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Non-ferrous Scrap Metal in Developing Countries

Vienna, Austria, 25 - 29 November 1969

UTILIZATION OF ALUMINIUM SCRAP: TECHNOLOGY AND EQUIPMENT [1]

by

J. Jakobi,
Joint Managing Director of the International
Alloys Ltd., Aylebury, Bucks., United Kingdom

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UTILIZATION OF ALUMINIUM SCRAP: TECHNOLOGY AND EQUIPMENT

Addendum 1:

Specific Suggestions for Establishing Scrap Recovery Facilities[1]

by

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Joint Managing Director of the International Alloys Ltd.,
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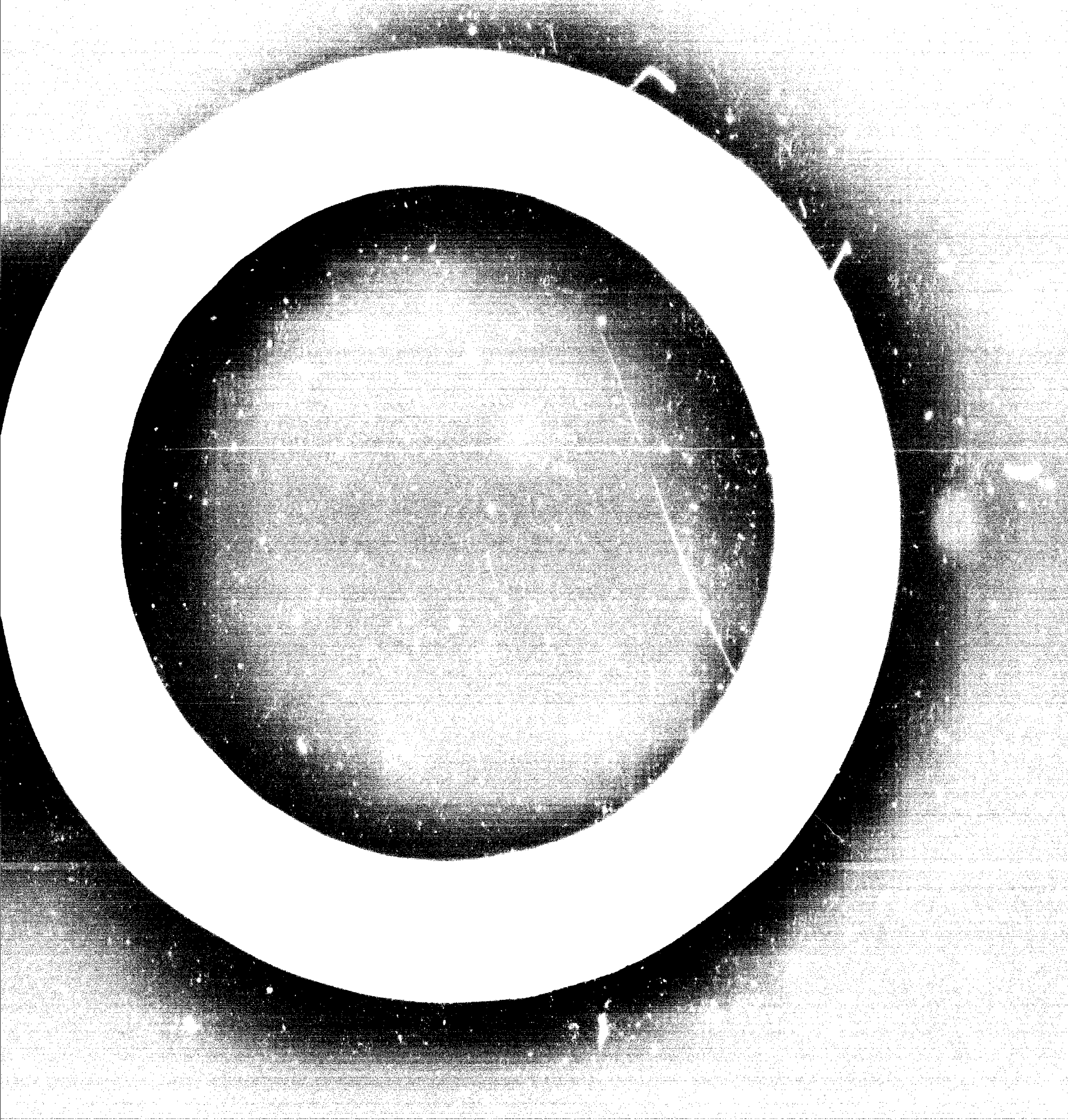

In this paper we have analysed the various methods of dealing with light metal scrap, particularly aluminium scrap. Therefore it remains to make specific recommendations for installing basic plant and equipment according to the availability and the nature of local material, economic and marketing resources.

In areas where arisings of non-ferrous scrap are less than 500 tons per annum efforts should be confined to collection of scrap and preparing it for transportation to a centralised depot. This basic operation would probably employ three men on a full time basis and the only other requirement would be for an area of hard standing and a number of barrels or other secondhand containers for packing the various grades of material.

A larger depot to cater for between 500 and 1000 tons should be supervised by a foreman who has acquired some training in sorting techniques in a developed country and should himself be able to teach the necessary skills to the other workers under his supervision. He [illegible] also guide the [illegible] in smaller depots by regular visits.

When the quantity approaches 1000 tons per annum a basic furnace can be installed for melting scrap into ingots for ease of long distance transportation to larger smelters. If a local foundry industry is already established or being developed it could be worthwhile to consider installing basic laboratory facilities at the same time as the furnace in order to analyse raw materials and resulting ingots and to enable the production of alloys suitable for the foundry to be most effective.

At this stage the employment of a technically qualified chemist or spectrographer would be necessary. The furnace for this type of operation should have a capacity of about 2 tons so that when operated on a three-shift basis the annual production capacity could rise to 2,000 tons. Employment could be found for twelve men to operate the furnace and pack ingots, eight men would be needed to receive, sort and prepare raw material. Staff functions would probably be carried out adequately by the supervisor, the chemist and one or two clerks.

The next stage would be to plan for a production unit capable of a 3,000 to 4,000 ton per annum output. This is the minimum size that should be considered as a viable smelting operation. A single rotary type furnace can be recommended as the most suitable equipment for melting dirty scrap and the widest variety of scrap groups. A furnace capacity of 5,000 Kg is the minimum size consistent with a reasonably large feeding orifice to enable scrap to be charged without undue difficulties which can result from scrap sizes and shapes. Raw material preparation would require equipment to minimise the same difficulties. An alligator shear or a small baling press should be considered.

An approximate current cost estimate for the basic equipment of a smelter of this size is given below:

	$
5,000 Kg capacity furnace (Melting rate 1,500 Kg per hr.)	7,500
Furnace pyrometry	250
Furnace chimney (30 m)	4,000
Slag pans	350
Casting benches and 250 ingot moulds	2,500
Alligator shear	1,750
Weighbridge	1,500
Air compressor	800
Air tools	250
Oil services	1,000
Electricity services assuming supply is available to site	600
Miscellaneous tools	2,000
Fork truck	3,500
Laboratory	5,000
Buildings, foundations, etc. (400 sq.metres)	18,000
Other desirable equipment would be:	
Water cooled casting wheel	7,000
Portable baling press	9,000
Total	65,000

Employment for this operation could be found for between 30 and 40 people.

