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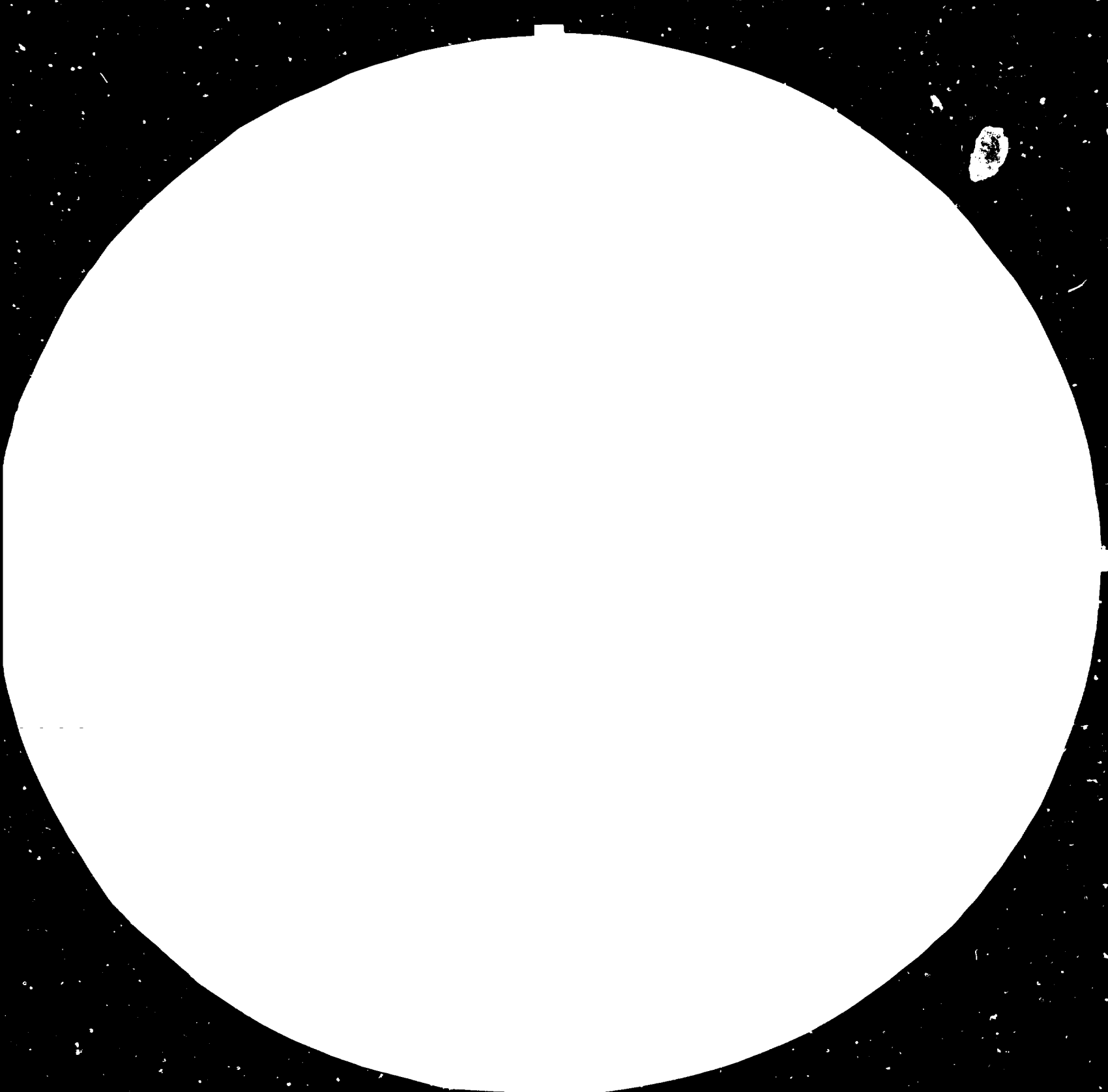
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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

Advances in Materials Technology: MONITOR

Issue Number 1

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November 1983

Dear Reader,

Materials are an important element in the industrialization process, both as inputs and outputs. Rapid developments are taking place both in the production and use of existing materials and in the development of new materials. However, no systematic monitoring of developments in the field of materials, particularly in regard to their potential and implications for developing countries has been made till now.

As part of its programme on technological advances, the UNIDO secretariat is examining the potential and implications of several advances for developing countries. A beginning has been made in regard to advances in the field of materials. The International Forum on Technological Advances and Development, held at Tbilisi, Union of Soviet Socialist Republics, in April 1983, recommended the periodical dissemination of information on materials for the benefit of the developing countries.

In response to this, a state-of-the-art series in the field of materials has been initiated called Advances in Materials Technology: Monitor. This Monitor is addressed to a select target audience of policy makers, scientists, technologists and industry in developing countries. In each issue a selected material or group of materials will be taken and an expert assessment made on the technology trends in that field. In addition, other relevant information of interest to developing countries in that field will be provided. In this manner, over a cycle of several issues, all different materials relevant to developing countries could be covered and a state-of-the-art assessment hopefully may be available in each field, say once in two years.

The series is designed to be issued four times a year. In the nature of things, it is an experiment, and it is proposed to keep the format and content under review, based on the suggestions of readers, particularly from developing countries. It is hoped that the information provided will serve the particular needs of the developing countries.

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P.O. Box 300, A-1400 Vienna, Austria

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The UNIDO secretariat would welcome the provision of information on different types of materials, particularly from institutions in developing countries.

The present issue, which is the first of the series, is devoted to the subject of steel. It deals in particular with high strength, low alloy (HSLA) steels. The main feature of the issue is a special article by Michael Korchynsky, Director of Alloy Development in the Metals Division of Union Carbide Corporation. The rest of the issue is devoted to information on alloy steels, their production, application, the minerals from which they are made, and developments in these fields of particular relevance for developing countries. In addition, some information in the nature of current awareness in regard to steel and related materials has been included.

G.S. Gouri
Director
Division for Industrial Studies

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Advances in materials and developing countries *

New materials and process technologies are liable to alter radically the global industrial scene, sooner rather than later. They will have an impact on the economies of all countries, varying in magnitude according to the level of production, use and trade of each. They largely determine the comparative economic advantage of countries in regard to particular industrial sectors. Once such an industrial structure is established in a country, it is often difficult and costly to change. Therefore, before developing countries embark on a major industrial programme it is essential that the effects of possible new materials and process technology be considered.

Owing to the diversity of materials and developing country conditions, a selective approach needs to be adopted. Each country will have to identify specific materials and the criteria on the basis of which policy action should be taken.

The criteria would cover and be guided by such factors as the country's imports and exports, the possible local use of substitute materials, the energy implications of the new materials and the local conditions, skills and facilities to use them.

The central role that materials play in industrial and economic development is such that all countries would benefit from the formulation and adoption of a comprehensive materials policy. The development of such a policy is, however, a very difficult task. Some developed countries have attempted to formulate national materials policies but these have only been partially successful. The position for developing countries is even more difficult for the following reasons: there are a large number of materials and composites in use; the substitution of materials is a techno-economic consideration in the hands of different enterprises; different materials are critical for different countries for import or export reasons; materials is a dynamic field.

One area of direct policy action open to all developing countries concerns the specification and purchase of materials by the public sector. Many construction programmes in the developing countries are wholly or partially under the control of national or local government. This could provide an effective instrument for the introduction of at least some elements of a materials policy.

Another area worthy of strong policy support is composite materials. This class of materials maximizes, through the use of modern technology, the value of low cost, locally available resources. Composites, in their many different forms, have a very wide range of applications in developing countries in virtually all economic sectors and will reduce the need for imported materials.

Many new materials are still in the early stages of development but it is already clear that some will have major impacts on the market for traditional materials. It is, therefore, essential that developing countries monitor and assess these new developments. This will require as a first step some form of materials information system. The next and most critical stage would be the evaluation and incorporation of this information in government policy making which would require a multidisciplinary team, including material technologists, economists and information specialists. Finally, for the effective implementation of policies on new materials, there will be a need for a wide understanding of the subject throughout all economic sectors, which will require specially designed awareness programmes.

Materials science is now a recognized discipline and developing countries should examine the need for strengthening their institutions in this field both at the national and the international level. The area of materials is so wide that each country will of necessity tend to be selective in carrying out research and development. Therefore co-operation between materials science laboratories in both the developed and developing countries would give access to information on a wide range of new materials. In this connection research and development on new materials and technology should not be restricted to a narrow specialist field of study but should have a wide orientation including techno-economic considerations, and design and manufacturing aspects. This would allow the advances in materials science to be readily translated into new policies and products.

The elements of a selective materials policy would include mining and mineral laws, land use regulations, environmental regulations, import/export regulations including tariffs, investment and tax laws, patent laws, national programmes of technical education and training, and research and development.

* This section is excerpted from an article by Gamini Seneviratne, which appeared in Development Forum, Business Edition, Number 131, 31 July 1983, and from UNIDO documents ID/WG.384/1/Rev.1 and ID/WG.389/6.

The field of materials

The field of materials and the related technologies is a wide one. Firstly, there are existing materials and new materials used for making existing and new products. New technologies are also involved in the production of existing or new materials. The technological aspects extend from exploration, production and primary processing of material to its application and use in making a final product and its possible recycling for secondary use.

HSLA steels in perspective *

In the developed world, the steel industry is in a state of flux. In the United States and Western Europe it appears to be characterized by over-production, plant closures and lay-offs. But this is not regarded as a sign of steel's role becoming obsolete, rather that it is undergoing changes in balance. Steel remains an essential material in which demand will exceed supply for a very long time. In fact, some 65 countries - led by Algeria and Egypt; Saudi Arabia; Argentina, Brazil, Colombia, Mexico and Venezuela; Bangladesh and India; and Australia and New Zealand, in the different regions - are building up steel industries as essential sectors of their industrialization programmes. This, however, is an extremely expensive, capital-intensive exercise.

Each annual ton of capacity requires an investment of \$600 to \$1,000, or, for a million-tons-a-year plant, possibly \$1 billion. The returns on this capital outlay are slow. A case in point may be China, which, in its drive to modernize, plans to be fully industrialized by the year 2000. At the same time, its steel capacity is not expected to increase by more than 2.5 million tons a year during the next five years.

New plant construction has to be stretched out because of the expense. The HSLAs could ease the growing pains. The new steels are obtained by the addition of certain micro-elements, often in tiny quantities, at the initial stage of production. Conventionally, the smelting and hot-rolling process, which produced low-grade steel, was concerned with turning the semi-finished block of steel into required dimensions. Higher tensile strength had to be obtained by substantial additions of alloys. Improvements in ductility, toughness, formability and weldability required further processing.

The micro additives enhance all these qualities to varying degrees at the first stage. Most importantly, they increase tensile strength two to three times. There are three of these micro alloy additives - vanadium, niobium and titanium. They need to be added - 'literally thrown into the smelting pot, like pepper and salt into soup', according to Michael Korchynsky (author of the special article in this issue) - in percentages as low as 0.02 of the steel produced.

The cost-advantage equations vary with the end product but they are clear from the first stage on. The additional cost is often no more than the price of the additive. For example, the price of a ton of steel today is about \$300. The extra material needed to upgrade that ton would be between \$5 and \$10, and the producer could expect to sell it for \$312-315, while the purchaser would need perhaps 30 per cent less (weight) of it because of its higher tensile strength.

The basic advantages are carried on, often enhanced, down the line of steel production and use. At the end of the day, the country has in effect increased its steel production by, say, 30 per cent, without building any new plant.

In a paper, "Some significant advances in materials technology", by Edward Epreman (UNIDO/ID/WG/384/10), the implications of HSLA steels for developing countries are defined as follows:

- A new segment of the steel industry with high potential for growth.
- A class of products that have higher value than the plain carbon grades they replace, but at the same time are more cost-effective in service.

* This section is excerpted from an article by Gamini Seneviratne, which appeared in Development Forum, Business Edition, Number 131, 31 July 1983.

- HSLA steels are more consistent with materials conservation; service is performed in applications using less material.
- HSLA steels are more consistent with energy conservation.
- Production requires a deeper understanding of metallurgical principles and tighter control of production practices.
- As a higher-value product, HSLA steels represent a better use of the investment in steelmaking facilities than carbon grades.
- Some plants may require additional equipment for producing HSLA steels.
- Full and proper use of HSLA steels in industrial applications requires that designers be well informed about the properties and characteristics of these steels.

Some possible activities to foster the production and use of HSLA steels in developing countries would be the following:

- Workshops on the theory and practice of HSLA steels for steel production engineers and metallurgists;
- Preparation of data books and manuals on the use of HSLA steels for designers;
- Visits to plants where HSLA steels are produced;
- Working fellowships for professionals to spend an extended period of time at plants where HSLA steels are produced;
- Stimulate or possibly subsidize attendance at professional society conferences on HSLA steels.
- Loans to assist in the necessary modifications of steelmaking equipment.

Special article on HSLA steels

Introductory note by the UNIDO Technology Programme

In this paper, prepared by M. Korchynsky, for Advances in Materials Technology: Monitor, the importance of steels as an engineering material is stressed. Despite many new materials, per capita steel consumption is still the yardstick of the economic development of a region. Values range from 500-700 kg for highly industrialized countries to 15-40 kg for developing nations. Development of a domestic steel industry is sought by many nations, but costs can be a tremendous burden. HSLA steels can help in this case by increasing the effectiveness of existing or planned capacity.

