditure of up to 40 million U.S. dollars. A plant of the same capacity with a considerably more modest scale of mechanization may roughly cost 13 million dollars; in this event, however, a labour force of about 80 will have to be employed.

### 4.44.4 Miscellaneous usages

In addition to aluminium outlets discussed in the foregoing, the building trade also uses a multiplicity of other aluminium applications including

- aluminium tube scaffolding for construction or renovation
- curtain walls, exterior building claddings
- banisters, friezes, ladders
- building engineering installations, air ducts, radiators and coolers /see also sub-chapter 4.3/.

In recent times the complex prefabrication and use of small aluminium-framed building constructions have been steadily gaining ground. /In the early post-war period when a great deal of aircraft manufacturing capacities had become idle, the first of such aluminium constructions had appeared on the U.S. and British market; however, owing to using an unsuitable alloy giving rise to corrosion, coupled with certain shortcomings in design, these first attempts proved to be a failure/.

At present two systems of small prefabricated aluminium building constructions are used on a commercial scale:

- the so-called mobile homes, a sort of "dwelling containers", which are transported to and erected on site as a completely prefabricated and self-contained single unit;

- the module system, permitting a large combination of the framing, roofing, side panels, room dividers, window frames and doors to be assembled on site.

In price, aluminium constructions like this fall short of comparable buildings where traditional materials are used. Such aluminium constructions are viable nonetheless when applied with foresight for specific aims where their usage is justified. Such usage includes

- temporary premises that have to be moved later and where dismounting and re-erection costs are lower than that of building new ones /e.g. at sites where a new building development or industrial project is being set up/;

- in areas difficult of access or where manoeuvrability is poor;
- where quick construction is aimed at.

In regions of inadequate infrastructure they may present the following extra advantages:

- with transport over longer distances being costly and difficult, the lightness of building structures and their components is an important consideration;

- labour - especially skilled one - is often hard to come by on site; by contrast, work involved in the assembly or installation of such prefabricated constructions is minimal.

Aluminium-framed building constructions may have maximum two storeys; their premises are designed with medium or small spans not exceeding 6 metres. They may be used with advantage as

- bungalows or bunkhouses
- offices
- workshops, laboratories, engine rooms
- schools, dispensaries, consultation rooms and motels.

The first mobile homes were developed in the United States. The aluminium framing is usually dispatched with welded joints to site, ready for installation. Its material is a high-strength AlZnMg alloy lending itself well to welding.

The aluminium-framed system developed by Alusuisse is similar; here the welded frames are dispatched to site to be joined by screws.

The "Trelement" and "ASB" /Aluminium Struktur Bau/ systems developed in Federal Germany feature aluminium rods cut to measure, bored and fitted with fastening devices to be secured with screws on site.

The so-called "ALUTÉR" system now being developed by the Hungarian Aluminium Corporation is featuring maximum prefabrication coupled with a minimum of labour. The framing is of a welded design and the inside partitions and outer panels too are prefabricated; to permit the variability of space inside, each panel and partition is fastened to the framing by a simple catch.

All the systems outlined above have two things in common: on one hand, they take utmost advantage of the possibilities afforded by the design of the extrusions, and on the other hand they apply joints easy to manipulate in connecting joists, roofing and sidewalls with the framework.

The amount of aluminium used in these systems vary from 10 kilogrammes to 30 kilogrammes per square metre of each storey.

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## 5. SOURCES OF KNOW-HOW AND TECHNOLOGY

Exploring new aluminium outlets and replacing traditional structural materials by aluminium is a complex and difficult task calling for plenty of foresight and a great deal of information.

There is an extensive network of research and designing institutes as well as technical development agencies throughout the world dealing with a large variety of scientific and practical aspects of metallurgy, semi-manufacture, casting, plastic deformation, welding and surface treatment of aluminium. They represent one source from which useful information may be forthcoming to those who are already engaged at some particular stage in aluminium production or who are about to embark on such a venture. While the role of these institutions is significant in imparting such information, the various engineering echelons responsible for running industry may not dispense with the experience of specialists operating in actual field work, that is, where the aluminium products are manufactured or equipment for their manufacture may be obtained. Accordingly, potential sources of technology and know-how are also inseparable from

- the long-standing experience of the large aluminium producers,
- technical information and assistance available from the manufacturers of specific products,
- the expertise of equipment manufacturers, and
- the experiences of those operating such equipment or of customers buying products made with the aid of such equipment.

The large aluminium producers of the world are, as a rule, prepared to act as consultants and to impart technical information and know-how, when called upon to do so. In such cases, however, they also count on the cooperation of their business partners in helping them appraise the market situation prevailing on site.

There is no general recipe of how to proceed in such cases. With issues involved being complex and depending on a combination of circumstances, the following are just some random examples chosen from three most essential fields of aluminium usage to demonstrate as to how and from what source technology and know-how may be obtained.