The above figures are subject to substantial revision for local conditions and are only quoted as a guide. For example, the major item of "Buildings and foundations" will depend on the local climate and ground structure, the output and employment possibilities assume that production can take place over 12 months. No provision has been mentioned for coping with spent slag, effluent or fume problems other than to include a basic chimney with the furnace which is also necessary for the efficient functioning of the furnace.

UNIDO could assist by preparing a simple handbook describing various types of scrap and basic classifications. It should provide a section on weighing techniques and incorporate a basic procedure which should be recommended for melting and casting with due allowance for detailed operating instructions normally provided with individual items of equipment. References 1, 2 and 6 can be used as a basis for this work.

Further assistance can be given by carrying out feasibility studies in the countries interested in scrap recovery and providing advice on the most appropriate operation to meet local requirements.

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1. INTRODUCTION

There are certain types of segregated scrap of known composition which can be incorporated into the production of commercial castings in foundries and a fairly high proportion of process scrap from the wrought products of fabricating operations can be re-used if facilities exist for recycling scrap within one factory. However, in this paper it is the intention to show the importance of scrap recovery in specialised plants where skills and equipment have been developed to upgrade its value in the production of specification alloy ingots with controlled compositions, to the extent where the advantages to the user enables him to concentrate expensive technical supervision on his end product and eliminate many variables connected with scrap segregation and metal alloying. It is even doubtful if an economic case could be made for any foundry to plan production based on clean segregated scrap since it would be necessary to compete with other users who can afford to pay higher prices for this material where it may be possible to replace more expensive virgin aluminium.

The recovery of scrap has been concentrated at smelting plants in which materials of varying composition from many sources can be processed and blended and to which alloying constituents are added for the production of alloys.

The largest proportion of smelter production is in alloys for the castings industries. Foundry alloys have higher concentrations of added elements that, depending on the specification, permit greater tolerances on the levels of impurities. Hardeners can be produced from scrap and are used for adding alloying constituents to melts of aluminium from which the wrought alloy industry produces billets for extrusion and forging and slab for rolling. These hardeners such as 20% silicon, 10% manganese, 50% copper will dissolve in large melts of wrought alloys at lower temperatures than the pure metals. Problems of superheating are avoided and fuel savings are possible.

A third and much smaller outlet of the aluminium scrap smelters is to the steel industry for deoxidisation.

A comparison of published statistics on virgin aluminium and alloys recovered from scrap demonstrates the significance of aluminium ingot makers.

Virgin aluminium production is largely carried out in areas far removed from its main markets and is dictated by the cost for power and bulk transport. Scrap arises during fabrication and as a result of the discard of aluminium-containing products in centres of industry and population. It is here, close to their raw materials and to their markets that scrap smelting operations have developed. The foundries which utilise most of the production are in turn close to the manufacturers of motor vehicles, domestic appliances and to the general engineering component and equipment makers.

Under normal conditions of fairly balanced supply and demand and for up to 80% of the common foundry alloys used in commercial castings it can be shown over a long period that scrap based alloys have been sold at prices about 20% below that of virgin aluminium. However, these alloys are more price sensitive to market conditions than virgin aluminium because scrap is bought on a day to day basis whereas the sources of raw materials for virgin aluminium are contracted for by the producers over periods of many years at a time. In times of plentiful supply, foundry alloy prices may be very depressed and this is reflected in the prices paid for scrap. But in times of shortage which may coincide with a tight supply position for virgin aluminium, alloy prices have occasionally exceeded the price of virgin aluminium.

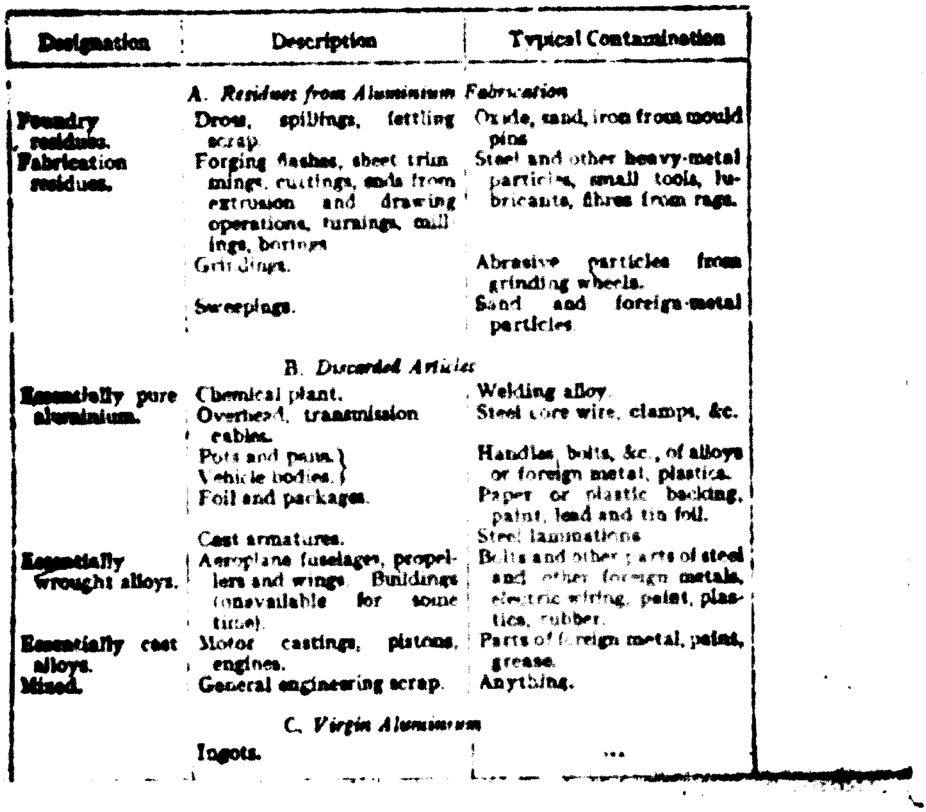
2. CLASSIFICATION OF TYPES OF SCRAP WHICH CAN BE USED ECONOMICALLY

PROCESS SCRAP generated during the fabrication of aluminium and alloy products is usually in a consistant form from each individual process and accumulates in substantial quantities. With reasonable attention to material flow this scrap can be kept segregated by alloy in the works where it arises and, if a melting shop is available in the same factory, it can be recycled within the production unit. When it is made available to scrap smelters, it provides a high quality raw material which can readily be absorbed into related alloys with close composition tolerances. Common examples include billet ends, extruded section and sheet offcuts. Other lower grade types include turnings, sawing chips and grindings, dross and runners and risers in foundries.

OLD SCRAP is collected from redundant or obsolete articles and equipment including kitchen utensils, motor vehicles, wire and cable, engine components and aircraft. As more aluminium is used in the construction of buildings, more scrap becomes available when they are eventually demolished. The quantity available from each source depends on the amount of aluminium used in the production of that source at the beginning of its life cycle. For example, in order to estimate current availability from cars it is necessary to determine an average age for cars being scrapped, say eight years, review the data on aluminium used by manufacturers per car unit during the period around 1961 and arrive at the approximate quantity. Similarly, certain types of building erected 20 years ago may have finished their useful life. If they were constructed of aluminium as the basic material, they could now be a singificant source, the size of which can be assessed.