Korchynsky lists the advantages of HSLA over carbon steels in detail; i.e. higher strength coupled with higher toughness, better low temperature properties and good weldability.

Increased energy costs have made heat treatment - another method to achieve similar properties - in many cases uneconomical. The search for ways to achieve weight reduction of steel components to conserve energy has intensified. Increased yield for existing steelmaking capacity is also an important bonus.

He explains why minute additions of vanadium, niobium and titanium (or their combination) lead to such excellent property improvements. The strengthening mechanism is by precipitation of carbides and/or nitrides of these elements, resulting in precipitation strengthening and a very fine ferrite grain structure.

Hot rolling practice can have an important effect on properties, depending on the alloying element used. In general the vanadium steels are less sensitive, for niobium steels a special hot rolling practice might be required. Cooling from hot rolling temperature to 600° C is beneficial.

The different alloying elements and their effects and applications are discussed in detail.

Titanium must be added to fully killed (deoxidized) steel, it can combine with sulphur (i.e. increases the tolerance for sulphur), but requires a low nitrogen content which is a problem with electric arc steels.

Strengthening is by titanium carbides, for vanadium by nitrides. The latter element makes the steel non-aging and is particularly useful for electric arc steels without special secondary refining treatment. For niobium the strengthening is with carbides, these steels show an aging tendency if higher nitrogen levels are present. Details about production technology, alloy addition, casting and rolling practices are given.

For the production of high strength weldable concrete reinforcing bars, particularly vanadium or vanadium-nitrogen HSLA steels are recommended as no changes in melting, processing, casting and hot rolling practices - as used for carbon steels - are required. The non-aging effect is beneficial for earthquake areas. This also holds true for the production of other long products like flats, angles and structural shapes.

For the production of sheets continuous hot strip mills are required to fully take advantage of the HSLA as-hot-rolled properties. To process HSLA steel, the mills need accelerated cooling on the run out table and some method of maintaining the coiling temperature of 600° C for optimum precipitation (coil box).

Plate can be produced by conventional carbon steel practices with vanadium and vanadium-nitrogen HSLA steels. If better low temperature toughness is required, then controlled rolling of niobium-containing steels is necessary. This method requires considerably higher mill loads which are only possible on modern plate mills. In the future controlled cooling could be substituted instead, if the problem of maintaining flatness can be overcome.

Korchynsky discusses a problem arising specifically with HSLA plate and sheet. Segregation of non-metallic inclusions, particularly sulphides, result in directionality of mechanical properties and are particularly deleterious to impact values and bending properties. With continuous casting, this problem is solved by increasing steel quality through secondary refining (see references 1 and 2). With ingot casting, inclusion shape control is possible by adding rare earth elements, zirconium or titanium, usually into the ingot mould.

For developing countries Korchynsky gives the following advantages for the production of HSLA steels.

1. More effective utilization of existing equipment capacity;
2. Production without licensing requirements;
3. Added value for production;
4. Upgrading of engineering standard in the country;
5. Production of HSLA steels to substitute for costly imports of heat-treated alloy steels;
6. Improved competitive stance in export markets.

He stresses the point, however, that it is not sufficient for a country to simply produce HSLA steels; users have to be made aware of their improved properties so that full advantage can be taken of their benefits.

For countries with standard carbon steel facilities, particularly also mini-mills with electric furnaces and continuous casting plants, his recommendation is to start with the production of vanadium HSLA concrete-reinforcing bars, followed by other long products. The switch from carbon steel can be made immediately and no change in production practices are necessary. To guarantee uniformity in properties, good control of analysis, microstructure and rolling practices is required.

For countries with hot strip mills, a controlled cooling system, exact control of the coiling temperature as well as some form of inclusion shape control is required.

High strength low alloy steels
by Michael Korochynsky *

Summary

High strength, low alloy (HSLA) steels comprise a new class of engineering materials. They are low-carbon steels modified with a small (usually less than 0.10 per cent) addition of one of the following elements: vanadium, niobium, or titanium.

Compared to common carbon steels, the HSLA steels exhibit a two to three times higher yield strength, ranging from 300 to 500 MPa. In addition to strength, the new steels exhibit an attractive balance of engineering properties, such as ductility, toughness, and weldability.

While the properties of HSLA steels approach those of much more expensive heat-treated alloy steels, their cost is only slightly higher than the cost of plain carbon steel. The cost-effectiveness of HSLA steels is due to the low-alloy content, frequently referred to as microalloying. Furthermore, all the properties are developed in the course of hot-rolling, eliminating the need for costly heat-treatment.

Both steel producers and steel users derive benefits from HSLA steels. For the user, the higher strength allows a significant weight reduction which more than offsets the slightly higher cost of HSLA steels, compared to carbon steels. Lower weight offers additional benefits, such as higher payloads, lower transportation cost, etc. The low carbon content of these steels accounts for the ease of fabrication by cold forming and welding.

For the steel producer, HSLA steels represent an added value product, contributing to better profitability. Of particular importance is the fact that through the use of HSLA steels, the weight of machinery and engineering structures can be substantially reduced by 10 to 25 per cent. Because of that, the existing steelmaking capacity can be utilized more effectively reducing thus the pressure for additional capital-intensive expansions of facilities.

Many aspects of the technology of HSLA steel production can be easily adopted to existing facilities, without changing steelmaking, casting, and rolling practices. The microalloying additions: vanadium, niobium, or titanium are in plentiful supply and readily available throughout the world.

Because of the unique cost-effectiveness of their properties, the HSLA steels are replacing not only the more costly heat-treated alloy steels, but also the less costly (on the per ton basis) plain carbon steels. This accounts for the continual growth of the production and usage of HSLA steels. The economic benefits accruing from a broad use of HSLA steels are of importance for both the industrialized as well as developing countries.

Importance of steel

Availability of engineering materials is an essential ingredient for providing a basis for economic and industrial development. Among the large family of engineering materials, steel was, is, and will remain in the foreseeable future the key member.

There are many reasons for steel to occupy the dominant position:

- Iron ore is abundant and readily available around the globe;
- Once the steelmaking facilities have been established, the resulting product is relatively inexpensive;
- And, finally, steel exhibits unique versatility, offering a wide spectrum of properties to satisfy an endless variety of engineering requirements.

It is not surprising, therefore, that we continue to live in the "iron age", in spite of many new materials being made available. In fact, the amount of steel produced or consumed annually per capita is a sensitive yardstick by which to rate the level of economic development in a given region. (1)

During the past quarter of a century, the average consumption of steel in the world increased from about 75 to 180 kg/capita. But the average consumption can be very misleading: in highly industrialized countries, like Canada, Japan, the Soviet Union, Sweden and the United States of America, this figure ranges from 500 to 700 kg/capita. By contrast,

* Director, Alloy Development, Union Carbide Corporation, Metals Division, Robinson Plaza II, Route 60, Pittsburgh, Pennsylvania, 15205, United States of America.

in the developing countries, exemplified by China, Columbia, Egypt, India, Nigeria or Peru, the per capita steel consumption is as low as 15 to 40 kg.

It is not surprising, therefore, that development of a viable domestic steel industry is one of the highest priorities among developing nations. As an example, great successes in building a domestic steel industry have been achieved in Mexico and Venezuela, in India, Hong Kong, Singapore and Indonesia, in Saudi Arabia and Egypt.

Efforts to expand the steelmaking capacity are accompanied by very heavy capital expenditures. It is estimated that each annual ton of steel may require an investment in excess of US\$ 1,000.

Classes of steel

Among a broad variety of steel grades, a new class of engineering steels has emerged during the past two decades. These new steels, called high strength, low alloy (HSLA) steels, or "microalloyed" steels, have captured the imagination of metallurgists and engineers all over the world.

These new steels:

- Have attracted a large amount of research and development efforts, as attested by numerous publications, monographs, symposia, and conferences;
- Continue to show one of the highest growth rates, compared to traditional steels, and an expanding sphere of applications;
- Have contributed to a material revolution in the fully mature automotive industry.

To appreciate the impact of HSLA steels on design and application of steel, one has to compare them with more traditional grades of steels.

The most common variety of steel, representing the largest tonnage, is the carbon steels, i.e. alloys of iron and carbon.

They are generally used in as-hot-rolled condition, i.e., without any further processing or heat-treatment.

The strength of these steels depends on their carbon content: the higher the carbon content, the higher the strength. Strengthening of steel by means of carbon addition is the cheapest, most economical way of increasing the yield and tensile strength properties.

High strength, however, though desirable, is only one of many properties required of an engineering material.

In addition to strength, the steel must have good ductility to facilitate fabrication by bending or cold forming. It must be resistant to impact or shock loading by having high toughness, especially at low temperatures. Since joining by welding involves melting and rapid cooling, the steel must exhibit good weldability and retain its original properties.

Unfortunately, these important engineering properties: ductility, toughness, and weldability, deteriorate rapidly as the carbon content of the steel is increased.

Consequently, to maintain a balanced combination of properties, the carbon content, and thus the strength of steel, must be reduced.

The problem, inherent in as-hot-rolled carbon steels, can be overcome by heat-treatment such as quenching and tempering. For the quenching operating to be effective, however, the alloy content of the steel has to be increased by the addition of such elements as chromium, nickel, molybdenum, or others. Heat-treated alloy steels are capable of combining high strength with other desirable engineering properties. This well balanced combination of properties, however, contributes to a serious economic penalty: (a) cost of expensive alloying additions, and (b) cost of heat-treating.

The newly developed high strength, low alloy steels seem to combine the best of the two worlds, represented by the above two classes of steels: excellent balance of engineering properties, expected from costly heat-treated alloy steels, combined with the low cost, typical of carbon steels.

This unique combination of properties is achieved by modifying the common hot-rolled carbon steel by means of small additions of one of the three elements: vanadium, niobium, or titanium. (2)

Since the addition of one (or a combination) of these three elements is usually less than one tenth of one per cent, the term microalloying is frequently applied to this class of steels.

The unique set of properties present in HSLA steels is not the only factor accounting for their speedy acceptance and rapid growth rate during the past decade. They arrived on the scene at the right time, satisfying the most urgent needs of the engineering community.

During the recent past, the world experienced the shock of major increases in the cost of energy. At the same time, the growing demand for raw materials, especially minerals, made them far less available and more expensive.

Both these occurrences increased the cost of heat-treated alloy steels and made their use economically unattractive.

At the same time, there was a growing awareness of the necessity to reduce the weight of products made of steel. Weight reduction was essential in mobile equipment, to reduce the energy consumption. Compared to low-density materials (aluminum, plastics), the use of high strength steels offered a most cost-effective way to reduce weight.

Weight reduction of steel constructions and machinery, achieved by the use of high strength steels, has additional vital implications. It means that engineering tasks can be completed, using the same steelmaking capacity. Instead of spending capital to build new steel plants producing low strength steels, the same end-results can be attained by using existing steelmaking capacity to produce high strength steels.

It is important to understand how micro-additions of either vanadium, or niobium or titanium (or their combination), transforms the common hot-rolled carbon steel into a much more advanced material: HSLA steel.

For this purpose, it is helpful to look into the anatomy of steel, to recognize the various mechanisms influencing its strength, ductility, toughness, or weldability.

Strengthening mechanisms in steel

To gain an insight into the mechanisms by which hot-rolled steel attains its strength, it is necessary to examine the microstructure. (3)

When observing the structure of hot-rolled steel under an optical microscope, one can recognize two structural constituents: the light-etching crystals or grains of iron (ferrite), and the dark-etching areas rich in carbon (pearlite). These two constituents can be quantified by determining the amount, i.e., volume fraction of each. Furthermore, the size of ferrite grains can be measured and expressed by the mean diameter. The contribution of these two constituents: ferrite and pearlite can be calculated: the larger the volume fraction of pearlite is (i.e., the amount of carbon in steel), and the smaller the diameter of grains of ferrite is, the greater the increase in the strength of the steel.

Additional strengthening is derived from the presence of alloying elements usually present in carbon steels: manganese and silicon.

These are not visible under the microscope, since they are completely dissolved in iron (in ferrite). These elements are in solid solution.

Some elements are dissolved in iron at high temperatures, but are rejected (precipitate) as the temperature is lowered. The microalloying elements: vanadium, niobium, and titanium belong to this category. Precipitation of these elements in combination with carbon (carbides) or nitrogen (nitrides) provides additional strengthening. In general, to be an effective strengthener, the precipitates must be extremely small. They can be seen only at very high magnifications. The structural components in steel revealed by microscopic examination contribute to four different but additive strengthening mechanisms:

- amount of pearlite (% carbon);
- solid solution of manganese and silicon;
- grain size of ferrite;
- precipitation of vanadium, or niobium, or titanium as carbides or nitrides.

Each of the four strengthening mechanisms exerts a somewhat different effect on mechanical properties: strength, toughness, ductility, and weldability. To obtain the best balance of properties, the metallurgist has the option to use the preferred strengthening mechanism at the expense of the others.