## 5.1 Electrical engineering

As to how aluminium may best replace other structural materials in electrical engineering has been amply expounded in chapter 4.1. In this field nearly all large aluminium companies of the world may furnish technical advice and assistance or sell technology and know-how, especially as far as the manufacture of up-to-date conductor material is concerned /composition of the conductor, manufacture of rod wire by continuous casting from molten metal, the drawing and heat-treatment of wires/. Cases in point are the Hungarian Aluminium Corporation /Pozsonyi ut 56, H-1133 Budapest, Hungary/ with great experience in the manufacture of unalloyed and alloyed wire for overhead lines, CEGEDUR /Avenue Marceau, F-75361 Paris, France/, a subsidiary of the Pechiney concern, which has developed an advanced technology for the manufacture of a high-strength alloyed conductor of excellent conductivity, or the Southwire Company

/Fertilla Street, P.O.B.1000, Carrolton, Georgia 30117, USA/, a manufacturer of flexible conductor of reduced creep, especially suited for installation or winding purposes. A firm wishing to take up conductor manufacture is advised to contact one of the large specialists in this field with a view to concluding arrangements for the purchase of its know-how and technology. The firm imparting such technical information should also be ready to furnish his partner a list of references, stating the experiences of its own customers in using such conductors. Thus a prospective buyer may be familiarized with the current experiences of firms installing or using overhead lines, aerial cables, service mains and telecommunication networks. The latter may also make useful suggestions as to the selection of suitable fittings, an important consideration in reliable installation work.

Hungarian industry has been a major manufacturer of aluminium cables, electrical engineering equipment and fittings for more than 30 years. Next to meeting the impact of domestic demand, significant volumes are also exported. In order to apply advanced technologies in manufacture, installation and usage, Hungarian industry has concluded numerous cooperation agreements with foreign firms as well. Some of these cooperation arrangements call for joint ventures in third countries /e.g. a complete long-distance power transmission line in Jordan; power works in cooperation with FIAT in Turkey, featuring aluminium outdoor switchgear; the complete lighting system of sports grounds and stadiums, etc./.

Know-how and technology as a whole at different stages of production and consumption are intimately tied up with one another. To permit a better understanding of how such underlying issues are interwowen in electrical engineering, a few concrete examples may be found in <u>Table 35.</u>

## 5.2 Chemical engineering and food industry

Whether and how far further advances may be made in aluminium usage in electrical engineering rests a great deal with the innovative spirit of industries concerned in the generation, transmission and use of electric power. To this end, the aluminium industry as such, furnishes the raw material only; in doing so, however, it certainly does incur a certain amount of financial risk in testing new possibilities and if promising, developing new technologies. The situation with regard to the food industry, however, is different. Here it is up to the aluminium industry in the first place to launch new ideas especially in the field of food packaging, assuming full responsibility for the costly and often lengthy trials involved, together with most of the financial risks of the latter. At times it is also setting up joint ventures or even subsidiaries with the participation of major potential consumers for the implementation of programmes after having tested their feasibility by trials on a laboratory or pilot plant scale. /E.g. beer casks in partnership with breweries; various types of cans in partnership with the canneries; new foil combinations in partnership with the food processing industry; packaging in partnership with oil refineries or pesticide manufacturers. /The aluminium industry in most cases is fully familiar

Table 35.

Complex sources of know-how exemplified in the field of electrical engineering

| Product | | Technology | | Technical development, application, installation | |
|---|---|---|---|---|---|
| Item | Sources of know-how | Item | Sources of know-how | Item | Sources of know-how |
| 1. | 2. | 3. | 4. | 5. | 6. |
| Raw material of overhead conductors and cables | Hungarian Aluminium Corporation /MAT/, Pozsonyi ut 56, H-1133 Budapest, Hungary. | Continuous casting of rod wire | Hungarian Aluminium Corporation /MAT/ Pozsonyi ut 56, H-1133, Budapest, Hungary | Technical development of and specifications as to stranded conductors, aluminium bars, fittings, joints, load-bearing structures and claddings | Research Institute of Electrical Engineering /VEIKI/ Zrinyi utca 1, P.O.B. 233. H-1368 Budapest, Hungary.<br>Research and Development Institute of the Hungarian Aluminium Industry /ALUTERV-FKI/, P.O.B. 128. H-1389 Budapest, Hungary. |
| Unalloyed and alloyed uninsulated wires and cables | Hungarian Cable Works /MKM/, Budafoki ut 60, H-1117 Budapest, Hungary<br>"December 4" Wire Works, H-3501 Miskolc, P.O.B. 17. Hungary | Continuous extrusion with extra smooth surface | Hungarian Aluminium Corporation /MAT/ Pozsonyi ut 56, H-1133, Budapest, Hungary | Overhead conductor and cable testing station | Research Institute of Electrical Engineering /VEIKI/ Zrinyi utca 1. P.O.B. 233, H-1368 Budapest, Hungary. |
| | | Continuous casting of alloyed rod wire | CEGEDUR 66 Avenue Marceau F-75361 Paris. France | Design of power networks and sub-stations | Designing Enterprise of Power Stations and Networks /ERŐTERV/ Széchényi rakpart 3, P.O.B. 23. H.1361 Budapest, Hungary |
| Insulated conductors and cables /up to 120 kV/ | Hungarian Cable Works /MKM/, Budafoki ut 60, H-1117 Budapest, Hungary<br>Sieverts Kabelwerk AB, 10 Alingsas, Lörkv, Sweden<br>Alcan Ltd., Dufourstrasse 43, Zurich, Switzerland | Plastics insulation, insulation of sheathing, screening with continuous aluminium strip | Hungarian Cable Works /MKM/, Budafoki ut 60. H-1117 Budapest, Hungary | Installation of overhead lines and aerial cables | National Electric Transmission Line Enterprise /OVIT/, P.O.B. 57. H-1325 Budapest, Hungary.<br>South Transdanubian Electric Power Supply Enterprise /DÉDÁSZ/ P.O.B. 95. H-7601, Pécs, Hungary |
| Cables stranded from alumoweld wires | Vereinigte Metallwerke Ranshofen-Berndorf Uraniastrasse 2, A-1010 Vienna, Austria | | | | |