Most old scrap is contaminated with undesirable matter. The aluminium may be coated with paint, be joined to other metal parts, plastic components or rubber. The table below gives a summary of the raw materials for the production of remelted aluminium ingot(1)

—*Raw Material for Remelted Aluminium Ingot*



Designation	Description	Typical Contamination
	A. Residues from Aluminium Fabrication	
Foundry residues.	Dross, spillings, fettling scrap.	Oxide, sand, iron from mould pins.
Fabrication residues.	Forging flashes, sheet trimmings, cuttings, ends from extrusion and drawing operations, turnings, millings, borings.	Steel and other heavy-metal particles, small tools, lubricants, fibres from rags.
	Grindings.	Abrasive particles from grinding wheels.
	Sweepings.	Sand and foreign-metal particles.
	B. Discarded Articles	
Essentially pure aluminium.	Chemical plant.	Welding alloy.
	Overhead, transmission cables.	Steel core wire, clamps, &c.
	Pots and pans. Vehicle bodies.	Handles, bolts, &c., of alloys or foreign metal, plastics.
	Foil and packages.	Paper or plastic backing, paint, lead and tin foil.
	Cast armatures.	Steel laminations.
Essentially wrought alloys.	Aeroplane fuselages, propellers and wings. Buildings (unavailable for some time).	Bolts and other parts of steel and other foreign metals, electric wiring, paint, plastics, rubber.
Essentially cast alloys.	Motor castings, pistons, engines.	Parts of foreign metal, paint, grease.
Mixed.	General engineering scrap.	Anything.
	C. Virgin Aluminium	
	Ingots.	...

Before the best use can be made of the scrap, these contaminant materials must be seperated from the aluminium. In most countries a pattern has developed in which small scrap dealers collect relatively small lots, which are then sold to larger metal merchants who carry out a basic sorting and grading operation before disposing of the graded materials to the most appropriate consumer. The aluminium bought by smelters may require further sorting. Alternatively, more attention may be directed at the standardisation of the form of the material for feeding furnaces to reduce operating costs. Where 'in-line' processing units are installed, uniformity of material is essential for successful and economic running of the plant.

In countries or areas trying to develop new industries, the consideration of a scrap smelting unit should be discouraged until scrap material is available in sufficient quantities to service it economically. Scrap can only be collected in reasonable amounts if the per capita usage of aluminium has been significant for a long enough period. As their economies develop, their aluminium consumption will rise until it becomes feasible for them to set up a basic smelting unit.

3. PREPARATION OF RAW MATERIALS IN SCRAP FORM

The raw materials available for the production of alloy ingots have been described previously. In addition, virgin aluminium may be required for the production of alloys with very low impurity contents and to dilute certain elements to meet the requirements of the specification.

For the optimum utilisation of scrap materials it is necessary to know the typical composition of each batch. This composition is best achieved by sampling on a statistical or controlled basis, but occasionally random or grab samples have to be taken. The sample is used not only to determine the composition of the batch but also the yield to be expected when the material is melted. This information is required in calculation of the furnace charge and also in assessing the quantity of flux required.

The effort and expense which can be justified for the sorting of different alloys and the removal of non-aluminium material is governed by the increase in value which can be achieved in total process.

Sorting of scrap into different alloys makes use of both physical and chemical methods( ). Many wrought alloys in sheet form can be distinguished from pure aluminium by a simple bend test, or castings in some alloys have typical fracture characteristics and can be sorted by fracture appearance. Chemical methods are generally more reliable and can be simple spot tests for the rough estimation or presence only of one or two elements, or the application of a visual spectroscope in which spectra produced by arc or spark from a standard and sample can be compared simultaneously. The latter method is probably the most useful technique for sorting under production conditions

Experience and knowledge of the application of alloys greatly facilitates identification, as often a component is known to be made in one of two alloys only, and a simple test will distinguish one from the other.

Scrap is often collected by merchants from breakers yards and roughly segregated into various grades. However, process and redundant scrap as delivered to the secondary aluminium work is seldom in a suitable condition for melting without some form of treatment. The factors which determine the treatment to be applied are 1) size, 2) type of contamination.

Furnaces for the melting of scrap will be discussed later, but obviously size of scrap must be limited according to furnace size. Thus bulky light scrap may have to be cut to permit charging into the furnace, in other cases clean scrap such as sheet cuttings, old rolled, foil, may be reduced in bulk by baling. The modern baling press comprises a chamber into which bulky scrap is charged, fitted with a shear to remove excess material, and the scrap is compressed within this chamber to produce a compact bale.

The treatment of process scrap such as dross or swarf from machining operations is of importance in heavily industrialised countries, as much of the raw material for the secondary smelters is available in these forms.

Dross and skimmings are treated by milling in wet or dry ball mills or by breaking in an impact crusher. The principle of separation is the same in both types of equipment. As dross consists of metallic aluminium in the form of globules or networks to which aluminium oxide and fluxes are attached, the method of separation is to crush the friable oxide and flux, leaving the metal in the original size. The fines are then removed by screening, leaving an enriched metal fraction. The free aluminium content of dross as delivered is usually between 30 and 50%, and the recovered fraction in a size range of 150 mm. cube down to 1 mm. has a metal content of around 70%. Attempts to produce a metallic fraction with higher metal content have been made, but this is only achieved by increased loss of aluminium in the finer fraction.

Swarf is usually contaminated with cutting oils, either of the straight mineral oil type or emulsion type. In addition, they frequently contain free iron in the form of steel turnings or even broken tools.

As iron readily alloys with aluminium during the melting operation and cannot be removed in refining operations it is essential to remove it before melting. This can be easily done by magnetic separation, provided that oil and water are virtually absent. For efficient magnetic separation to achieve free iron contents of less than 0.1%, the oil and water contents must be reduced to a similar value.

The oil and water contents of swarf as delivered can be as high as 25%, with free iron contents of up to 10%. Many methods of oil and water removal have been tried, including centrifuging, solvent washing, and drying in open flame drums. All these methods have disadvantages either technically or economically, and the method now accepted as the most practical and economic involves treatment in a heated rotating drum to produce distillation with restricted air flow(3) (4). The air entering the heated drum allows part of the oil to burn, thus providing heat to maintain the drum at the required temperature to distill off the oil and water. The mixture of partly burnt oil and oil vapour passes into a combustion chamber which is maintained at a temperature of at least 700°C by an oil burner in which additional air is supplied to complete combustion of the oil vapour. The drum requires preheating initially by an external burner, but when the plant is in operation the heat derived from the limited combustion of oil from the swarf is usually sufficient to maintain the drum temperature. This temperature is controlled by automatic means by adjustment of feed rate, and external drum heating. Later developments have included provision of oil or water spray to the incoming swarf to give a more uniform operation. This process has three important advantages over conventional driers:

a) Control of the drum temperature prevents overheating and oxidation of turnings.

b) Control of air flow prevents excessive heat requirements for drying and combustion of waste products.

d) The combustion chamber or afterburner ensures that only clean combustion gases leave the chimney.