In common carbon steels, in the absence of microalloying elements, there is no precipitation, and ferritic grains are relatively coarse. The strength depends mainly on the amount of pearlite (or per cent carbon) and elements in solid solution. Since carbon is highly detrimental to toughness, weldability, and ductility, the high-carbon, high strength steels have a limited engineering utility.

The most powerful strengthening mechanism is grain refinement. Small grains of ferrite account for the only mechanism by which both the strength and toughness are increased, without affecting weldability or ductility. By developing very fine ferritic grains, high strength can be achieved even at low carbon levels. In consequence, fine grained, low-carbon steels have high strength, excellent toughness, weldability, and ductility. In these low-carbon steels, additional strengthening can be obtained by precipitation of vanadium, niobium or titanium compounds.

The newly-developed HSLA steels derive their strength mainly by exploiting these two strengthening mechanisms: grain refinement and precipitation strengthening. These two structural characteristics are made possible by the addition of microalloying elements. The elements: vanadium, niobium, and titanium, thus fulfill a dual role: they contribute to grain refinement, and to precipitation strengthening. Since the strength of these steels does not depend on carbon, the carbon content of HSLA steels is low, with resulting improvements in toughness, weldability, and ductility.

Role of hot rolling

While the microalloying elements contribute both to grain refinement and precipitation strengthening, the final microstructure is also influenced by deformation during the hot-rolling process as well as the subsequent rate of cooling.

During hot rolling, a portion of microalloying elements precipitates in the high-temperature phase of iron (austenite), interacts with grain boundaries and creates in austenite conditions which are favourable for the formation of many fine grains of ferrite. The remaining portion of microalloy precipitates at a lower temperature in ferrite, and contributes to precipitation strengthening.

The effect of hot-rolling practice on microstructure and properties depends on the type of microalloying element. In general, vanadium steels are less sensitive to wide variations in the rolling practice than the niobium steels.

The rate of cooling from the hot-rolling finishing temperature to about 600° C (i.e. through the austenite to ferrite transformation range) has an effect both on grain size and precipitation strengthening. In general, an increase in the rate of cooling from conventional air cooling to about 5 to 12° C/sec is beneficial, and contributes to higher strength both through grain refinement and formation of smaller particles of precipitate.

Microalloying elements

Although all the microalloying elements fulfill a dual role: they contribute both to grain refinement and precipitation strengthening, they are not interchangeable. Each of them has its own intrinsic characteristics. In deciding which of the three: vanadium (V), niobium (Nb), or titanium (Ti) should be used, several factors have to be taken into consideration.

The three microalloying elements show different affinities with regard to elements present in steel. (2) This is indicated schematically in the table below. Here, the number of + signs indicates the degree of affinity toward each of the four elements commonly present in steel: carbon (C), nitrogen (N), sulphur (S), and oxygen (O).

Elements in Steel

	<u>C</u>	<u>N</u>	<u>S</u>	<u>O</u>
V	++	<u>/+++/</u>	0	+
Nb	<u>/+++/</u>	+	0	+
Ti	<u>/++/</u>	++++	++	+++

Note: Brackets denote main strengthening effect.

With respect to oxygen, both V and Nb show low affinity, and may be used not only in killed, but also in semi-killed steel or even rimmed steels. Titanium is a strong deoxidizer and must be added to fully killed steel.

Only titanium has the capacity of combining with sulphur. The favourable shape of titanium sulphides in the form of globules contributes to improved impact properties and reduced directionality of properties.

Titanium is also the strongest nitride former among the three microalloying elements. Titanium nitrides precipitate at very high temperatures, and do not contribute to strength. Strengthening in titanium steels is the result of precipitation of titanium carbides. The strengthening effect depends only on the amount of titanium which is not combined with nitrogen, sulphur, and oxygen. For that reason, the strength properties of Ti-steels are difficult to control reproducibly.

Vanadium is a stronger nitride-than-carbide-former. The effectiveness of vanadium is greatly enhanced in the presence of nitrogen in steel. Furthermore, vanadium - by combining with nitrogen - eliminates the negative effects of dissolved (free, or mobile) nitrogen, making the steel non-aging. For that reason, vanadium is particularly useful in electric furnace steels which are notoriously high in nitrogen.

The strengthening effect of niobium depends mainly on grain refinement promoted by precipitation of niobium carbides in austenite. Niobium steels have the tendency to age, since nitrogen remains in uncombined form.

Production technology of HSLA steels

HSLA steels are produced by a variety of steelmaking practices: open hearth, basic oxygen furnace or electric furnace.

Among the microalloying elements, vanadium and niobium, singly or in combination, are most widely used.

The addition of these elements is made to the ladle during tapping the steel from the furnace. To assure high recovery, the deoxidizers Mn, Si, and Al are added first, followed by microalloy additions made at the base of the tapping stream. To assure good mixing, the addition should be completed by the time the ladle is half full.

The HSLA steel can be cast either in ingots or continuously.

Rolling practice has a stronger influence on properties of niobium steels than on those of vanadium steels. Vanadium steels are particularly suitable for normal rolling practices, using relatively high finishing temperature. Niobium steels, on the other hand, offer best properties when processed by controlled rolling practice. This practice involves deformation in a low temperature region and requires a low finishing temperature.

The slab or billet reheat temperature should be high enough to assure a complete solution of all carbides and nitrides. For that reason, the reheat temperature of niobium steels must be significantly higher than that for vanadium steels. Low reheat temperatures offer several advantages: a finer and more uniform grain structure, in addition to substantial savings in heating energy.

Applications of HSLA steels

Low-carbon, microalloyed HSLA steels are being produced as bars, sheets, plates, structural shapes and tubular products. In addition, in medium and high-carbon steel grades,

small amounts of vanadium were found useful in the production of cold drawn bars, forging steels, and rail steels, leading to weight reduction in the general steel construction industry, fabricating and shipbuilding industries.

Bar and long products

The changing requirements for concrete reinforcing bars offer an instructive illustration of the utility of microalloying. (4) The current trends indicate a growing demand for high-strength (400 to 600 MPa yield strength), but weldable reinforcing bars. The weldability requirement excludes the possibility of using the traditional strengthening by carbon addition to steel (0.3 per cent carbon, or higher). For good weldability, the carbon content has to be lowered to the 0.10 to 0.22 per cent range. The resulting loss in strength must be compensated by some other mechanism. Of the three approaches available: cold working, heat-treatment from the hot-rolling temperature, or microalloying, the latter was found to be most flexible and cost-effective.

The microalloying approach can be adapted immediately without any modifications or additions to the existing steelmaking and rolling equipment.

The high strength of reinforcing bars reduces substantially the tonnage requirements. Excellent bendability and weldability of low-carbon grades contribute to low fabrication costs. And the non-aging characteristics of rebars microalloyed with vanadium provide an additional margin of safety, of critical importance in areas prone to earthquakes.

The same technology as practised for microalloyed reinforcing bars can be used for other long products, such as flats, angles, structural shapes, etc.

Sheets

For sheet products processed on continuous hot-strip mills, microalloying is particularly effective when combined with controlled (accelerated) cooling on the run-out table. (5) The majority of modern hot-strip mills are equipped with a water cooling system, consisting of a series of cooling banks. The intensive cooling of the strip, emerging from the last finishing stand, is achieved by sprays from the bottom and laminar (low-pressure) water flow from the top. As a consequence of this cooling, the temperature of the strip entering the coiler is reduced to about 600°C.

The results obtained by controlled (accelerated) cooling have been summarized as follows: "One of the main benefits accruing from controlled cooling on the run-out table is grain refinement. Finer grain size contributes not only to an increase in strength of steel, particularly in yield strength, but - what is most significant - it also contributes to an improved notch toughness of resistance to brittle fracture. Furthermore, the use of grain refinement as the primary strengthening mechanism permits an appreciable reduction in the carbon content while still maintaining the same strength level. The lower carbon content, because it results in less pearlite, improves formability and contributes to a superior notch toughness and weldability. In consequence, adoption of controlled cooling the normal practice for flat, hot-rolled products assures a balanced combination of mechanical properties and narrows the gap in properties currently existing between the hot-rolled, high strength, low alloy steels, and those requiring a special heat treatment". (5)

Additional strengthening is obtained by precipitation during the slow cooling in the coil. (6) For best results, the coiling temperature is maintained at about 600°C. A higher coiling temperature may lead to overaging and loss in strength. A too low coiling temperature may reduce the strengthening effect of precipitation and also contribute to formation of low-temperature transformation products, such as bainite, which are undesirable because of their embrittling effect.

Plates

In hot-rolling HSLA plates for heavy gauge constructions, two practices can be applied: (a) conventional rolling practice, or (b) controlled rolling practice.

In the conventional practice, rolling is performed at relatively high temperatures, as evidenced by the high hot-rolling finishing temperature in the neighbourhood of 1000°C. This practice can be applied on the majority of the existing plate mills. When using this rolling practice vanadium and vanadium-nitrogen microalloyed steels are particularly suitable, by offering an attractive combination of strength and toughness. (7)

To achieve still better toughness, at ambient and sub-zero temperatures, controlled rolling is very effective, especially for niobium steels. Controlled rolling implies that a substantial amount of deformation, generally in excess of 60 per cent, is performed below 900°C. In consequence, the hot-rolling finishing temperature is also low. This causes high mill loads, and only the most modern, rigid plate mills are fully suitable for controlled rolling.

Controlled rolling is generally applied for plates used in critical applications, such as line pipe. The yield strength of the steel is of the order of 500 MPa (X-70 line pipe grade), combined with excellent low temperature toughness and welding properties. The most frequently used HSLA steel contains both niobium (0.02 to 0.04 per cent) and vanadium (0.06 to 0.08 per cent). (8)

Since the majority of plate mills has only a limited capability for controlled rolling, efforts are continued to develop desirable plate properties by a conventional hot-rolling practice.

Inclusion shape control

The strength of controlled cooled coiled sheet or plate may be as high as 550 MPa, coupled with good toughness and weldability. One of the problems encountered with these products is the strong directionality of mechanical properties. Particularly, the impact properties and the bendability may be satisfactory in the direction of rolling (longitudinal), but significantly lower in the direction perpendicular to rolling (transverse). This may lead to cold forming difficulties, especially when attempting bending over a tight bend radius.

The reason for the directionality (anisotropy) of properties is the presence of non-metallic inclusions, particularly of sulphides. (9) During the process of rolling, these inclusions - being softer than the surrounding steel - tend to elongate to form long stringers. These elongated inclusions contribute to weakness in the transverse direction and are responsible for breakage on severe bending. (10)

To overcome the problem of directionality of properties, two approaches were found to be successful:

- (a) To minimize the amount of inclusions by reducing the sulphur content of steel from about 0.02 per cent to below 0.008 per cent, * or
- (b) to change the shape of sulphide stringers to globules, by the addition of strong sulphide formers, such as rare earths (mainly cerium), zirconium, or titanium.

When using an ingot practice (rather than continuous casting), the second approach is quite simple. In this instance, to achieve "inclusion shape control", addition of strong sulphide formers, such as rare earth, can be made directly to the ingot mould during pouring from the ladle.

In steels microalloyed with vanadium, the use of rare earth for inclusion shape control is the preferred method. Zirconium should be added to niobium, but not to vanadium steels. Adding zirconium to vanadium steels would tie up the nitrogen in the form of massive zirconium nitrides, preventing the formation of vanadium nitrides. In consequence, the effectiveness of vanadium as a precipitation hardening agent would decrease, resulting in a drop in strength.

For steel slabs made by continuous casting, the elimination of directionality can be best achieved by reducing the sulphur content to the desirable low level. To this end, techniques have been developed for the injection of calcium-silicon deep into the ladle. This method has the advantage of producing a cleaner steel, with less non-metallic inclusions, compared to steels treated with rare earth.

Future trends

In spite of the maturity of HSLA steels and their successful performance in a variety of engineering applications, efforts are being continued to diversify their usefulness and to further enhance their properties.

* Editors Note: See 'Processing, melting/refining, continuous casting', on p.16 of this issue.

To characterize future trends, the following examples may serve as an illustration.

Forging steels

The standard practice for many forging steels is to subject them - after forging the part - to a quenching and tempering operation. Through heat-treatment, the forged parts attain the specified mechanical properties. To make forgings more competitive with castings - being used for automotive components such as crankshafts and connecting rods - it is necessary to reduce the cost, by eliminating heat-treatment.

To this end, precipitation hardenable steels have been developed which acquire strength properties on cooling from the forging temperature. No additional heat treatment is required. Vanadium was found as the most efficient precipitation strengthening agent, and is added in the amounts of 0.10 to 0.15 per cent. (11)

Heavy gauge coils

A modern hot-strip-mill represents an enormous capital investment of many hundred millions of US dollars. To fully exploit the high production capacity of a hot-strip-mill, the coilers have been strengthened to coil strip 20 to 25 mm in thickness. For this purpose, in addition to powerful coilers, uncoiling, levelling and shearing equipment has been developed. Spirally-welded line pipe is one of the major applications of the heavy gauge coiled products. (12)

Accelerated cooling of plates

The benefits of accelerated cooling from the hot-rolling temperature are well documented for bars and sheet. The rate of cooling ranges from 5 to 15°C/sec., in the range from hot-rolling finishing temperature to about 600°C.