| 1. | 2. | 3. | 4. | 5. | 6. |
|---|---|---|---|---|---|
| Overhead conductors and cable fittings | Electric Equipment and Apparatus Works /VBKM-EKA/ Füzér utca 37-39, P.O.B. 20, H-1457 Budapest, Hungary.<br>Allgemeine Elektrizitäts-Gesellschaft /AEG/, Bebelstrasse 24, D-7 Stuttgart, Federal Germany<br>AMP GmbH für lötfreie Anschlusstechnik, Ampere-Strasse 7-11. D-607 Langen bei Frankfurt/M, Federal Germany | | | Cable-laying and installation instructions | Designing Enterprise for Electric Power Stations and Networks /ERŐTERV/, Széchényi rakpart 3, P.O.B. 23, H-1361 Budapest, Hungary. |
| | | | | Laying of underground cables | Budapest Electric Power Works /ELMŰ/, Váci ut 72-74. P.O.B. 511, H-1393 Budapest, Hungary<br>Electrical Installation Enterprise, /VIV/, Sip utca 23, P.O.B. 67, H-1400 Budapest, Hungary. |
| Aluminium telecommunication cables | Southwire Company, Fertilla Street, P.O.B.1000, Carrolton, Georgia 30117, USA | Plastics-sheathing, oil-filled insulated cables | Southwire Company P.O.B. 1000, Fertilla Street, Carrolton, Georgia 30117, USA | | |
| Aluminium bars | Székesfehérvár Light Metal Works, Adonyi ut 64, P.O.B. 102. H-8001 Székesfehérvár Hungary | | | Installation of service mains, indoor conductor bars | Electrical Installation Enterprise /VIV/ Sip u. 23, P.O.B. 67. H-1400 Budapest, Hungary. |
| Aluminium cable chabbeks | Balassagyarmat Metalworking Enterprise, P.O.B. 30. H-2660 Balassagyarmat, Hungary | | | | |
| Metal-clad bars and switch equipment | Electric Power Works Designing and Installation Enterprise /VERTESZ/, Fehérvári ut 108-112, H-1509 Budapest, Hungary<br>Electric Equipment and Apparatus Works /VBKM-VAV/ Kőérberki ut 36, P.O.B. 59. H-1502 Budapest, Hungary. | | | Installation of outdoor switch equipment | Electric Power Works Designing and Installation Enterprise /VERTESZ/, Fehérvári ut 108-112. P.O.B. 7, H-1509 Budapest, Hungary |

| 1. | 2. | 3. | 4. | 5. | 6. |
|---|---|---|---|---|---|
| SF6 insulated aluminium switch equipment | BBC Aktiengesellschaft Brown-Boveri, Postfach 85, CH-5401 Baden, Switzerland.<br>Ganz Electrical Works, Lövőház utca 39, P.O.B. 63, H-1525 Budapest, Hungary | | | Export and import of electrical equipment, apparatus, conductors and cables | TRANSELEKTRO Hungarian Electrical Foreign Trade Company, Münnich Ferenc utca 13, P.O.B. 377, H-1394 Budapest, Hungary. |
| Aluminium-wound transformers | Csepel Transformer Factory, XXI.Gyártelep, P.O.B. 72. H-1751 Budapest, Hungary.<br>Transformatoren Union A.G., Katzwanger Strasse 150, Nürnberg, Federal Germany.<br>Westinghouse Electrical Company, Shargon, Pa. 16146, USA. | | | | |
| Capacitors | Mechanical Works Kamaraerdő, P.O.B.64. H-1502 Budapest, Hungary. | | | | |
| Lighting gear | Electrical Equipment and Apparatus Works /VBKM-EKA/, Füzér utca 37-39. H-1475 Budapest, Hungary. | | | | |

with the manufacture of such items. In buying such know-how, however, it has to acquire also full technical information as to how such items have to be used /e.g. how to fill and sterilize them at the breweries or canneries, what regulations apply to charging liquid gas bottles and cylinders, etc./.