The subsequent magnetting operation is carried out using rotating drum magnetic separators.

The drier described above can also be used for the removal of paper or plastic coatings from aluminium foil. Treatment in the drier gives a product which can be melted without serious smoke emission and with good metal recovery.

The treatment of redundant and obsolete scrap is very much influenced by the degree of contamination with other metals or non-metallics, and the fact that often more than one aluminium alloy is present. For relatively simple components, e.g. saucepans, and similar cooking utensils, only removal of iron handles and rivets may be required. For complex assemblies such as aircraft and automobile engines and airframe scrap, this material can either be processed before melting, giving the best separation, or subjected to a liquation process

The scrap arising from aircraft and aircraft engines is normally examined for lead and magnesium contamination which is removed as far as possible. In special cases where economically justified, parts of valuable aluminium alloys may also be removed before melting. Cylinder barrels in air cooled aero engines or pistons are examples of components which sometimes justify special sorting. The remainder is charged into a liquation or sloping hearth furnace, which permits separation of metals according to differences in melting temperatures.

Liquation furnaces are typically reverberatory furnaces with an outside bath or ladle to receive the liquid aluminium alloy which runs away from the higher melting point metals, combustibles such as paint, wood and plastic are burnt off.

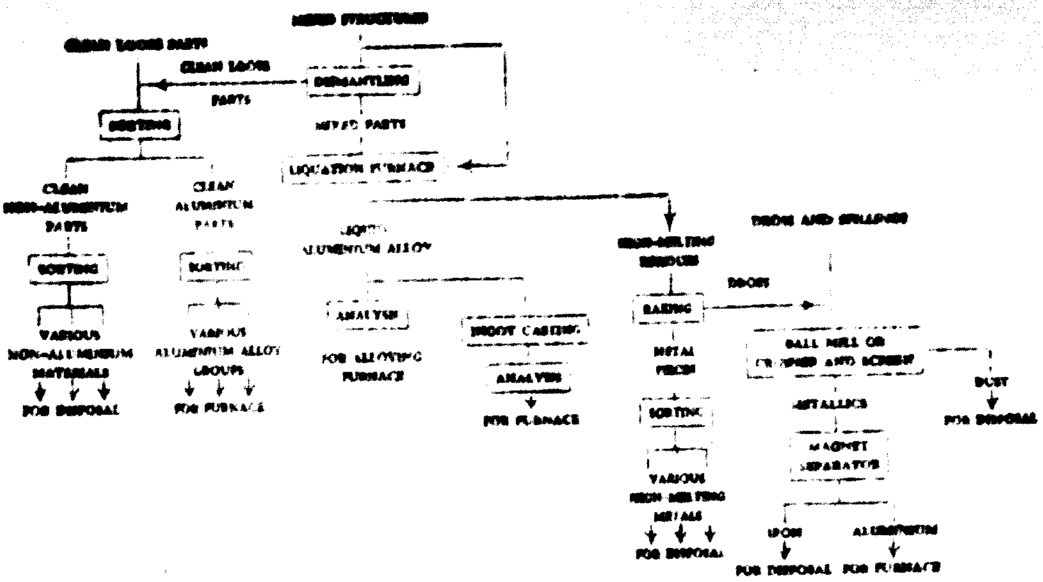
With careful selection, it is possible to make a saleable product directly, but generally the metal recovered is ingotted and subsequently used with other scrap to make saleable alloys.

Development of large swing hammer crushing machines in the last 10 years has made possible the cleaning of scrap which formerly would have had to be melted in the liquation furnace. These machines, powered by 200 - 350 kw. motors are capable of breaking up sheet scrap up to 3 mm. thick and castings up to

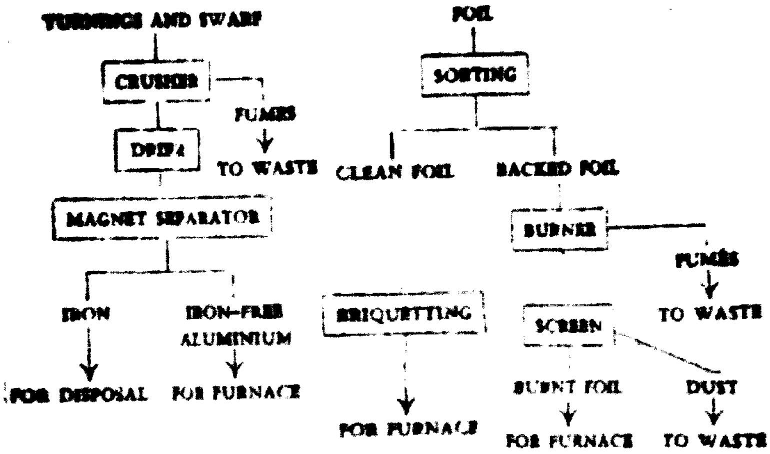
10 mm. thick into pieces approximately 50 mm. square. During the crushing process, paint, glass and plastics are broken into small pieces and can be removed by screening, and iron attachments can be separated from aluminium.

The crushed material is now suitable for treatment by magnetic separation and/or sink and float processes. Magnetic treatment is effective where iron is the only contaminant, but where copper, zinc, stainless steel or magnesium are present, the sink and float process, which separates according to density, must be used. The latter process was developed by the mining industry for mineral separation, by using suspensions of ground ferro silicon or galena in water, densities in the range 2.5 - 3.1 can be achieved. Thus heavy metals with densities greater than 3.1 and light metals or non-metals with densities less than 2.5 can be easily removed. The density can be controlled within a range of about 0.1, thus permitting separation of different aluminium alloys according to density, for example, alloys of high copper content, with densities about 2.9 can be easily separated from magnesium containing alloys of density about 2.5, or slightly less effectively from silicon containing alloys with densities of 2.6 - 2.7.

The swing hammer crushing machine and the sink and float process are both very high in capital cost and are only justified for large scale operations. Summaries of the operational sequences for the processing of aluminium scrap are shown below.



—Operational Sequence for Processing of Aluminium Scrap



—Operational Sequence for Processing of Aluminium Scrap.

4. MAIN TYPES OF FURNACES IN USE

The traditional melting furnace used in Europe has been the rotary furnace, with capacities ranging from 1 to 15 tons. The rotary furnace is typically a fully rotating furnace about a horizontal axis, which is charged at one end through an opening. In some designs the burner is positioned on a hinged door which covers this opening during the time the burner is in operation. In others the burner can be fitted at one end with charging at the other end. The scrap is melted under a thick flux cover by the direct flame of oil or gas burners.

Although these furnaces are still in use and completely satisfactory for certain materials, the open well furnace developed in the U.S.A. has become more popular. This is basically a reverberatory furnace with an open well extension at one end. These furnaces are currently in operation with capacities up to 60 tons. The use of flux for melting of light scrap in such furnaces is limited to the open well, but the metal bath must be first produced by melting heavy scrap or supplying liquid metal from other furnaces. The transfer of heat from the main part of the furnace to the well is achieved by movement of metal through the openings between the two parts of the furnace.