Recently, equipment has been developed to apply controlled (accelerated) cooling to plates and to maintain good flatness. As a result of this practice, the strength of plate is increased, without loss in toughness. (13)

Currently, the feasibility is being explored of using accelerated cooling as a trade-off for low-temperature deformation during controlled rolling. The object of this development effort is to produce a good combination of strength and toughness in plates rolled by conventional practice on the existing rolling mills.

Economically, this approach is very attractive, since the cost of installing a plate cooling system is small in comparison with the investment needed for a new rolling mill.

HSLA steels and the developing countries

For the developing countries, there are several incentives to initiate production and promote usage of HSLA steels. The benefits resulting from these programmes may be outlined as follows:

- More effective utilization of limited steelmaking capacity;
- Immediate exploitation of lengthy and costly research and development efforts, available at no cost from published sources;
- Improved profitability of steel plant through the added value of products representing a major tonnage;
- Upgrading to modern standards the level of domestic engineering in material usage;
- Production of cost-effective, hot-rolled steel products as a substitute for more costly and frequently imported, heat-treated alloy steels;
- Improvements in the competitive position in export markets.

The key to full utilization of these benefits is an active interaction with, and education of potential users, to make them aware of the technical and economic advantages offered by the application of HSLA steels.

In many developing countries, the steel industry is typified by mini-mills. The raw material source is either scrap or pre-reduced pellets. The electric furnace is most frequently used as the melting unit. Continuous casting is the preferred method for producing billets for conversion by rolling into a variety of long products. Typical examples of such steelmaking facilities can be found in Malaysia, Singapore, Thailand, Hong Kong, Philippines, Saudi Arabia, and other countries.

In these situations, the easiest way to initiate production of HSLA steels is through the upgrading of quality requirements of one of the simplest products, such as concrete reinforcing bars.

To meet modern specifications for high strength but weldable reinforcing bars (exemplified by British Specifications BS 4449), the use of microalloying offers the simplest solution. The amount of microalloy addition ranges usually from 0.03 to 0.10 per cent, depending on the required strength level. The added cost of microalloying is more than balanced by weight reduction, made possible by the higher strength.

The majority of suppliers of microalloy additives, mainly vanadium or niobium, offer specific instructions as to the most efficient method of making the addition to steel.

Experience has shown that the switch from the production of plain carbon steels to HSLA steels can be made immediately, since no changes in established practices are required.

The only precaution for making the ladle addition of microalloying elements is the prior addition of deoxidizing elements, such as manganese, silicon, and aluminium. Good practice suggests that all additions should be made before the ladle is half full.

Many HSLA steels, particularly those containing vanadium, show a high degree of insensitivity to variations in the rolling practice. For that reason, when hot-rolling these HSLA steels, the same procedures can be used as those for rolling common carbon steels.

Further improvements can be attained by lowering the billet reheat temperature. This measure may improve properties through grain refinement and substantially reduce the cost of heating.

Once sufficient experience and confidence has been generated in producing reinforcing bars, additional HSLA steel products may be added to the product mix: flats, angles, cold drawn bars, forging steels, spring steels, etc.

In training personnel, modern concepts relating microstructure to properties should be emphasized. To achieve this objective, full use should be made of the published technical literature, available in great abundance. Through this approach, equal importance will be attached both to meeting specifications for chemical composition and adhering to the established procedures when hot-rolling the steel. By controlling both steel chemistry and rolling practice, a high degree of uniformity of properties will be achieved.

A higher level of complexity is available in steel plants capable of producing flat rolled products, such as hot-rolled strip and plates. This situation exists, for example, in Indonesia, China, Mexico.

For the effective utilization of HSLA steel sheet produced on a hot-strip-mill, an efficient cooling system on the run-out table is most useful. Special personnel training is required to develop skills in operating and maintaining the cooling system. Of special importance is an adequate control of the coiling temperature ($\pm 200^{\circ}\text{C}$), which is essential for providing uniform properties throughout the coil.

To assure good cold forming and bending properties, control of the sulphur level in steel and inclusion shape control will be required. This involves experience and knowledge in using rare earth additions, and - ultimately - application of ladle metallurgy for injection of a desulphurizing addition. All improvements in the quality of steel products through the use of HSLA steels, must be paralleled by the ability of the users to apply the new products to their economic advantage. As a starting point, experience gained in the use of microalloyed reinforcing bars may provide important guidelines for the promotion and utilization of the products.

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* * *

Selected Aspects of Manufacturing Alloy Steels

The following paragraphs provide additional information on selected aspects of manufacturing alloy steels. The sources of information, for which a reference number is given in brackets, are listed on page 39.

A. Processing, melting/refining, continuous casting

The demand for higher quality steel, together with the requirements for continuous casting, have led many steelmakers to employ a secondary steelmaking process. In producing HSLA steels, low sulphur, low hydrogen and, for certain alloy systems, low or a controlled amount of nitrogen are important. While not absolutely necessary, the secondary steelmaking processes below might prove highly beneficial to attain and maintain consistent high quality.

Secondary steelmaking (including ladle metallurgy) processes are used for:

- alloying
- temperature and composition homogenization
- deoxidization
- desulphurization
- degassing
- inclusion agglomeration and flotation
- sulphide shape control
- oxide inclusion modification

These goals are being achieved to a varying degree by a wide range of secondary steel-making processes, which can be divided into four types:

- Vacuum degassing, (DH, RH, Stream etc.)
- Ladle desulphurization, TN, Scandinavian Lancers, etc.
- Heated ladle vacuum, (ASEA-SKF, Finkl-Mohr, ladle furnace (LF), etc.)
- Ladle gas stirring

The attributes of these processes vary significantly.

It is generally accepted that the heated ladle vacuum systems, particularly vacuum arc degassing (VAD) (1) offer the greatest degree of flexibility in achieving the goals of secondary steelmaking. However, argon oxygen decarburization (AOD), after its wide acceptance for the production of stainless and high alloy steels, is recently also finding increased application for carbon and low alloy steels.

It should be noted that ladle (lance) desulphurization alone, or in combination with vacuum degassing, can achieve all the key goals as well.

Selection of secondary steel refining equipment should be based on the impurities encountered, the availability of raw materials used in the different systems, particularly industrial gases, and the projected quality requirements. In general some licence fee for the equipment will be necessary.

Process comparisons

"Composition control-alloy trimming, whether done in a vacuum degasser (e.g. DH), a heated ladle vacuum system (e.g. VAD), or an AOD vessel, can generally control C, Mn and Si levels to within +0.015 per cent +0.04 per cent and +0.04 per cent, respectively.... Even tighter chemistry control has been reported for the Daido ladle furnace system....

"The heated ladle vacuum systems and AOD have the advantage of being able to add large quantities of alloys if necessary, since heating can be performed as well.

"Desulfurization - desulfurization is carried out in secondary steelmaking by a combination of special fluxes or by the injection of calcium bearing compounds. The ladle desulfurization system can achieve sulfur contents of 0.005 per cent and less by injecting compounds such as calcium-silicon into a bath covered with a lime-spar flux. The heated ladle vacuum system achieves desulfurization with a flux addition and with an occasional assist from calcium alloy additions...With long treatment time or by sacrificing some degassing ability, very low sulfur contents are reached...The AOD process can readily achieve sulfur contents below 0.005 per cent by reaction with simple basic lime-alumina-silica slags without raising final gas contents and without the addition of desulfurizing alloys.

"Temperature control - of all the secondary steelmaking processes, only the heated ladle vacuum system (e.g. VAD, ladle furnace, ASEA-SKF, etc.) and the AOD process enable positive as well as negative temperature control. In those systems, heat is supplied by arc heating with carbon electrodes while AOD generates heat by exothermic oxidation reactions. Temperature control capability is $+4^{\circ}\text{C}$ for ASEA-SKF, ... $+5^{\circ}\text{C}$ for Finkl-Mohr, ... $+4^{\circ}\text{C}$ for LF, ... and $+5^{\circ}\text{C}$ for AOD. In general, the vacuum degassing processes and other unheated ladle systems can lower the temperature to within $+4^{\circ}\text{C}$ of the aim, but have no provision for reheating.

"Degassing - three dissolved gases are of interest to the steelmaker: hydrogen, oxygen and nitrogen. Hydrogen control is generally considered the best measure of degassing ability...

Table IV: Hydrogen Capability Product Sample in PPM

Stream degassing	1.5
Vacuum casting	1.0-1.5
LF	<1.5
RH	1.5
Finkl-Mohr (VAD)	1.5
AOD	<2.0
DH	<2.5
ASEA-SKF	<2.5

"Nitrogen control is also important in the production of high quality steel. Many of the ladle desulfurization and ladle gas stirring systems experience unwanted nitrogen pick-ups during treatment. In particular, with calcium injection, nitrogen increases of 40 ppm from 100 to 140 ppm have been reported. ... In general, the vacuum systems have little influence on final nitrogen level. They remove about as much as is added, especially at the low nitrogen levels typical of BOF steels. ... In electric furnace steel, which tend to run higher in nitrogen content, there may be some nitrogen removal, especially in processes such as Finkl-Mohr (e.g., 20 ppm removal from 80 to 60 ppm).... The AOD process enables efficient removal of nitrogen and control over the final nitrogen level by switching from nitrogen to argon at the appropriate time in processing.

"The oxygen content of steel, which profoundly effects steel cleanliness, is largely determined by final deoxidation practice and degree of slag-metal stirring. Vacuum systems offer the simultaneous possibility for oxygen removal by CO formation and flotation of reaction products, (but) it is still difficult to produce steel with an oxygen content less than 15 ppm. ... In practice, the heated ladle vacuum systems achieve total oxygen contents of 20-35 ppm. In ladle desulfurization systems, final oxygen content is quite dependent on furnace tap conditions and slag carryover. While 35 ppm can be produced in systems such as TN from an initial total oxygen level of 95 ppm, substantially higher levels can occur if slag FeO contents are above 9 per cent. ... As a result of the intense slag-metal mixing in the AOD, product oxygen levels may run 10 ppm higher than reported for heated ladle vacuum systems. These oxygen levels are generally adequate for all but bearing quality steel.

"Shape control - shape control refers to not only sulfide shape control but also oxide inclusion modification. The shape of sulfides in the final steel, even at low sulfur levels, can be important for critical applications such as line pipe. To achieve complete sulfide shape control, some form of calcium or rare earth addition is required. Consequently, only processes such as ladle desulfurization or some of the heated ladle vacuum systems achieve sulfide shape control. Although oxide shape control is achieved in the AOD process by intense mixing with basic slags, a subsequent calcium or rare earth addition is required for complete sulfide shape control." (2)

Continuous casting

Stricter parameters are necessary for the continuous casting of HSLA linepipe steels. Secondary cooling, casting speed and particularly strand containment, with close spaced rolls, is important to eliminate bulging, which in turn leads to central segregation and material defects in HSLA steels. Some continuous casting equipment producers have assembled considerable experience in the production of HSLA steel slabs. (3,4,5,6)

B. Dual phase steels

To further improve specific properties of low alloy steels, a predetermined two-phase structure is produced by heat-treatment.

The main principle is to produce two phases where the advantages of the second phase are optimized and the less desirable features are offset by the other phase. The size, distribution, shape and volume fraction of the second phase critically control the mechanical behaviour of the dual phase system. These structures, therefore, offer a degree of metallurgical flexibility, absent in single phase structures or in many precipitation strengthened systems.

Considerable development effort has been expended in the production of these "dual phase" steels, however the results of this research are protected by patents and trademarks by the respective steel companies.

A typical example was the development by Jones and Laughlin of a dual phase steel for automotive applications, incorporating improved strength and stretch formability over conventional HSLA steels. The following extracts of an article (7) describe the development of a highly formable high strength low alloy steel for deep drawing applications in the automotive industry. By a combination of steel chemistry and heat treatment the dual phase structure with the required properties is achieved. After considerable research, the goal of high ductility, excellent flow characteristics and high strength has been met. The results have been patented and the alloy covered by a trade name. Similar developments for specific applications have been made by a number of steel companies.

"The trade name chosen for this product is VAN-QN. The VAN prefix indicates its similar chemistry to the company's earlier family of HSLA formable steels, while QN refers to the quasi-normalised process used to develop properties...

"VAN-QN's unique combination of high strength and high ductility results from the heat treatment operation which produces a microstructure commonly referred to as dual-phase. This generic term indicates that the components of the structure consist primarily of a mixture of 'soft' ferrite and 'hard' martensite or lower bainite. The tensile properties of dual-phase steels are characterised by a low yield stress with no indication of yield point phenomena, a high work hardening rate leading to a high ultimate tensile strength and simultaneously, high uniform and total elongations. These properties allow high strengths to develop during the forming operation and promote favourable strain distribution so that localised necking is delayed until quite large strains are reached. Consequently, parts requiring high stretch or plane strain formability can be shaped while, in the same operation, the strength potential of the steel is being achieved.