Items under this heading have been amply discussed in sub-chapters 4.2 and 4.3. From the point of view of how technology and know-how may be acquired, they may be classed into three principal groups.

The first group includes tanks and containers with all their complementary equipment used by the breweries and dairies. With regard to these, in most cases the aluminium industry itself is in a position to furnish full documentation and know-how. However, it is desirable that the holder of know-how should also be familiar with techniques of how such tanks are to be cleaned, as well as with all current experiences by their users. E.g. as to special cleaning techniques of dairy equipment the Dairy Research Institute /Bakáts utca 8, H-1093 Budapest, Hungary/ or as to the storage of raw fruit and the cleaning of such containers the Research Institute of Canning of the Paprika Industry /Földvári utca 4, H-1097 Budapest, Hungary/ has a great deal of experience. As for high-pressure liquid gas transport cylinders, technologies developed by Kaiser Aluminium and Chemical Corporation /300 Lakeside Drive, Oakland, Cal. 94643, USA and Kvaerner-Moss of Norway /see Aluminium /Düsseldorf/ 53:12:741-745, 1977/ may be recommended. Further information on the latter may also be furnished by Skanaluminium, P.O.B.1857, Vika, Oslo 1, Norway.

The second group includes producers of equipment manufactured in large series on behalf of the chemical engineering industry or for other ends. Items of special interest in this connection are heat exchangers /see sub-chapter 4.3/ and liquid gas bottles. Know-how and documentation relating to the manufacture and use of heat exchangers may be obtained in Hungary from the Refrigerator Works /P.O.B. 64, H-5100 Jászberény, Hungary/, whereas information on the use and manufacture of ribbed tubes used in heat exhangers /see sub-chapter 4.21/ may be available at the Hungarian Aluminium Corporation /Pozsonyi ut 56, H-1133 Budapest, Hungary/.

In Europe, virtually the only manufacturer of aluminium liquid gas bottles and cylinders is the Aluminium Ware Factory /Erzsébet királyné ut 57-61, H-1142 Budapest, Hungary/. The firm is prepared to furnish know-how and information as to how facilities for the manufacture of such items may be set up. A latest novelty on the market are aluminium seawater desalinators.

Aluminium roll bonded integral tube sheets have recently made also penetration into solar energy collecting systems. One firm running a pilot plant testing this novelty is Arbonia A.G. of Switzerland /Firedenstrasse 11, CH-Arbon, Switzerland/. Further information on this experiment is obtainable from AFEDES of France /Association Francaise pour l'Etude et le Development des Applications de l'Energie Solaire, 28 rue de la Source, F-75016 Paris, France/.

The third group encompasses manufacturers of thin-walled packaging items and foils. The largest aluminium consumers in this field are the beer and soft drink can producers employing a wall-reducing deep-drawing /ironing/ technology in forming the body of such cans and using easy-opening tops of special design for their closure. Their manufacturing technology has been developed by the Aluminium Company of America /1501 Alcoa Building, Pittsburgh, Pa.15219, USA/ and Kaiser Aluminium International Corporation /300 Lakeside Drive, Oakland, Cal.94643, USA/. The cans are manufactured partly by their own subsidiaries or by the Continental Can Company 4 Landmark Square Stamford Connecticut 06901 USA/ or the Metal Box Company Limited /Queens House, Forbury Road, Reading, Berkshire, England/ cooperating with them. Inquiries as to know-how and technical information should be addressed to either of these firms. Technology and know-how of aluminium can making /generally up to 200-300 ml capacity/ as well as of easy-opening lids and closures may be purchased from CEBAL of France /47 rue de Monceau, Paris 8e, France/, a subsidiary of the Pechiney concern or from Boxal S.A. of Switzerland /Fribourg, Switzerland/, a subsidiary of Alusuisse, but many other firms too are engaged in turning out cans in large series from lacquered aluminium strip supplied by the large aluminium manufacturers of the world. One of such prominent can manufacturers is e.g. the Blechpackungswerk, Stralsund, in the German Democratic Republic. Wall-reducing deep-drawing /ironing/ lines and equipment for making easy-opening can tops are made by various engineering firms including Karges-Hammer Maschinen G.m.b.H. of the Federal Republic of Germany /Frankfurter Strasse 36, D-3300, Federal Republic of Germany/.