Another basic type of furnace is the coreless induction furnace, whose main advantage is the low melt loss, metal recoveries 4% higher than those of fuel fired furnaces are claimed. Generally the mains frequency type is used, with capacities up to 5 - 6 tons. Clean scrap is essential as flux treatment is undesirable, both for its effect on the furnace lining and fume extraction from the operating area. The use of these furnaces is limited because of the high capital cost, high power cost, relatively small size and the requirement for clean scrap.

Small furnaces of about ½ to 1 ton capacity of the same rotary type, which are stationary during melting, but can be tilted for casting, are suitable for the melting of relatively clean scrap, not requiring large quantities of flux.

These furnaces are oil or gas fired, with the flue in the roof or opposite end to the burner. Charging is carried out through a door in the side of the furnace.

For small scale operation, crucible furnaces of capacities up to 250 kg. can be used, but they are expensive to operate in respect of the cost of crucibles. The crucibles are usually of clay-graphite or bonded silicon carbide, and although resistant to molten aluminium, are rather fragile and can be easily damaged in the charging of heavy scrap or ingot. For melting of light scrap, a furnace similar to a concrete mixer, with a refractory lining. has been used with satisfactory results. This type of furnace is fired by an oil or gas burner through the top opening, and can be tilted for tapping. The choice of the type of melting furnace employed depends on factors such as quantity of production in respect of total weight and weight of individual alloys, extent of mechanisation and type of scrap to be melted. In general for large scale production, the well furnace, which lends itself to mechanical charging is preferred. The rotary furnace is probably better for dealing with low yield materials, e.g. metal recovered from dross. The problem of salt fume emission from the rotary furnace is worse than that of the well furnace as in the latter case, less flux is used and is only added to the well, where there is no direct flame impingement. Greater flexibility of operation is possible with the well furnace as fluxes can be added and spent fluxes removed during a melt. In the rotary furnace one flux bath may be used for one or more melts, depending on the cleanliness of the scrap being charged.

The agitation necessary for efficient scrap melting is provided in the rotary furnace by the rotating action, assisted by hand or mechanical raking. The stationary well furnace obviously requires more vigorous agitation to be supplied from external sources. There are some thermal currents, but mechanical stirring to promote transfer of hot metal to the well for scrap melting and to obtain uniformity of composition is essential. Originally hand raking or paddle type stirrers were used, but recent developments in metal pumps have led to improved methods of mixing. A method giving positive mixing is the pumping of metal over a wall built into the well, thus promoting circulation through the main bath.

Well furnaces can be readily adapted to some form of automatic temperature control by thermocouples inserted in the metal bath to avoid overheating of the metal or inserted in the brickwork to limit the refractory temperature to a safe working limit. Automatic temperature control of rotary furnaces is not practicable, but obviously there is less danger of overheating of the refractory lining as the furnace is rotated during the melting operation.

The refractory linings of both rotary and well furnaces are usually of brick construction. The bricks used in the part of the furnace in contact with molten aluminium contain at least 40% alumina.

In recent years, the study of new furnace designs has been undertaken to obtain rapid melting on a continuous basis, e.g. the shaft type furnace. Some furnaces are in successful operation for the melting of ingot or heavy scrap, but are not suitable for dealing with light scrap.

5. TECHNOLOGY OF MELTING

The problems encountered in the melting of aluminium scrap are essentially those of surface contamination. Aluminium in ingot form or in thick section scrap does not present any difficulty, but when it is contaminated with oil or paint, or in a finely divided form, it is necessary to use special techniques.

The surface of aluminium when exposed to air is always covered with a protective oxide film, thus for finely divided materials, with a high ratio of surface area to volume, considerably more oxide is present per unit weight than with thick section scrap. The oxide film is only about 10^{-5} mms. thick at atmospheric temperatures, but increases in thickness to about 10 times this value by heating in air or by reaction with moisture. The toughness of the oxide film is such that it is possible to melt fine aluminium within its own oxide film and the particles do not coalesce.

The oxide layer on the surface of a melt of aluminium can under unfavourable conditions contain fine droplets of aluminium which if further heated can oxidise rapidly to produce a rise in temperature and loss of aluminium. Aluminium oxide cannot be reduced to metal except in the electrolytic extraction process, and therefore metal which is oxidised cannot be recovered in normal melting operations.

The oxide present on aluminium at normal melting temperatures and below consists of light fluffy films of density lower than that of molten aluminium, but heating to higher temperatures converts this oxide to a denser type, with densities equal to or higher than that of molten aluminium. This dense oxide will be suspended in the melt or sink to the bottom, and as it is extremely hard, it is a source of harmful inclusions often found in castings.

Melting techniques for aluminium are therefore based on three main considerations:

1. Minimising the contact between scrap and flame when heating to the melting temperature.
2. The use of appropriate fluxes to exclude air and remove oxide.
3. Agitation of the bath to aid coalescence of metal globules.

The usual practice for melting scrap is to first melt a heel of flux into which the scrap is charged. The quantity of metal charged is controlled to allow rapid melting out of contact with air. Once a heel of metal has been formed, further and gradually increasing quantities of scrap can be added, ensuring that each batch is melted quickly and the temperature of the bath is not allowed to fall below the freezing point of the alloy.

The characteristics required in a flux are:

1. Melting point slightly higher than that of the metal to aid separation
2. Density lower than that of the metal.
3. Low viscosity.
4. Low surface tension.
5. Relatively low in cost.

These requirements are met by using flux essentially consisting of sodium chloride, sometimes with additions of potassium chloride to reduce the melting point, to which a fluoride is added

It was originally believed that for a flux to be efficient it should dissolve alumina, and for this reason fluxes always contained cryolite. Examination of spent fluxes or slags suggested that solution of alumina does not occur, and surface tension appeared to be the most important factor. Subsequent investigation of the mechanism of fluxing confirmed that surface tension was in fact the means by which oxide was separated from metallic aluminium. The alumina was found in the slag in the form of flakes, which were responsible for the high viscosity of the spent fluxes(5). Fluxes containing chlorides only were almost as effective as those containing fluorides, thus confirming that solution of alumina was not a significant factor. However, fluorides are added for their beneficial effect in reducing surface tension.

The major refining operation in the melting of aluminium scrap is the separation of oxide, but other refining operations may be required to remove unwanted elements. The only elements which can be removed by simple techniques are magnesium and minor elements such as sodium and calcium.

Magnesium can be removed by allowing the melt to oxidise, but this method is slow and results in a loss of aluminium at least 2 or 3 times that of the magnesium removed. Two methods are normally used, a) use of fluxes containing fluorides, b) chlorine gas. The flux method uses cryolite, sodium silico fluoride or aluminium fluoride as fluoride containing salts. These are added as the pure salt, or mixed with sodium and potassium chlorides to give a fluid flux. The efficiency of the flux is about 50% in all cases, for example, according to the equation $3Mg + 2AlF_3 \rightarrow 3MgF_2 + 2Al$, 2,1/3rd Kg of AlF_3 are required to remove 1 Kg of magnesium, but in practice 4 - 5 Kg would be required. The efficiency of removal falls off as the magnesium content is reduced.