"Fig. 14 shows the extent of strength-ductility improvement compared to the conventional VAN steels discussed previously. The flow characteristics of VAN-QN compared to those of VAN-80, VAN-50 and aluminium-killed low carbon steel are shown in Fig. 15; the yield strength of VAN-QN is close to that of VAN-50 but due to its high rate of work hardening at relatively low strain levels, its flow stress rapidly approaches that of VAN-80. Fig. 16 is a plot of uniform elongation against ultimate tensile strength for various types of VAN-QN, covering cold rolled steels as thin as 0.022 in. hot rolled steels as thick as 0.164 in. and galvanised steels in both cold and hot rolled thicknesses. From this, and the relationship shown in Fig. 14, it can be seen that strength has a significant effect on ductility. At a given strength level, there is an appreciable variation in ductility according to the chemistry-processing combination. As production experience has grown, properties characteristic of the top end of the scatter band have been achieved more consistently. However, the main significance of the results shown in Fig. 16 is that there is essentially one strength-ductility combination which is largely independent of the thickness of the sheet or the use of a coating. This is in marked contrast to the outcome of conventional approaches to strengthening where cold rolled uncoated and galvanised products could not achieve the full range of strengths possible in hot rolled steel. The ability to produce the optimum strength-ductility relationship over a full range of sheet products is an important advantage of VAN-QN over conventional HSLA products."

Fig 14. Comparison of strength-ductility relationships for VAN-QN and conventional VAN steel.

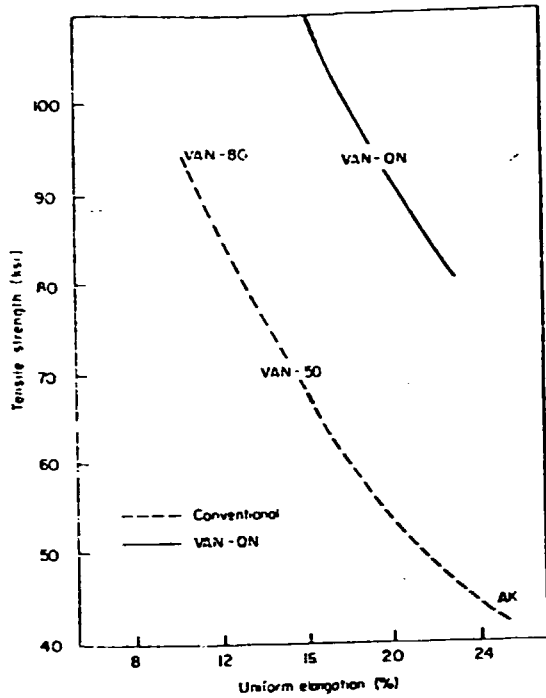


Fig 15. Flow characteristics of VAN-QN compared to VAN-50 and VAN-80.

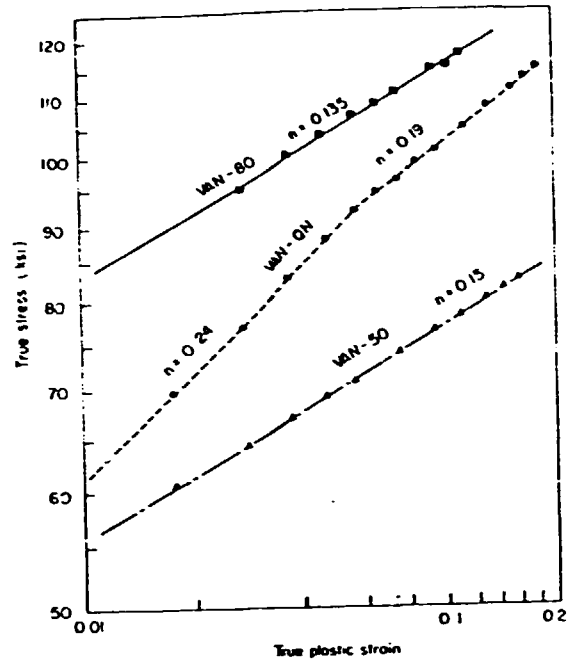
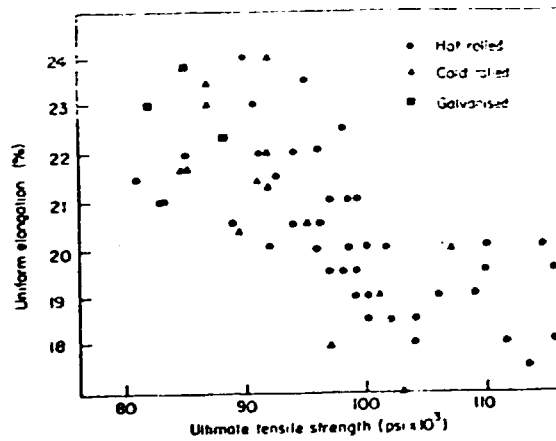


Fig 16. Relationship between uniform elongation and ultimate tensile strength for cold rolled, hot rolled and galvanized VAN-QN.



Results of systematic alloy design programmes are given in a paper (8) by G. Thomas of the Materials and Molecular Research Division, Lawrence Berkeley Laboratory, University of California, United States of America.

The paper, extracts of which are reprinted below, is an example of a systematic alloy design programme as carried out by a university research laboratory. Of particular interest in this instance was the production of high strength coupled with optimized wear properties.

The figures which are reproduced show the property improvements achieved with two high carbon dual phase steels compared to typical commercially available carbon and heat treatable high alloy steels. Wear properties achieved are superior to many commercial wear-resistant alloys. Similar results were also reached with low carbon steels where, by exact processing and simple alloy additions, a fibrous structure results.

Further examples for duplex steels, where specific processing replaces expensive alloying additions and many HSLA properties are exceeded, are given. It has to be remembered however, that heat treatment and hardenability requirements as well as poor welding response will limit applications of these steels at this time.

"Examples are presented...of martensite/austenite (-2-5%) mixtures designed for optimum combinations of high strength, toughness, and wear properties in medium carbon steels, e.g. for mining and agricultural applications, and martensite/ferrite (-80%) structure for high strength, good formability and improved low temperature ductility in low carbon steels. Applications to sheet, line pipe, and wires will be demonstrated for the latter class of steels."

The strong, tough, wear-resistant medium carbon structural steels have been termed "qua-tough" steels.

"The excellent combinations of strength and toughness exhibited by the qua-tough steels can be seen, even in the untempered condition, as shown in figures 2-3. Tempering in the 300-400°C temperature range leads to tempered martensite embrittlement (TME), and the drop in toughness is associated with the decomposition of the retained austenite to interlath carbide.

Fig. 2

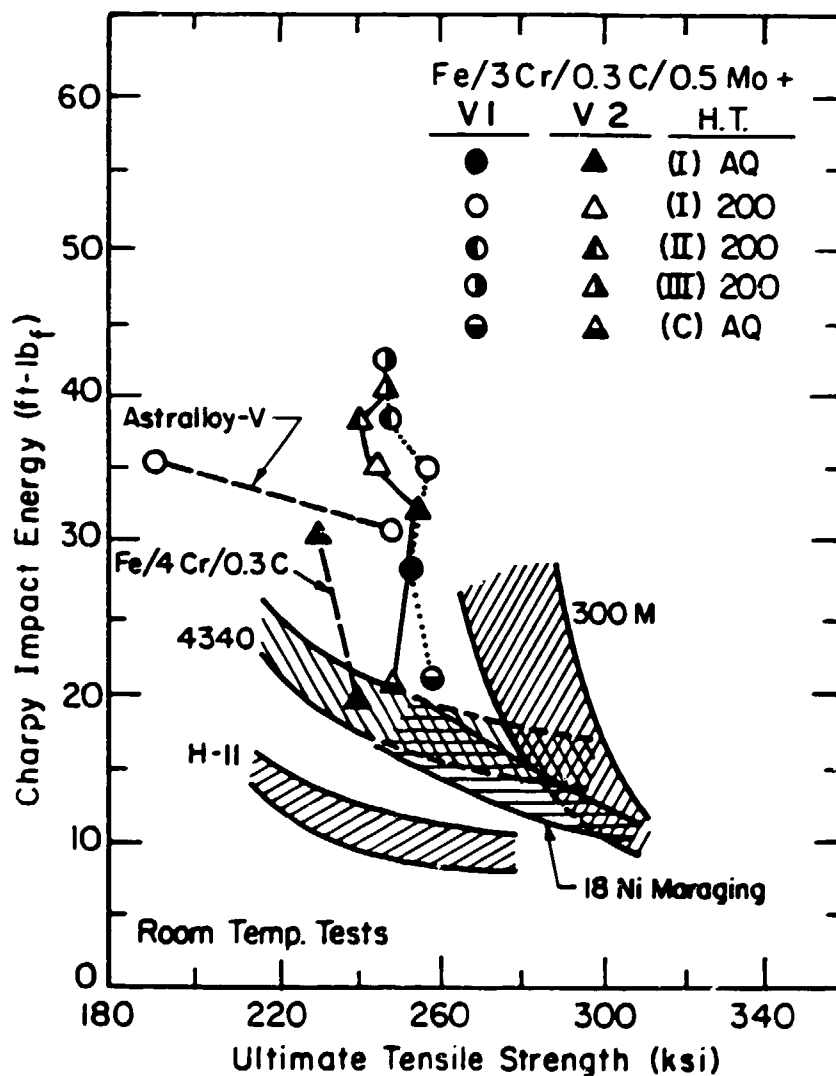
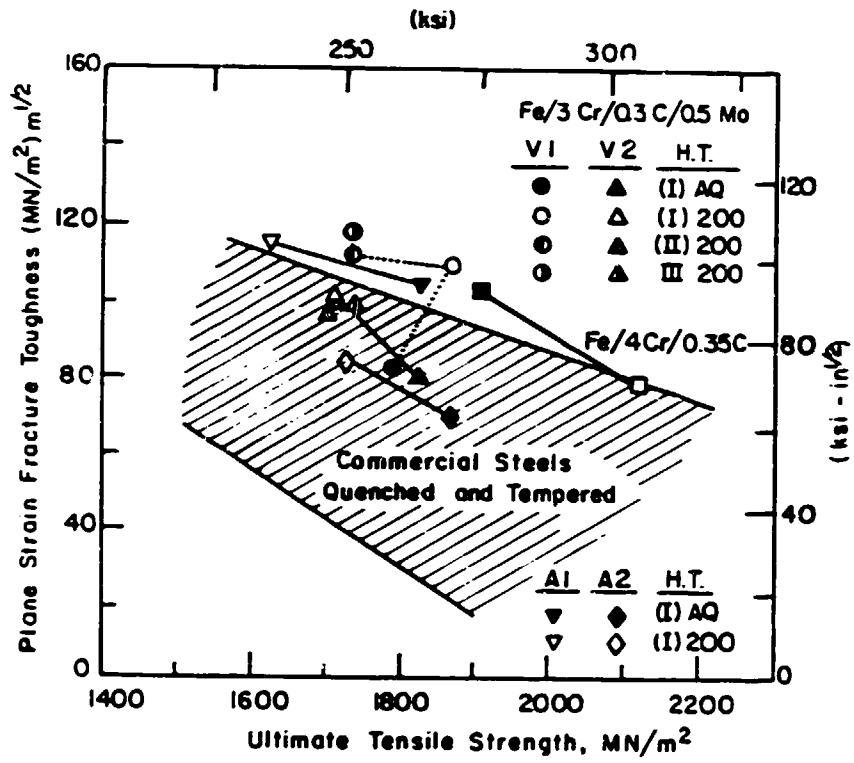


Fig. 3



Many of the uses of structural steels require not only good strength-toughness characteristics, but also good wear-corrosion-resistance. As part of the alloy design programme, both sliding and abrasive wear behaviour have been examined and measured for the qua-tough steels (Kwok, 1982, Salesky and Thomas, 1981). The results show that the duplex martensite/austenite microstructure of these steels exhibits good wear-resistance in both categories of wear, and are superior to many commercial alloys that are described as wear-resistant alloys (see figures 5a and 5b). Sliding wear behaviour was found to be beneficially affected by tensile strength, hardness, fracture toughness, and grain-refinement, whereas abrasive wear was found to be positively affected by only the first two factors.