The up-to-date closure of glass jars is ensured by the so-called PANO screwless twist-up caps. They are manufactured by the Pano Verschluss G.m.b.H. of the Federal Republic of Germany /Gausstrasse 29, P.O.B. 1526, D-2210 Itzehoe, Federal Republic of Germany/. As for the so-called OMNIA caps, information is available from Thomas Hunter Ltd., Omnia Works /2011 Rugby, England/. Food packaging in cold-extruded collapsible aluminium tubes is making great headway all over the world /see sub-chapter 4.23.5/. In Hungary 25% of collapsible tube usage may be accounted for by the food processing industry. Next to CEPAL in France and BOXAL of Switzerland referred to earlier, in Hungary know-how and technology of collapsible tube manufacture may be obtained from the Matra Region Metal Works /H-3332 Sirok, Hungary/. Also in Hungary, complete equipment for the manufacture of collapsible tubes is manufactured by CHEMIMAS /Noszlopy ut 1, H-1103 Budapest, Hungary/ cooperating with MALL's of the United Kingdom. Full know-how as to the processing of food to be packed in collapsible tubes is obtainable from the Research Institute of Canning and the Paprika Industry of Hungary /Földvári ut 4, H-1097 Budapest, Hungary/. Automatic equipment for filling and sealing collapsible tubes have been developed, amongst others, by Hamac-Hansella G.m.b.H. of the Federal Republic of Germany /Viersen, Federal Republic of Germany/.

And finally, special mention has to be made of diverse aluminium/plastics foil combinations used in foil packaging. In Europe, pioneer work in this respect was done by Alusuisse, putting a sterilizable aluminium/polypropylene foil combination on the market known as Terlacon. In recent times similar packaging has been developed by the Reynolds Metals Company /Richmond, Virginia, USA/ under the trade name of

Flex-can, and by AB Akerlund and Rausing Förpackningsföretaget Södra Industriomradet of Sweden /S-22101 Fack-Lund, Sweden/ featuring polypropylene/aluminium foil/polypropylene combination cans experiencing significant gains on the market. The same combination is also used in the manufacture of collapsible tubes by the American Can Company /Greenwich, Connecticut 06830, USA/. In Europe equipment for making such collapsible tube is sold by TUBMATIC Mägerle and Geiger of Switzerland /Ackerstrasse 43, CH-8630 Uster, Switzerland/.

## 5.3 Miscellaneous fields

The producers and possibilities of acquiring technology and know-how as outlined in sub-chapters 5.1 and 5.2 are to a certain extent similar, in that the large aluminium concerns as a rule may bring influence to bear on electrical engineering firms, manufacturers of food packaging items and the food processing plants to sell know-how and technology to interested parties. In contradistinction with this, know-how and technology relating to general engineering, building and construction is usually held by smaller firms which are ready combine the sale of know-how and technology with that of equipment and machinery. A case in point is a cooperation agreement concluded by the Advance Pressure Castings Corporation of the USA /53 State Highway, Denville, N.J.07834, USA/ and the Hungarian Aluminium Corporation, under which not only know-how and technology has been furnished to Hungary, but also advanced equipment warranting the high international standard of castings.

An almost endless number of similar examples could be cited from other fields of general engineering as well. In the following, let us discuss only two of these, which may be of general interest to the student of advanced methods of joining and surface treatment.

The first one refers to automatic aluminium welding. Specialists in this field like Oerlikon A.G. Schweissindustrie of Switzerland /Birchstrasse 230, CH-8050 Zurich, Switzerland/, Sciaky S.A. of France /119 Quai Jules Guesde, F-94400 Vitry/Seine, France/ or ESAB Elektriska Svetsnings AB of Sweden /Herkulesgatan 72, Fack, S-40270 Göteborg, Sweden/ besides supplying equipment and filler wire, are also prepared to furnish know-how and technology.

The second area deserving special mention is anodisation. Here the position is somewhat different, in that manufacturers of anodisation equipment are not always in a position to furnish know-how and technology of anodisation along with the equipment. It is therefore expedient to contact specialists of this field like e.g. Langbein-Pfannhauser Werke A.G. of the Federal Republic of Germany /P.O.B. 317, D-4040 Neuss/Rhein, Federal Republic of Germany/ or Friedrich Blasberg G.m.b.H. Spezialfabrik für Galvantechnik also of the Federal Republic of Germany /D 5650 Solingen 13, Federal Republic of Germany/, and to insist on technology and know-how to be furnished as well, as far as possible. However, when especially delicate technologies of anodization are sought for /e.g. extra-hard anodization or electrolitically coloured integral anodization/, it is indispensable that know-how and technology be obtained simultaneously with ordering the equipment. Such know-how and technology may be furnished by the manufacturer himself or by some independent expert or scientific institute. The reader is referred to in this connection to the so-called "electroforming" anodization process mentioned in sub-chapter 4.22, a technique used by the Refrigerator Works of Hungary /P.O.B.64, H-5100 Jászberény, Hungary/ in providing the inside of aluminium casks with a suitable surface before a synthetic resin coating could be added.