Chlorine gas is very efficient for removal of magnesium, with efficiencies of near 100% at magnesium contents above about 1%, falling to about half of this value when the magnesium content is below 0.1%. The sodium and calcium contents are also reduced to very low values by chlorine treatment. Special precautions must be taken in the handling of chlorine gas and of the fumes emitted during the chlorination process.

The other impurity which can be removed by metallurgical treatment is hydrogen gas, which is the cause of gas porosity in aluminium castings. Hydrogen can be removed by degassing treatment using chlorine or nitrogen, or a mixture of the two gases. Organic compounds such as hexachlorethane, which liberates chlorine on heating can also be plunged into the melt to remove hydrogen. Allowing the melt to stand under a flux cover can reduce gas content if the furnace atmosphere does not contain water vapour or hydrogen, but this method is slow and more active degassing methods are normally used.

The melting temperatures of most commercial aluminium alloys lie in the range 650 - 560°C, and the melt temperature for casting ingot would normally be in the range 680 - 750°C. During the melting of scrap and the alloying of some elements, temperatures up to about 850°C are employed. The melting point of fluxes based on sodium chloride are around 800°C and this temperature must be exceeded to provide a heel of molten flux into which light scrap is charged to permit rapid melting.

For the production of hardener or master alloys, significantly higher temperatures may be required, in some cases up to 1,000°C or even higher. Temperatures in these high ranges are difficult to achieve in normal aluminium melting furnaces and hardeners which require high temperatures are usually made in special furnaces.

6. PROVISION OF FACILITIES FOR LABORATORY CONTROL

The size and type of the operation will determine the extent of the laboratory facilities which have to be provided. The smelter which melts scrap for conversion into ingot form but not of a specific alloy may operate without any facilities. Under these conditions there would be no control of composition and the product would be of low value. A small chemical laboratory capable of carrying out simple chemical spot tests for alloy identification and analysis to determine the composition of the remelted ingot would appear to be the minimum requirements.

The introduction of the compact types of the direct reading spectrograph has enabled laboratories with a staff of 2 or 3 only to carry out analysis for identification of scrap, control analysis during melting, for example to check magnesium content during magnesium removal treatment and to determine the final analysis of the melt. The spectrograph requires accurately analysed standards for calibration, but these can now be purchased from a number of sources to cover most alloy compositions.

The sampling of scrap and melting down of samples is often a laboratory function. For this purpose, the laboratory requires facilities for reduction of the sample to a suitable size, drying of wet and oily materials, magnetting to remove iron, and melting equipment to carry out assays on scrap such as swarf or dross metallics to determine yield and average composition. The technique used for melting scrap is similar to that used in production, but usually the flux consumption is higher in laboratory assays and the yield under carefully controlled conditions can be 1 - 5% higher than those achieved under production conditions.

Laboratory facilities of the larger secondary alloy producers cover a much wider range of activities. In addition to the direct reading spectrograph, the laboratory would include a wet chemical section for provision of calibrated standards and also check analysis as required by government inspection organisations. Other analysis may be required for determination of oxide content, unusual impurity elements, composition of fluxes, fuels and effluents.

The metallurgical section controls the quality of the ingot in respect of oxide content, gas content, grain size and other special requirements. The official specifications for some alloys require mechanical tests to be carried out on test bars produced from the ingot melt or from the remelted ingots when shaped castings are to be made. The ingot maker must therefore satisfy himself that the ingot which he supplies will meet the specified values. This requires facilities for the casting of test bars, and for tensile testing. In addition, a service to customers may be provided which would include metallographic examination of castings, and non-destructive tests to determine the cause of defects and to suggest means of avoiding these faults. The provision of melting furnaces similar to those in the customers' foundries allows the ingot maker to investigate melting techniques and also to make castings in moulds or dies provided by the customer, to establish procedures for the production of difficult castings.

It is necessary to stress the importance of correct sampling to ensure that the sample analysed or examined represents the batch of material from which it is taken. Methods of sampling of scrap are given in a recently published booklet published by O.E.A. (6). The sampling of melts and method of preparing the actual analysis sample from the cast sample is described in a number of official specifications, e.g. those issued by the B.S.I. (7) or A.S.T.M. (8)

7. AUXILIARY EQUIPMENT

The plant and equipment required in a secondary smelter has been partly described in discussing the treatment of scrap and in types of melting furnace. One important item not yet considered is the equipment for ingot casting.

Ingot casting was one of the last arduous tasks to be mechanised in most works. The main reason for this was the slightly poorer appearance of ingot cast in mechanised units. Customers attached some importance to the surface appearance of ingot, although it is debatable whether the inherent quality of the metal is related to a superficial visual inspection. The use of mechanical casting conveyors has been retarded by the difficult design requirements necessary to effect suitable casting rates, especially in countries where foundries demand small ingots of 5 - 10 kg. as compared with those countries such as the U.S.A. where ingots of 15 - 26 kg. are acceptable.

For small scale production, simple cast iron moulds, which are air cooled, would be suitable for hand casting. When mechanised casting is employed, water cooled moulds are required. There are two basic types of casting conveyors, one with an endless belt with moulds either parallel or at right angles to the conveyor axis, or a horizontal wheel casting machine which takes less room. Ingot moulds on the endless belt conveyor are usually cooled by water spray, in the wheel casting machine, water jacketed moulds can be used.

It is now common practice to stack ingots into bundles secured by steel wires or banding to facilitate handling. The shape of ingot is sometimes designed to provide self locking, thus making a firmer and safer bundle.

The introduction of the fork lift truck has increased the degree of mechanisation, and the use of rotating head trucks with simple bins, or drop bottom bins, has reduced material handling considerably.

Some degree of instrumentation is necessary in the simplest operation, for example for measurement of temperature. This is usually measured by a thermoelectric pyrometer, using a thermocouple connected to the instrument by compensating lead. Chromel-alumel thermocouples are almost universally used. An unprotected hot junction can be used for short immersion, but for continuous immersion some form of protection is required. This can be a cast iron sheath protected by a refractory coating, or a non-metallic sheath.

Foundry tools such as rakes, skimmers, hand ladles, are usually constructed of mild steel, but as molten aluminium attacks steel fairly rapidly, some protection is necessary, and refractory coatings are applied. It is essential to apply coatings carefully to ensure satisfactory adhesion and to repair damaged coatings immediately

Launders for the conveyance of molten aluminium are usually of mild steel construction with a refractory lining. When using water based refractory coatings, or cements and lining materials which contain water, it is important to dry the equipment thoroughly before use. Heating to 100°C is not sufficient and it is necessary to heat to at least dull red heat to ensure that the 'combined' water is driven off.

It is preferable to keep scrap dry when it has been processed ready for charging into the furnace. In some countries climatic conditions will permit outside storage, but in others it may be preferable to provide covered storage space for prepared scrap and finished ingot. For a simple remelt operation only sufficient storage space is required for a few days operation, but when ingots to specific alloy compositions are to be produced, much greater storage area would be required to allow stocks to be maintained, thus permitting blending of different types of scrap to produce the required composition.