Fig. 5a

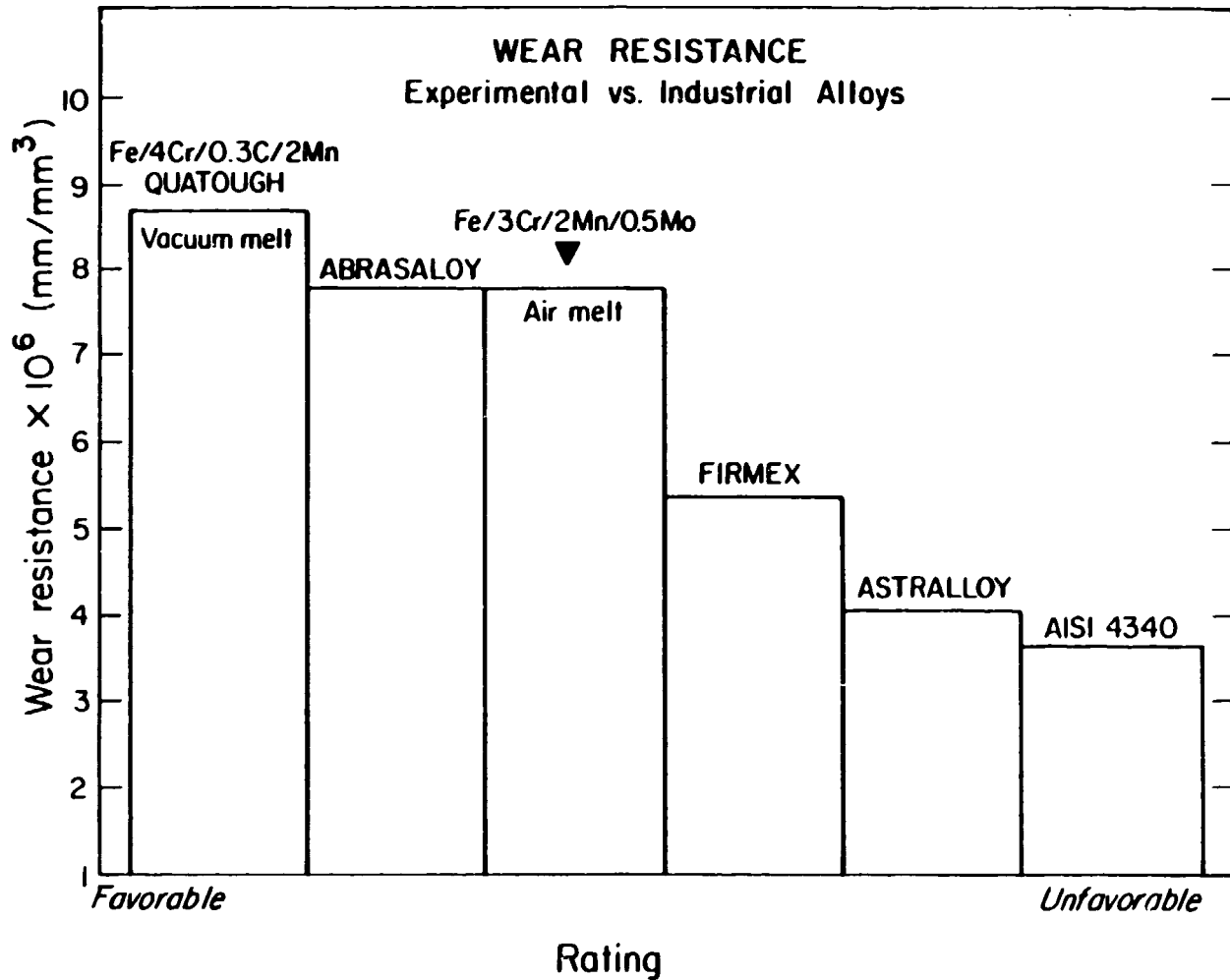
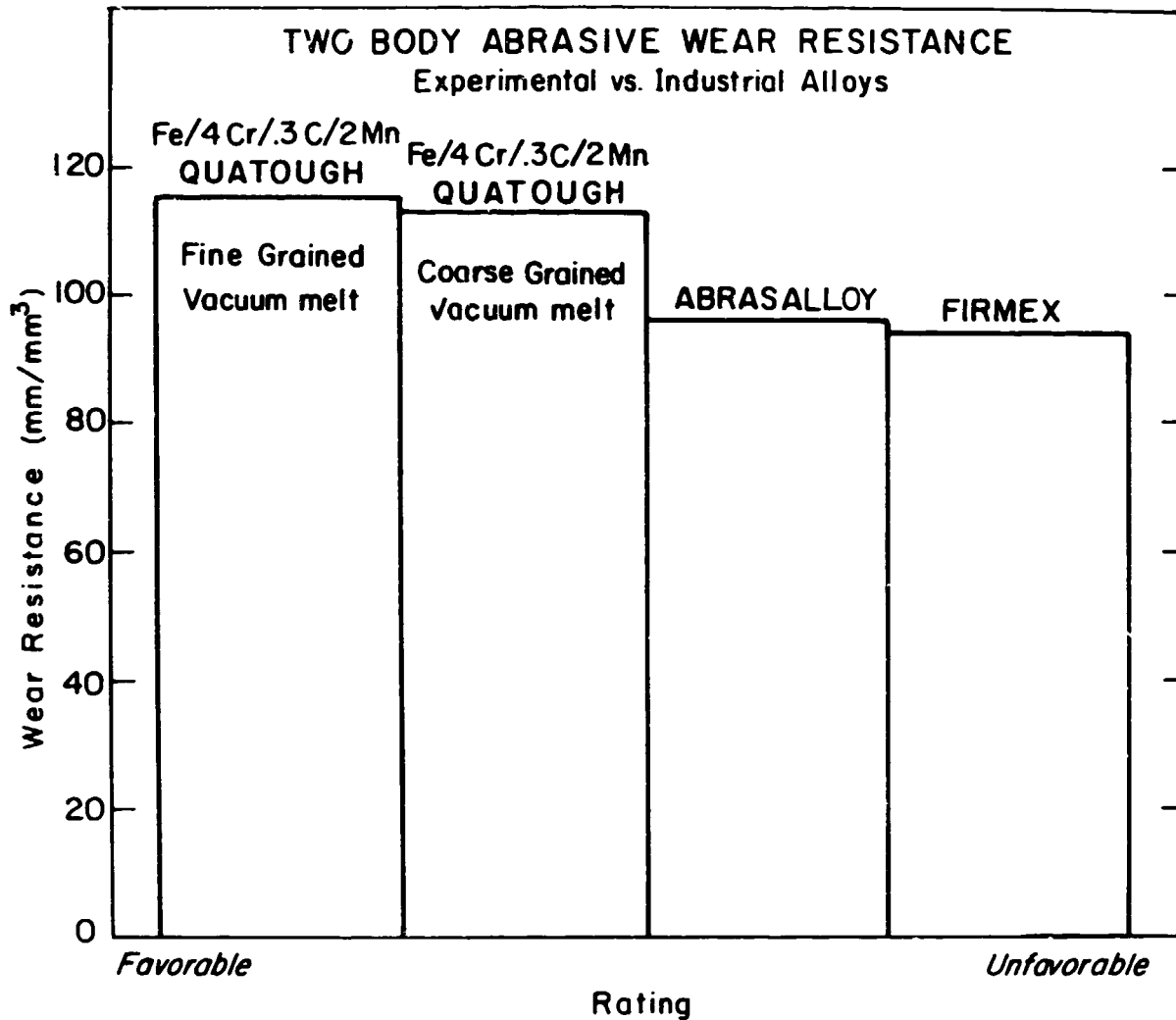


Fig. 5b

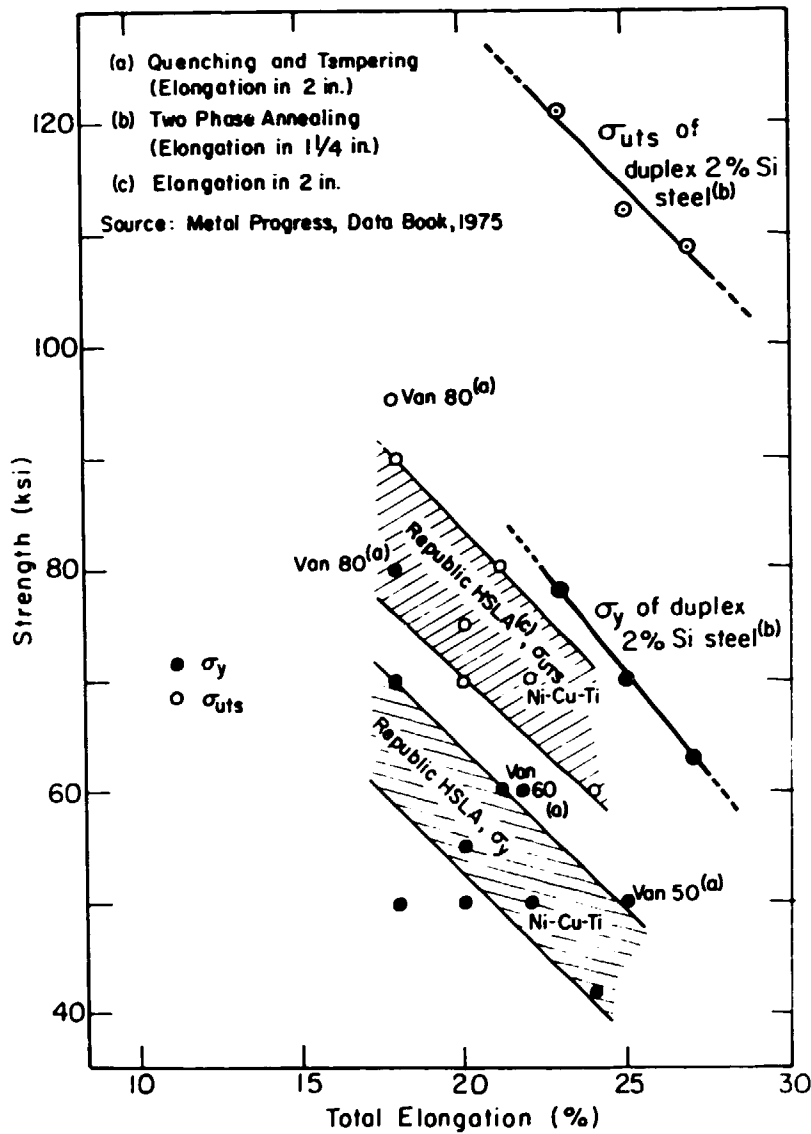


Dual-phase, low-carbon steels

"The strengthening principle of the dual-phase structure involves the incorporation of inherently strong martensite, as the load-carrying constituent, in a soft, ferrite matrix, which supplies the system with the essential ductility. Thus these alloys can be considered equivalent to fibre composites, with the advantage of producing coherent phases by solid-state phase transformation...the complex interactions of parameters such as morphology, properties and volume fraction of constituent phases must all be controlled when designing dual-phase alloys. When this is achieved, excellent mechanical properties can be realised, with high strengths attainable for relatively low carbon alloys (see figure 11). Moreover, the alloy compositions are quite simple, with no need for microalloying elements, and are therefore inexpensive, and by controlling the composition, considerable flexibility (i.e. strict heat treatment is not needed) in intercritical annealing temperature is possible (Thomas and Koo, 1979).

"Utilising these principles several ranges of alloys have been developed, starting with a simple Fe/Si/C alloy, which has (a) fibrous structure...and excellent properties (Figure 11). The figure summarises our data in comparison with data for some high strength low-alloy (HSLA) steels that contain expensive microalloying additions.

Fig. 11



"Although interest in dual-phase steels has been generated largely by the recent fuel crisis and its impact on the need for weight savings in transportation systems, i.e. for flat sheet products, the potential application for dual-phase alloys are broad indeed. These alloys form a new class of strong, ductile steels for applications requiring tensile strength levels of ~100ksi for pipeline, and up to 400ksi for tensile wires, rods and bars. These properties can be obtained by cold wire drawing without the necessity for intermediate patenting heat treatments (Nakagawa (1982). Strengths up to 400ksi are indeed remarkable for such simple steels with less than 0.1wt% carbon.

"Steels used for pipeline must have high strength as well as high toughness (low ductile-to-brittle transition temperature). The alloy design principle for pipeline application is that high toughness can be obtained primarily by grain size control, while maintaining a dual-phase structure to simultaneously obtain high strength. Controlled rolling of an Fe/1.5Mn/0.06C alloy, followed by direct quenching produces a duplex microstructure in which upper bainite particles are uniformly distributed within the fine, ferrite matrix (Kim and Thomas, 1982). The mechanical properties of this ferrite-bainite steel, in the as-hot-rolled condition, far exceed the property specifications for arctic pipeline. A further advantage of this ferrite-bainite steel is that there is an abrupt increase in strength during pipe-forming due to its high work-hardening rate. This clearly demonstrates the potential use of dual-phase ferrite-bainite structures in pipeline applications (Table 2). . . ."

Table 2
PROPERTY SPECIFICATIONS FOR ARCTIC PIPELINE AND TYPICAL MECHANICAL
PROPERTIES OF THE AS-HOT-ROLLED Fe/1.5Mn/.06C STEEL
WITH AND WITHOUT COLD WORKING

	UTS MN.m ⁻²	Charpy shelf energy	
		Transverse	Longitudinal
Arctic Pipeline	585.7	92 J. at -60°C	136 - 170 J. at -60°C
Fe/1.5Mn/.06C (as hot-rolled)	642.2	149 J. up to -100°C	183 J. up to -100°C
Fe/1.5Mn/.06C (with 2% cold reduction)	649.0	129 J. up to -100°C	170J. up to -150°C

"The main limitations of low carbon dual phase steels for general applications are material dimensions, i.e. sufficient hardenability must be achieved (~0.5in thickness/diameter) to obtain martensite/bainite on quenching from the ($\alpha+\gamma$) field, and problems of microstructure control if welding must be done after the dual phase treatment."