In building and construction the situation is even more difficult. In light constructions usually each component is forming an integral part of a complete system. Here know-how and technology may no longer be confined to some minor detail, but every aspect of the complete system has to be taken into account, from the designing stage on up to how the components are to be joined, assembled, transported to and installed on site. Most of the major aluminium concerns, such as ALCAN Aluminium S.A. /13 Quai de l'Ile CH-1211 Geneva 11, Switzerland/, ALUSUISSE /Feldeggstrasse 4, CH-8034 Zurich, Switzerland/ and others, have documentation as to their own light construction systems. The Research and Development Institute of the Hungarian Aluminium Corporation /Pozsonyi ut 56, H-1133 Budapest, Hungary/, too, has developed - in cooperation with CEGEDUR of France - a light construction system especially suited for use by agriculture and animal farming. Its know-how and designs have been sold to several other countries including Algeria, Iraq and Iran. Know-how and documentation dealing with such complex systems including the light constructions as well as full technological equipment are now obtainable in Hungary from the Bábolna State Farm /H-2943 Bábolna, Hungary/ or in case of cold-storage rooms from the Energy Management Institute /Bem rakpart 33-34, H-1027 Budapest, Hungary/.

Before going ahead with the manufacture of specific products or their adaption to local conditions, it is always advisable to contact specialists familiar with the technologies of their manufacture and with techniques of their installation and maintainance, with special regard also to the joints and other auxiliary parts to be used. The institutes and agencies referred to in sub-chapter 3.1 may usually help prospective manufacturers find suitable partners; they may also be of direct assistance and help, if they are designing and technical development specialists of that particular field themselves.

## 6. MEASURES TO FURTHER PRODUCT DEVELOPMENT EFFECTIVITY

For the aluminium industry of the world the boosting of aluminium consumption is at all times an objective of major concern. Not only does the finding of new outlets generate fresh demand in terms of volume, but also a pressure for the semi-manufacturing mills and other operators to develop advanced technologies, so as to meet more and more sophisticated requirements forthcoming from the consumer sectors in standards and specifications.

Aluminium has to face constant competition from other materials. To keep its position firm and to win new markets is a painstaking and difficult process. In these efforts assistance rendered by the advising agencies referred to in sub-chapter 3.1 may be invaluable. Next to the tasks discussed there at length, these agencies may also

- help elaborate the general outlines of standard specifications by means of suggestions and active participation in such work;

- cooperate in compiling and editing textbooks, documentation and reference tables, and in organizing lectures or post-graduate courses for the benefit of engineering staff in the consumer sectors and

- actively participate, in concert with the local authorities, in the implementation of projects calling for economies in power or a more rational use of materials in short supply /e.g. fuel economies in transport, the replacement of materials expedient at some given point in view of the country's balance of payments/.

Apart from exceptional cases, the penetration of aluminium into new fields usually occurs in the form of replacing some conventional material. In doing this, the innovator is invariably called upon to break age-old traditions and prejudices on the part of the consumer /see sub-chapter 2.23/.

In this contest - even if full support is given by the local authorities - the aluminium industry may not get the upper hand, unless backed by the help of reliable allies. The reader may be remined at this point of what R. Hartree, director of Alcan Laboratories Limited, once said claiming that there in no aluminium usage anywhere in the world whose nucleus could not be traced back to twenty years earlier [1].

This period of twenty years may be substantially reduced by a concerted effort of all who are likely to derive technological and financial benefits from the replacement of other structural materials by aluminium. Such work calls not only for determination, but also for various organizatory measures to be introduced by both industry and the local authorities /standardization, instructions and regulations pertaining to assembly and installation, reference tables, priorities, etc./.

## 6.1 Standardization

In case of a finished aluminium item, standardization is aimed to ensure the accuracy to size, easy exchangeability, operational safety, endurance and considerations of hygiene and enviromental protection of a product. To enforce such standard specifications, consensus on all these points has to be reached by a body made up from representatives of the principal producers and consumers.

Next in line come regulations and special standards governing the assembly and installation of such products and warranting the properties claimed by the product standard specifications.

Finally, the fabricators must come to terms with the smelters and mills as to the composition and specifications of ingots and semi-manufactures, the outcome of such negotiations to be thereupon firmly anchored in a separate set of ingot and semi-fabricated product standards. This is sometimes an arduous task, the interests of the parties being often conflicting. The aluminium industry is therefore at times faced with the necessity of introducing new and costly technologies before such standard specifications may be passed.

With the aluminium industry being highly integrated, its representatives should preferably take part in the deliberations of all there standardization committees and voice their opinion where this is necessary.

Despite the changing pattern of standardization from country to country, there are three principal types of these as summed up below:

- Raw material standards; they cover ingots and semi-manufactures, governing their composition, mechanical properties, sizes and more recently their technological properties /e.g. electrical conductivity, susceptibility to deep-drawing, etc/. They are usually drafted by aluminium experts, but before they may be passed, as mentioned above, the principal consumers have to be consulted.
- Finished product standards applicable to a particular sector; they enumerate the essential technical features of the material from which the finished product is processed and the principal

properties of the finished product itself; such standards have to be fully coordinated with those of the first group; they are usually jointly drafted by specialists of a given aluminium end-using sector /e.g. electrical engineering, building and construction, packaging etc./ and representatives of the principal consumers; the aluminium industry has to be consulted in each case;

- The third group includes certain technological standards /e.g. welding, surface treatment etc./. If such standards are initiated by the aluminium industry, principal fabricators to apply such technologies have to be consulted.