8. USER REQUIREMENTS - ALLOY COMPOSITIONS AND INGOT SHAPES

In foundry alloys the most common elements added to aluminium are silicon (5-12%) in order to improve casting properties, copper (0-4%) which increases hardness and improves machining properties. Magnesium (0-1.5%) is added as a hardening constituent but heat treatment is required before the benefits of maximum mechanical properties can be attained. Other elements may be added in small quantities such as sodium, titanium and boron to refine the metallurgical structure. Special purpose alloys have been developed with elements outside these ranges or with other additions such as the "Lo-Ex" group for pistons with typically 12% silicon and 1% each of copper, magnesium and nickel where a low coefficient thermal expansion and stable properties at moderately elevated temperatures are the most desired characteristics.

There is a natural tendency for customers and agencies which establish standard specifications to propose new alloys to suit individual requirements. It is therefore of some importance that published standards should have fairly wide composition limits consistent with the characteristics of an individual alloy to accommodate the largest range of applications so that production can be rationalised and the maximum use made of scrap raw materials. Some specifications required in limited quantities are inevitable but price structure, especially for alloys having closer tolerances within a specification, do not always allow for the recovery of the additional costs which are incurred for their production.

Selection of an alloy for a given application should be based on the consideration of the following factors :-

(a) Engineering requirements such as mechanical strength, ease of machining, resistance to corrosion.

(b) The method of casting which itself is a function of the component design and the scale of production envisaged. Sand casting for low volume work and prototypes, permanent mould casting mainly for medium volume, high strength production and pressure die casting for mass produced components.

(c) Casting properties form the important criterion of the proportion of sound castings which can be produced under normal factory conditions. It is sometimes impractical to choose an alloy which meets other requirements, is suitable for making the casting under controlled conditions but develops faults in the foundry.

Usually there is no ideal alloy for any single case and a compromise solution must be accepted.

The alloy most generally used for general engineering applications is aluminium with 5-7% silicon and 3-4% copper. It combines moderate strength, good casting properties and for many applications can tolerate impurity levels which allow the use of scrap. Where both high strength and high ductility are required, alloys which tend to have poorer casting properties must be used such as aluminium with 8-10% magnesium or aluminium with 5% copper. For resistance to corrosion, alloys of aluminium/silicon or aluminium/magnesium with low impurity levels are recommended.

The number of alloys suitable for pressure diecasting is restricted to those with silicon contents of 8-13%. Patterns of solidification which are characteristic of more complex alloys or those which are not so near to eutectic compositions prevent the use of rigid moulds. The wider the temperature range during which solidification occurs, the more likely is hot cracking or some other fault to develop, especially when the casting has sections of varying thickness.

Foundry alloys are delivered to the customer in several ingot sizes. From the producers point of view, the larger the ingot size, the lower will be the production cost because both ingot casting and bundling can be more readily mechanised and the actual rate of casting, an important factor in determining furnace capacity, can be increased. The foundry, on the other hand, remelts ingots either in a bulk melter or in small crucible or holding furnaces next to the casting station. Ingot size is not so critical if bulk remelting facilities are available, but for small furnaces large ingots are liable to cause damage to wall linings, so small ingots (about 5 to 10 kilos) are preferred.

Much attention has been paid to ingot shapes to enable stable self palletised bundles to be developed. Bundles of 500 or 1,000 kilos are most common and should be made suitable for handling by fork lift trucks. If melting is carried out, possibly at a subsidiary plant or at a distant site where bulky scrap has to be moved, in order to condense the scrap to ingot form for ease of handling. smelters will always find it more convenient and worth a premium, if ingots are supplied in pallets or in bundles suitable for mechanical handling. Sometimes remelt metal is cast into large sows of 500 to 900 kilos each. These blocks are then only suitable for re-use in furnaces where door sizes are large enough to accommodate them.

Techniques have been developed between some of the larger foundries and their main supplier for deliveries of molten metal even over fairly long distances - the critical factor being the transit time. This system of delivery has to be justifiable for each individual case with a minimum quantity and the availability of suitable facilities. It saves the alloy producer the cost of ingot casting which is more expensive and slower than transferring molten metal to a ladle. However, furnaces may be tied to peak requirements for despatches to meet difficult delivery times and may not be used to full capacity, thus increasing smelting cost. Most of the operating advantages accrue to the customer.

9. ECONOMIC ASPECTS OF ALUMINIUM ALLOY PRODUCTION

The aluminium alloy producers use as raw materials mainly scrap and alloying elements and are exposed to the economic law of supply and demand. In times of a scrap shortage the price tendency for aluminium alloys is upwards, during periods of abundance a weak market develops for alloy ingots.

A shortage can either be overcome by using virgin metal at a higher price, thus putting a ceiling on the price for scrap, always provided that sufficient virgin metal is available. Alternatively, scrap can be attracted from areas where it is more freely available but this frequently results in the payment of substantial premium due to additional freight or to different market criteria. In either case, and usually it is a combination of both of these factors, the results must be a firm market price.

Conditions for the remelt sector of the aluminium industry are very different from those in the virgin aluminium industry. Virgin production is based on long term planning and is therefore less exposed to pressures of supply and demand. Bauxite, the basic raw material, is available in abundance and the cost can be based on logistics. Transport costs to market areas, costs of electricity and labour, together with the servicing of the capital investment will determine the cost of virgin aluminium If the continuing trend for increases in direct costs are assumed at say 3 to 4% per annum, a reasonable estimate of price can be determined for a substantial time ahead. The variable factor which can unduly influence the price is therefore the sales volume, which depends for growth on the economic cycles in the major industrial countries. The market price for virgin aluminium is dependent on the overall demand on a world wide basis.

Management and planning required in the remelting industry are, however, very different. The raw materials price cannot be calculated or projected for long periods and this creates two major variables in the costing of products. A fair price must be offered for scrap so as to attract the maximum quantities available and maintain an incentive for its collection and accumulation. Old scrap can be very costly to collect and transport. The price for alloy ingots should, however, be sufficiently attractive to be competitive with other materials such as cast iron, zinc and, increasingly, plastics. Although ingot prices cannot be related to the published producer price of virgin aluminium, the industry has nevertheless been able to offer its products at 5% to 20% below this price over the long term except during the rare periods of metal shortage.

Because of the interdependence between scrap and virgin aluminium there has been a tendency for some virgin aluminium producers to either participate in or control substantial units of the foundry alloy industry. The marketing of virgin aluminium alloys is made more difficult without considering the price level of our industry. Aluminium produced from virgin metal and recovered metal compete in the market and can therefore not have independent price policies. This assumes that products of acceptable quality are offered to the consumer by branches. It has been established and is now widely accepted that most aluminium foundry alloys produced from scrap have equal properties to alloys with the same composition produced from new metals.

In areas where insufficient scrap is generated to sustain a smelting unit to produce alloys to specification an industrial operation can be developed through a number of stages. First, scrap sorting for despatch to the nearest existing smelting unit. Second, set up a very simple melting furnace to reduce the bulk of the scrap and the resulting rough ingots can be sent over a longer distance to a larger smelter where they can be upgraded by being incorporated in melts of specification alloys. The capacity of this type of operation should be of the order of 1,000 tons per annum. The next stage would be an operation with a minimum throughput of 3,000 tons per annum, where in addition to the furnace, basic swarf drying equipment, a small baling press and some mechanical handling could be introduced. A basic laboratory would be needed for analytical work but added costs can be recovered through the higher value of the end product as a result of upgrading. To justify 'in-line' processing and a full technical service both for quality control, operational improvement and customer service, it would be necessary to allow for a minimum 10,000 tons per annum. The capital requirements for setting up these various stages can vary from about £20 per ton of annual installed capacity up to £100 per ton, depending mainly on the size of output and quality of product planned.