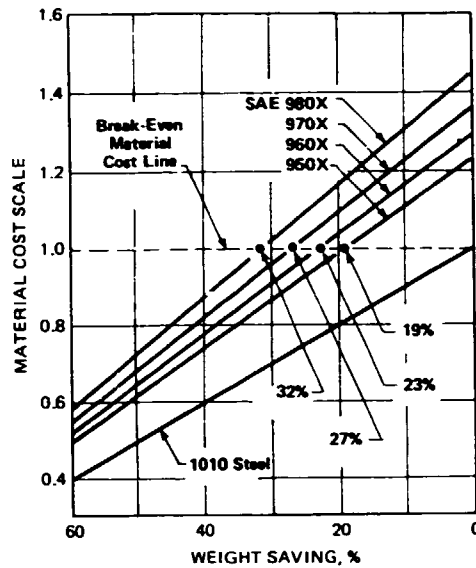
C. Applications

The application of microalloyed steels in cold-rolled sheets, concrete reinforcing bars and plates for various uses, including pressure vessels and shipbuilding were discussed in a session of the conference "Micro Alloying 75", 1 to 3 October 1975, Washington, D.C., United States. The examples discussed are typical for early HSLA steel development, and similar grades and applications can be considered by developing countries. The proceedings of this conference, which also covered alloy systems and thermomechanical processing in great detail, are available in book form and could form a technical basis for the production and application of HSLA steels.

In the summary by the rapporteur of the relevant session, several interesting factors were highlighted. Table I shows the various types of steels discussed, as well as their analysis, application and achievable property values.

Examples for actual weight savings in the construction equipment, large structure and shipbuilding industries are given and cost factors are considered (Figure 3). See reference (9).

FIGURE 3



The higher cost of HSLA steels, compared to plain-carbon AISI grade 1010 steel, can be balanced by weight reduction.¹⁰

"The various types of microalloyed steels described in the nine application papers are summarized in Table I. A wide range of applications was covered, but the alloy systems are quite similar. However, in reviewing these papers, it seems appropriate to consider the two applications by Oberhauser, ..., and Weise, ..., separately before examining the features common to the remaining applications.

TABLE I
CHEMICAL COMPOSITION AND APPLICATION DATA FOR MICROALLOYED STEELS

Principal Author	Application	Carbon	Manganese	Silicon	Sulfur	Aluminum	Columbium	Vanadium	Nitrogen	Other
Johnson	Truck Frames	0.14% typical	1.2% typical	0.3% typical	0.015% typical	0.03% typical	-	0.12% typical	0.015% typical	-
Oberhauser	Cold-Formed Sections	0.05% typical	1.6% typical	-	-	0.03% typical	0.05% typical	-	-	0.2% Mo typical
Weise	Concrete-Reinforcing Bars	0.18% typical	1.4% typical	0.35% typical	-	0.03% typical	0.03% typical	0.08% typical	-	-
Norring	Marine Structures; LPG Vessels	0.07% typical	1.53% typical	0.45% typical	0.010% typical	0.039% typical	0.022% typical	-	-	-
Kampschafer	Storage Tanks; Pipe Fittings; Marine Equipment	0.22% max.	1.15 to 1.50%	0.30 to 0.50%	-	-	-	0.04 to 0.11%	0.01 to 0.03%	-
Hamilton	Pressure Vessels*	0.20% max.	1.6% max.	0.50% max.	0.035% max.	0.015% min.	0.015 to 0.060%	0.02 to 0.20%	-	0.25% max. Cr 0.35% max. Cu 0.10% max. Mo 0.40% max. Ni
Carter	Low Temperature Storage Tanks and Pressure Vessels	0.20% max.	1.5% max.	0 to 0.50%	0.050% max.	-	0.10%†	0.10%†	-	-
Lubuska	Ship Steel	0.18% max.	1.60% max.	0.50% max.	0.04% max.	0.015% min.	0.02 to 0.05%	-	-	0.20% max. Cr 0.30% max. Ni 0.30% max. Cu 0.10% max. Mo

*Proposed International Standards Organization (ISO) Specification. †Columbium and Vanadium combined not to exceed 0.10%.

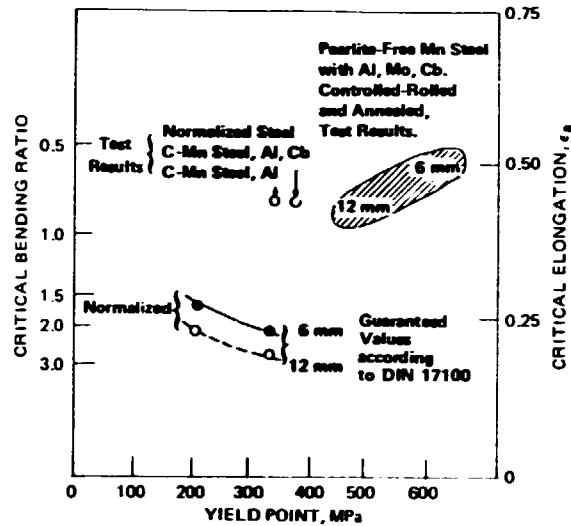
High strength strip

"Oberhauser et al. were primarily interested in the development of a high-strength steel strip for cold forming into light-weight, weldable components. They investigated in considerable detail the effects of alloy additions on both strength and those properties which help to define formability, such as elongation, maximum uniform elongation, reduction

of area, and the strain-hardening exponent. The authors found that pearlite had adverse effects on almost all the formability parameters so that carbon contents were restricted to very low levels. Steels killed with aluminum gave excellent formability, but such steels could not achieve the required strength levels in the pearlite-reduced condition.

When compared with vanadium, columbium (niobium) additions were found to have the least detrimental effect on formability and yet provided the needed precipitation hardening. To avoid the need for slow cooling or tempering after rolling to obtain the precipitation of columbium (niobium), a small quantity of molybdenum was found beneficial. The excellent formability is seen in Figure 4 where high critical elongations are reached at high-strength levels.

FIGURE 4

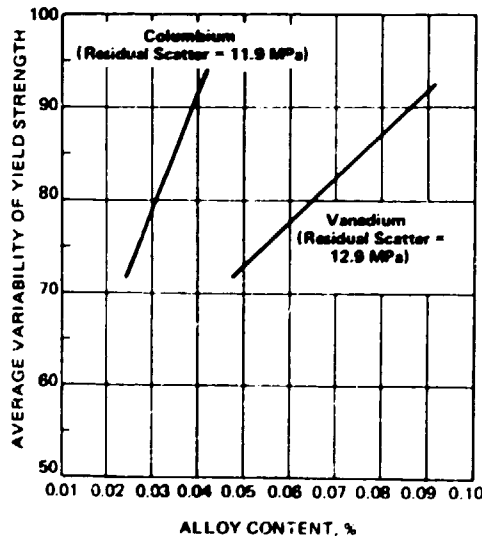


The cold forming of pearlite-free steel; compared with other steels.³

Concrete-reinforcing bar

Weise describes the development of a high-strength concrete-reinforcing bar with strict requirements for minimum yield strength, tensile strength, bend formability (including rebend requirements), fatigue strength, and weld strength. With the carbon content restricted to a 0.20% maximum to provide for good weldability, microalloying with columbium (niobium) and vanadium was a natural step in obtaining the desired 480 MPa (70 ksi) yield strength in the as-rolled condition. For the experimental heats rolled on production equipment, satisfactory yield and tensile strengths were obtained with enough consistency to allow the development of the regression equations shown in Figure 5.

FIGURE 5



- Calculated effect of alloying on variability of yield strength for 26 to 28 mm (1.0 and 1.1 in.) bar diameters.⁴

"The papers by Norring et al., ..., Kampschafer, ..., Hamilton, ..., Carter, ..., and Lubuska, ..., deal with related concepts applied to the use of heavy-plate material for pressure vessels and other heavy construction such as shipbuilding. With the exception of the steel described by Kampschafer, which is alloyed with vanadium and nitrogen, the steels are microalloyed with columbium (niobium) or columbium plus vanadium, with restrictions imposed on carbon equivalent to provide for good weldability and notch toughness. Heavy-gage steels for these applications are generally used in the normalized condition."

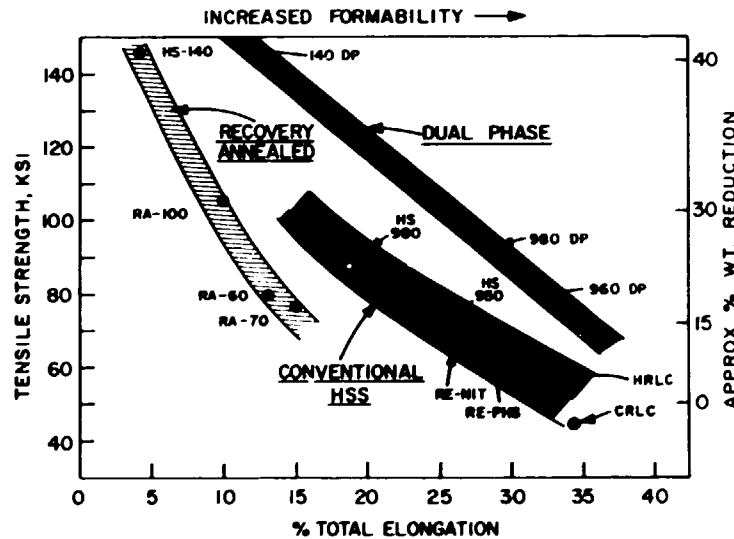
For these heavy plate applications, details about tensile and yield strength, weldability and notch toughness are given. The summary concludes with experience with microalloyed steels in construction and industrial equipment.

Automotive industry

High Strength Steels (HSS) offer a broad spectrum of opportunities for significant weight reduction in automobiles. The extracts of an article, (10) reprinted below, illustrate typical developments in the automotive industry. Steels for this application form a large market in industrialized countries. Weight saving is an important factor for energy conservation. The author discusses a wide range of high strength steels, their availability in different sizes, their application for specific parts and relative costs per unit of weight saved.

"...the two most important mechanical properties, particularly for automotive applications, are the tensile strength and the total elongation - both properties are, of course, simply measured in a tensile test...The tensile strength, ... is a reasonable indicator of fatigue resistance, ..., and crush resistance, ..., properties which dictate the design of many components. Total elongation, or overall ductility, gives a first estimation of formability, a critical property in determining the usefulness of a material in a component of complex shape. Thus, the data derived from...tensile stress-strain curves...can be re-plotted, Figure 5, to relate the tensile strength and total elongation of a variety of HSS. Note that such a comparison indicates basically three types of HSS, namely recovery annealed, conventional and dual phase steels.

Fig. 5 Tensile strength versus total elongation for a variety of HSS.



"Recovery annealed steels, which rely on cold work retained from processing, are only available over a restricted gage range of about 1.0-1.7 mm because of limitations on the rolling mill loads. In addition to the limited formability (ductility) of this class of HSS the strengthening mechanism (cold work) is inherently unstable under fatigue conditions (see later) and thus these steels must be used with caution in durability sensitive parts.

"The conventional HSS class (Figure 5) consists of the steels usually referred to as High Strength Low Alloy Steels (HSLA). These steels are strengthened by a combination of grain refinement, solid solution strengthening and precipitation hardening ... For the lower strength levels, a combination of grain refinement and solid solution strengthening is

adequate. As the strength level increases, ultrafine grain size and precipitation hardening are required. These conventional HSS are available in hot rolled gages ($>1.8\text{mm}$) over the complete strength range. However, in cold rolled gages only the lower strength levels are available.

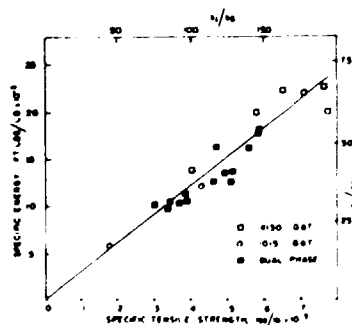
"It is fairly clear from Figure... 5 that the dual phase class of steels offer a distinct advantage from the tensile strength/total ductility basis. These steels basically consist of a dispersion of high carbon martensite in a fine grained ($<5\mu\text{m}$) ferrite matrix, produced by rapid cooling from the austenitic range. This structure is obtained as a final heat treatment stage, usually on a continuous annealing line. Consequently, dual phase steels should be available in all gages - however, limited facilities in the U.S. and Europe restrict the availability. The current steel industry expansion plans will significantly increase the availability of dual phase steels in the next five years.

"The differences in properties reflected in the classification system depicted in Figure 5 are obviously not based on equivalent costs. The better combinations of properties are accompanied by an increase in the price of the steel. For example, currently the recovery annealed are the least expensive and the dual phase are the most expensive for any specified strength level. However, if dual phase steels are produced from low carbon steels by utilizing high quench rates (as utilized by some Japanese steel companies), then the dual phase steel costs would be comparable to conventional HSS (HSLA).

"The impetus for the utilization of HSS in automotive applications rather than alternate weight saving materials (e.g. aluminium alloys, structural plastics) is basically two-fold. First, HSS offer the most favourable cost/weight trade-off, i.e. minimization of the cost penalty per pound of weight saved. For example, wrought aluminium alloys may yield a 50% weight saving in a given component application, but the associated cost penalty is usually considerably in excess of \$1 per lb. of weight saved. For the same application, HSS yield weight savings from 10-35% (depending on the strength level) at typical cost penalties in the range of 0-25 cents per lb. of weight saved. The second major reason for the rapid acceptance of HSS is the relatively minor effect on manufacturing methods and facilities. This change is, however, not simple and the proper utilization of HSS requires improved design methodology, improved stamping and assembly techniques and significant increases in material and process/quality control in both the steel and automotive plants."