In developed countries the properties and application of a very wide range of products is governed by standard specifications. These are often supplemented by a set of detailed technological and installation instructions or regulations. Evidently, it will be necessary for each country to revise these and to adapt them to local conditions prevailing on site, if necessary.

And finally, a few words about a system of recommendations introduced in Hungary in the early 1950's. Though not full-fledged standards, these documents were aimed to boost aluminium usage on one hand, and to restrict the usage of other non-ferrous metals, on the other. They give a clearcut answer as to whether aluminium usage for some particular purpose listed in the document is desirable, advisable, possible or impossible. Such recommendations, of course, have to be revised from time to keep pace with latest advances in technical development.

## 6.2 Handbooks and tables facilitating design

The training of staff to become proficient in the design, processing and usage of aluminium in different sectors of industry, is of paramount importance. Such staff includes designers, researchers, process and works engineers, specialists from other disciplines such as economists etc., and what is most important, skilled workers and craftsmen. Familiarity with aluminium should not be limited to those directly engaged in smelter or semi-manufacturing operations. Although they may be well versed in the fundamentals of their own field of erudition or experience, they may at the outset have no working knowledge of the specific technologies, standards, economic feasibility and other aspects of aluminium consumption past the semi-fabricating stage. While other metallurgical industries may often look back upon technologies of several generations' standing, this is certainly not the case with aluminium. Anyone entering this field in an engineering capacity will have to re-assess traditional concepts of technological thinking. He will have to familiarize himself, too, with the complex pattern of the end-using industries and their market demand, along with most of the fundamental technologies involved at that stage. When sufficiently competent, such researchers, designing engineers and consultants attached to the aluminium industry will have to take the initiative of drafting various handbooks, textbooks, pamphlets and tables, so as to disseminate knowledge and practical information among fellow-engineers, technicians and skilled workers engaged in the fabricating industries. As a concrete example of how the aluminium industry itself may be the editor of such literature, the case of the Aluminium Zentrale of Federal Germany may be cited, running a publishing firm of its own under the name of Aluminium Verlag. Similar activities, though on a somewhat smaller scale, are carried on by all major aluminium world concerns and most other large aluminium firms in different countries /see also sub-chapter 3.1/.

Principal types of literature in this context are as enumerated below:

- Handbooks summing up the mechanical and technological properties of aluminium, pointing out technical features of semi-maufactures and how they may be used for a multiplicity of ends /e.g. the large variety of extruded sections etc./, describing subsequent methods of processing, technologies and operations /e.g. casting, welding, surface treatment, machining etc./ and setting forth guidelines as to how aluminium products may best be designed, installed and used.

- Tables to assist the designing engineer in his routine work, with special regard as to how optimum designs may be arrived at by taking advantage of the essential features of aluminium. It should be remembered that designs of traditional materials may never be effectively and economically adapted to aluminium.

- Documentation and pamphlets dealing with a particular operation or technique. They are small booklets embracing a multiplicity of subjects, e.g. the plastic deformation, casting, welding, machining or surface treatment of aluminium. They should be factual, with plenty of illustrative material, written in a style easily understandable by engineers, technicians and skilled workers.

- Special publications dealing with a particular field of aluminium usage, describing where and under what circumstances may aluminium be used there effectively. Their language too should be descriptive and unambiguous, but here also professional jargon may at times be used if it cannot be avoided.

- Textbooks of training courses. They should be an abstract of lectures read at the training courses, expounding also some of the points more difficult to grasp; experiences of practical tuition in workshops too may be recapitulated here.

- Catalogues and leaflets describing various items of products. They may include detailed specifications of semi-manufactures or descriptive features of a particular generation of products, etc. Also, there should be sufficient propaganda material available dealing with auxiliaries used in the processing of aluminium /e.g. special lubricants, welding fluxes, surface treatment baths, etc./. It is desirable that the aluminium industry promote the publication and circulation of such leaflets, even if it is not a manufacturer of such products.

- The publication of an aluminium journal may only be recommended if in the region a sufficiently powerful aluminium industry is already operating. An aluminium journal is a useful instrument in fostering contacts between smelters, mills, the fabricating industries and consumers, and in promoting cooperation between designing and research institutes on one hand, and industrial firms on the other. The principal sponsor of such a journal /also financially/ should always be the aluminium industry.

Lecturers of training courses have to be currently posted up with latest developments in the aluminium field, so that they may consider these in their lectures and textbooks, as far as possible. Furthermore, it is desirable that the mechanical and chemical engineering faculties of institutions of higher education aluminium technology be optionally included in the curriculum of undergraduates or students just graduating.