At 1,000 tons per year the basic requirements include a simple building, a small furnace and chimney, ingot moulds, and fuel supply facilities. This operation would undoubtedly be labour intensive. At the other end of the scale, £100 per ton permits 'in-line' processing, mechanical handling - both cranes and fork trucks - a variety of furnaces for different types of material, and comprehensive laboratory facilities to maintain the highest quality and service for sophisticated customers.

One way of providing more advanced facilities where only limited possibilities exist, is to design an operation to cater for other non-ferrous metals such as copper, zinc, lead. Many of the techniques for sorting are the same and equipment for processing can easily be adapted to the various metals. For example, balers and mechanical handling equipment are common, swarf driers can be set for the material currently available. Furnaces and their operation are somewhat more limited in flexibility due to the different melting points of the metals and the risks of contamination by consecutive melts.

10. SUMMARY

This review of the aluminium scrap smelting industry has dealt with the problems of raw material supply, its sources and its makeup. Methods of preparation have been described to show how scrap can be upgraded for inclusion in alloys with higher values than remelt grades of aluminium and which provide uniform charges for furnaces to achieve maximum productivity. The various furnaces in current use have been shown and the metallurgical aspects of melting and alloying described.

Reccommendations have been made for the disposition of scrap depending on the volume of arisings and the scale of operations planned. Although quantities mentioned are in respect of aluminium scrap it is suggested that some facilities can be designed for treating other non-ferrous metals so that more advanced equipment can be justified where the arisings of aluminium alone are insufficient. Similarly, part preparation of scrap in a number of areas followed by transportation to one smelting unit may be desirable in less industrialised countries and if there is only a small market for foundry alloys, rough remelt ingot may be the most suitable products to sell to other countries for incorporating into a variety of higher value ingots. For quantities of less than 500 tons per annum, direct sale to the best market should be encouraged.

The size and scope of the industry in developing countries will grow in line with general industrial development but will be particularly dependent on the usage and manufacture of such articles as consumer durable goods, aluminium components in modern buildings and aluminium based electrical transmission equipment. The increase in scrap generation will be gradual and will limit the size of the scrap smelting industry.

As foundries are established to meet the demands for aluminium alloy castings the output of smelters will change from simple remelt ingots for subsequent processing and alloying in the early stages to alloy ingots made to standard specifications requiring close control and employing most up to date techniques.

The number and size of individual plants will depend on the geographical distribution of industrial concentrations; smaller and more numerous operations will be desirable if distances between centres are great a few large factories will be more viable if they are close to each other.

The furnaces, material handling and processing equipment, production techniques and laboratory control mentioned in this paper have all been developed in Europe and the U.S.A. to meet operating and commercial requirements in these areas. For new plants in countries where they would be entirely new ventures, local conditions may present opportunities and problems which could well lead to modifications and improvements in existing practices. Circumstances are continually changing as are the types of scrap available. It is therefore important that any installation should be capable of adaptation to suit the widest range of demands which may be made.

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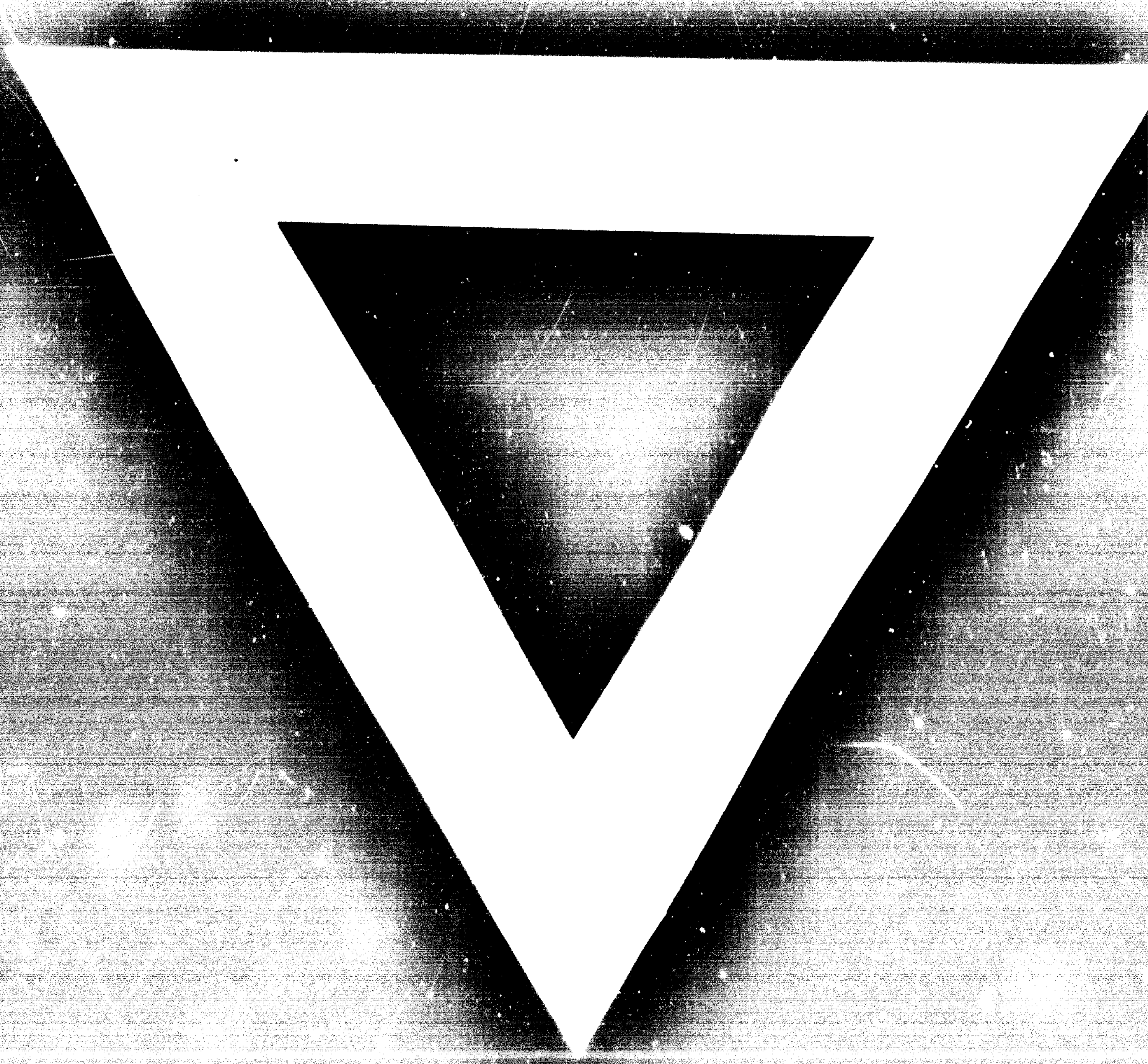

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