In conclusion, a few more worlds about staff training courses. They are organized for the benefit of engineering personnel or skilled workers, or to provide post-graduate studies for more advanced specialists. Moral or financial backing of such schemes by government agencies is highly desirable. At the conlusion of such training courses the successful candidate should be given a certificate.

## 6.3 Regulations by the authorities

As referred to earlier, it may take for an aluminium innovation 20 years to really mature. This is especially true when it comes to the replacement of a traditional material by aluminium. The initiator of such schemes are often faced with serious difficulties; the first of these is to find a really effective design; when this is available, the next step is to manufacture a prototype, which has to be tried out in actual practice. If the prototype does not prove to be sufficiently viable, it has to be re-designed; then only may the serial manufacture of an item begin. This is a long and wearisome process, going on in the face of serious competition from other materials, with no mean financial risks involved. The major aluminium concerns of the world are in most cases ready to bear the brunt of such risks in the hope of good financial returns and a further expansion of the aluminium markets. But in countries where aluminium producers independent from the majors operate or where the aluminium industry is part of the public sector, very often the state has to subsidize such ventures to help restructure the country's production pattern. Be that as it may, at one point or another the authorities will have to step in anyway, whether in the field of standardization /see sub-chapter 6.1/, vocational training /see sub-chapter 6.2/ or otherwise.

State intervention, minor or major, however, may only be effective if it forms part of and fits into a long-range economic strategy of a country or area. The aluminium industry of a country, real or potential, may be a significant factor in shaping the economic destiny of a country with its numerous implications affecting the raw material situation, foreign trade and living standards of a given region. To lay down the groundwork of an economically sound and viable aluminium industry, calls for a great deal of systematic thinking, foresight and patience, entailing great responsibilities. Such a concept, however, may hardly work, unless embracing a relatively long span of time. Although in the meantime short spells of ups and downs may occur in the market situation, fundamental changes in the principles underlying such a concept would be extremely harmful.

If conditions permit it, integration encompassing as many stages of production as possible should be the final goal. To this effect, a long-term schedule has to be elaborated, coordinating investment and development programmes at each subsequent stage of integration with special regard to market perspectives. In doing this, possibilities of replacing other materials by aluminium, too, have to be taken into account. A good example of this in Hungary, whose fully integrated aluminium industry had a remarkable effect on the country's economic life. Hungary's aluminium industry is governed by a long-term central development programme launched and approved by the government. In addition to dealing with the country's bauxite resources and covering every successive stage of integration /alumina manufacture, smelting and semi-fabrication/, it also sets long-range targets for developing the aluminium end-using industries [2] [3]. Special attention is devoted in the document to the replacement of other structural materials by aluminium wherever this is technologically and economically feasible. Objectives of long-term research and more details of technical development are set out in a second document forming an integral part of the central development programme [4] [5]. It deals with all practical aspects of how plans for subsituting other structural materials by aluminium have to be implemented and what facilities are to be installed to this effect. While setting priorities, the authorities give full moral and financial support in promoting such research, design, prototype work and pilot plant operations. The implementation of the objectives embodied in the central development programme and its addenda are controlled by a mixed working Committee wherein all concerned parties are represented. It also coordinates the work of research and designing institutes with that of the industrial enterprises, prepares from time to time evaluations of achievements and failures, as well as submits various recommendations to higher government authorities. At first sight, this may look a complicated procedure. However, the number of government agencies, scientific institutes and enterprises of often conflicting interests involved in such schemes is great; also the financial obligations and risks to be shared upon launching new projects may be considerable; therefore, under the circumstances this organizational pattern seems to be the optimum solution.

How much government intervention is necessary to run an aluminium industry effectively? This is a difficult question to answer, the situation being differential from country to country, depending on its economic system and structure, as well as on the potentialities of the local aluminium industry. To win new markets for aluminium, and to use it as a substitute for other structural materials, is not a spontaneuous process. There is often a built-in reluctance or hesitation by the consumers to accept something new. Most of them expect such solutions to be tabled to them in a completely elaborate form. In the implementation of new projects usually high capital expenditure and a great deal of human effort are involved. In developed countries the aluminium industry is run by major companies who have vast resources to face such risks and to penetrate into new markets, selling their products to the highest bidder. If necessary, they buy out smaller producers, establish subsidiaries or enter into joint ventures with them. In these countries the role of government agencies and of the public sector in aluminium /if existing at all/ is usually a subordinate one. The situation in the centrally planned economies and developing countries is different. Here the definition of long-term targets and the introduction of organizational measures to implement them, are tasks fully devolving upon the government agencies /see the Central Development Programme of the Aluminium Industry in Hungary/ [2][3]. Next to being responsible for the control and coordination of different branches of industry, here such government agencies also frequently share financial risks in the projects launched and set numerous priorities in boosting technical development efforts and innovations.

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/Chapter 6/

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