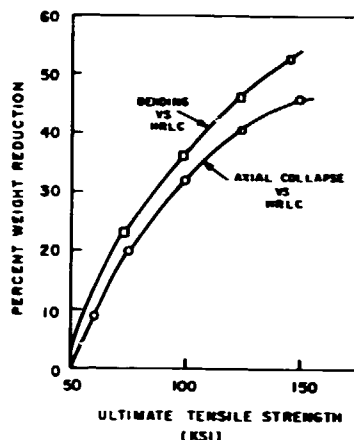
"...With respect to the materials aspects of energy absorption, the most significant effect is that the axial collapse loads are directly proportional to the ultimate tensile strength, ... - not the yield strength. (This result again reinforces the usefulness of a plot such as Figure 5 for classifying HSS). The collapse data are shown in Figure 14."

Fig. 14 The dependence of energy absorption on tensile strength for a variety of steels based on the axial collapse of tubes.



"... In Figure 15, typical weight reductions for different loading configurations are shown, as a function of tensile strength."

Fig. 15 Weight reduction as a function of tensile strength based on axial collapse and 3 point bending.



"... The weight reduction which can be achieved by substituting HSS for durability controlled components will be component sensitive since it depends on the state of loading, the particular spectrum of load-deflections and the notch sensitivity. However, one method of approach ... is to utilize a Neuber notch parameter ... at a specified life - Table I lists typical weight reductions for a variety of HSS based ... on a Neuber notch parameter for 10^7 cycles (K_N) and assuming (K_{Nt}^2) is constant. All the numbers are based on substitution for either cold rolled low carbon steel or hot rolled low carbon steel."

TABLE I
PERCENTAGE WEIGHT
REDUCTION FOR DURABILITY

MATERIAL	REPLACING CRLC	REPLACING HRLC
HS 140	45	42
DP 140	45	42
HS 100	40	35
HSLA 80	36	32
DP 80	36	32
DP 60	22	16
HSLA 50	18	12
HSLA 40	7	0

As a typical example of the use of HSS in automobiles, the 1981 model of a U.S. compact car (weighing approximately 1,000 kg) contained 85 kg of a total steel content of 500 kg (17 per cent). Of this quantity, 45 kg were HSLA-50 and 10 kg HSLA-80.

Line-pipe

This is one of the largest, but also the most demanding application for HSLA steels.

John P. Orton summarizes the papers covering this subject in the 1975 conference, mentioned on page 27 above. Aspects of line pipe production are listed as well as typical chemical compositions used by different steel producers to meet the American Petroleum Institute (API) pipe specifications. Reasons for these differences and the effects on properties, mill equipment requirements and processing choices are also discussed. Extracts of the summary (11) are given below.

"Intensive research and development has led to major advances in line-pipe technology for demanding applications, such as off-shore and arctic pipelines. The complex relationships among the metallurgical factors that must be considered in selecting suitable practices for the production of such pipe are illustrated in Table III.

TABLE III

ASPECTS OF LINE-PIPE PRODUCTION

Properties (Specification)	Factors	Tools	Metallurgical Structure
Strength - Minimum - Range	Wall Thickness	Alloy - Carbon - Columbium, Vanadium, Titanium - Nickel, Copper, Chromium - Molybdenum	Pearlite/Ferrite
	Diameter		Acicular Ferrite
Toughness - Shelf Energy - Transition Temperature - Heat-Affected Zone - Weld Metal	Bauschinger Effect - Forming - Testing	Steelmaking - Sulfur, % - Sulfide Modification - Vacuum Degassing - Vacuum Decarburization	Grain Size
	Equipment - Steelmaking - Strand Casting - Strand - Plate - Strip - U-O Pipe - Spiral Pipe		Precipitation Hardening
Strain Aging		Processing - Plate - Slab Reheat - Controlled Rolling - Controlled Cooling - Precipitation Treatment - Normalizing - Quench and Temper - Cross Rolling	Dislocation Hardening
Weldability			Solid-Solution Hardening
Stress Corrosion		Processing - Pipe - Forming Process - Cold Expansion	Anisotropy
	Costs		Cleanliness
	Availability		

"The producers have various tools available which can be applied within known limits to accomplish the desired goals. The goals consist of the strength and toughness requirements for a given pipe diameter and wall thickness. In applying the tools, account must be taken of the effects on other characteristics, such as weldability, strain aging, and susceptibility to environmental cracking. Limitations lie in the capacities and types of steelmaking, rolling, and pipe-fabrication facilities. Last, but not least, cost and availability of alloys and equipment must be considered in this analysis.

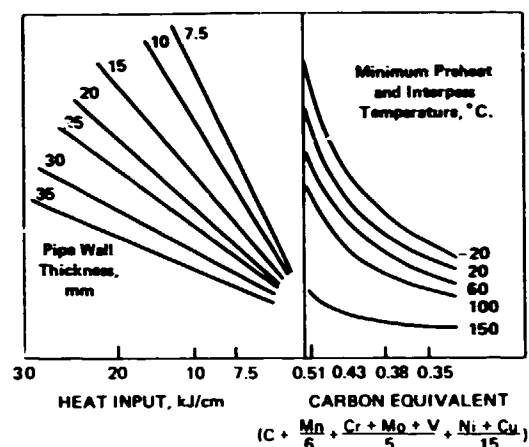
"The available technological tools consist of alloying, steelmaking, and processing."

Specifications

"... Most specifications today include limits on chemical composition that are designed to provide maximum assurance of freedom from underbead cracking. It is assumed that the pipe will be welded in the field by the manual electric-arc process using cellulosic coatings with a minimum preheat. This places a severe restriction on the chemical composition as seen in Figure 1, where the permissible carbon equivalent is related to heat input, wall thickness, and preheat temperature. Considering the weldability and weld-metal toughness may necessitate additional compositional restrictions.

"Requirements relating to material notch toughness have been the subject of much research. The need for providing a material having a ductile-to-brittle transition temperature below the operating temperature is well documented, at least for pipe with wall thicknesses up to about 20 mm (0.8 in.). The additional requirement providing for the arrest of a fracture propagating in the ductile mode has had to be established by costly burst tests."

FIGURE 1



The permissible maximum carbon equivalent for butt welds in line pipe using cellulosic (EXX10) electrodes based on minimum preheat and interpass temperature, pipe wall thickness, and heat input.¹

Alloy systems

"... To summarize the effects of chemical composition, the most common starting point is a low-carbon steel microalloyed with columbium (niobium). Carbon and columbium are the major factors in controlling strength, toughness, weldability, crack sensitivity of the heat-affected zone (HAZ), and the susceptibility to hydrogen or stress-corrosion cracking.

"Much research has been done on the effects and interaction of other elements used to supplement and control the material properties. The alloying elements may be grouped according to their major functions - additional precipitation hardening (vanadium, titanium, and high copper, accompanied by nickel); solid-solution strengthening (nickel, copper, and chromium); and high-hardenability additives (molybdenum, high manganese, and chromium). Presently, there are two basic types of steel - pearlite-reduced polygonal-ferrite steels and low-carbon acicular-ferrite steels."

TABLE I

TYPICAL CHEMICAL COMPOSITIONS OF EXPERIMENTAL AND PRODUCTION STEEL AS SHOWN IN LINE-PIPE PAPERS

Company	Grade	Thickness	Carbon	Manganese	Silicon	Columbium	Vanadium	Molybdenum	Nickel	Chromium
Australian Iron & Steel	X65	10.2 mm	0.17%	1.30%	0.25%	0.045%	-	-	-	-
Usinor	X65	16 mm	0.12%	1.45%	0.30%	0.045%	-	0.22%	-	-
IPSCO	X70	11.9 mm	0.045%	1.89%	0.10%	0.077%	-	0.25%	-	-
U.S. Steel Corp. Research	X65	12.7 mm	0.07%	1.40%	0.25%	0.035%	-	0.30%	-	-
Kawasaki Steel	X70	25 mm*	0.06%	1.70%	0.25%	0.04%	0.03%	-	0.30%	-
			0.07%	1.80%	0.25%	0.055%	-	-	0.20%	
			0.05%	1.80%	0.25%	0.06%	-	0.10%	-	
Nippon Kokan K.K.	X70	19 mm	0.08%	1.50%	0.30%	0.035%	0.10%	-	-	-
Hoesch-Estel	X65	15.1 mm	0.13%	1.62%	0.26%	0.039%	0.053%	-	-	-
Nippon Steel	X70	19 mm	0.10%	1.40%	0.25%	0.045%	0.10%	-	0.30%	-
		20 mm	0.08%	1.75%	0.11%	0.047%	0.25%	0.20%	-	
		X70 Q&T 15 mm	0.10%	1.30%	0.30%	0.03%	-	0.45%	-	
Sumitomo Metal Industries	X65	19 mm	0.09%	1.39%	0.33%	0.018%	0.08%	-	-	-
Italsider	X60/65	15 mm*	0.14%	1.50%	0.30%	0.04%	-	-	-	-
		X60/70	15 mm*	0.13%	1.50%	0.30%	0.035%	0.07%	-	-
		X70	30 mm*	0.06%	1.65%	0.35%	0.06%	-	0.35%	0.30%
USSR Research	X65 Normalized	40 mm*	0.15%	1.30%	0.23%	-	0.13%†	-	-	-

*maximum thickness
†plus 0.028% nitrogen

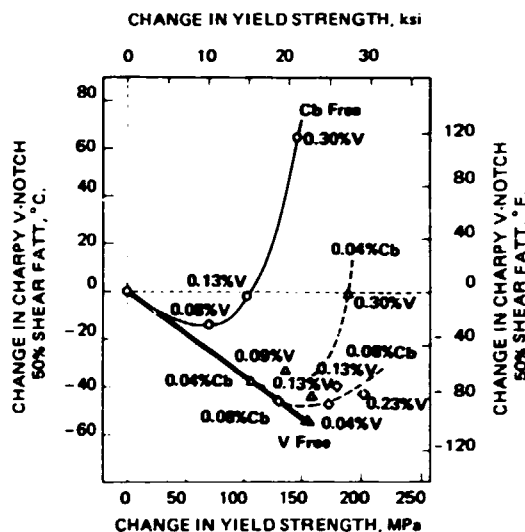
"The chemical compositions of the line-pipe steels given in this session (Table I) reveal a common pattern. Most steels are under 0.12% carbon. All but the normalized steel contain columbium (niobium), which provides the all-important grain-refining effect that increases the yield strength and counteracts the embrittling effect of precipitation hardening.

Vanadium and titanium

"In the 0.08 to 0.12% carbon range, vanadium may be added to increase the yield strength by additional precipitation hardening, though this may increase the fracture-appearance transition temperature (FATT)...."

"As seen from Table I, most experience is with columbium contents to about 0.07% and vanadium contents to about 0.10%. Figure 7 from Yamaguchi et al. summarizes the interaction effects of columbium and vanadium on strength and transition temperature of the polygonal-ferrite base plate. The position of the curves would probably change somewhat with carbon content."

FIGURE 7



-- Effect of columbium and vanadium on the yield strength and notch toughness (measured by the Charpy V-notch 50% shear fracture-appearance transition temperature (FATT)) of 20-mm thick controlled-rolled plate.⁷

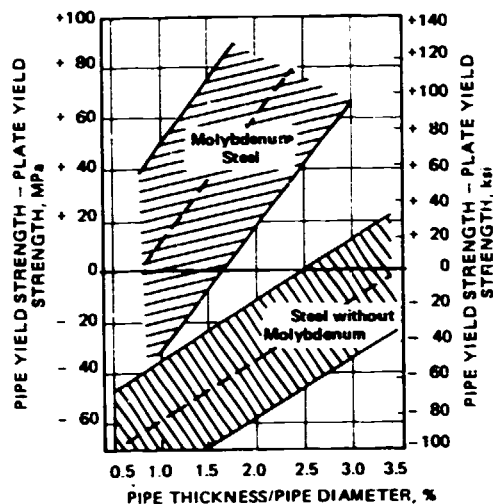
"...the use of small titanium additions (about 0.02%) (enhances) grain refinement, yield strength, and toughness. The improvement is related to raising the grain-coarsening temperature. This factor could also have a beneficial effect on HAZ toughness. With regard to any possible reduction in strain aging, the titanium effect would be masked by the presence of rare earths.

Role of molybdenum

"The addition of molybdenum contributes to the development of an acicular structure which allows the attainment of high strength at very-low-carbon levels. The advantages of these steels in expanded pipe are well covered..."

"Figure 8...shows the yield-strength response of molybdenum-alloyed steels to the forming of pipe from plate by the U-O process. In the presence of acicular constituents in the microstructure, there is no discontinuous yielding, and strain hardening is induced during pipe forming and cold expansion. However, ... the degree of acicularity also depends on the austenite-grain size, as influenced, for instance, by the slab-reheating temperature and the degree of controlled rolling. A fine-grain size reduces acicularity as might be expected from the known effect of grain size on hardenability."

FIGURE 8



- Effect of pipe geometry on difference in yield strength between pipe and plate of X60 and X65 steels.³

Other alloying elements

"Small quantities of other alloying elements, such as copper, chromium, and nickel, help to increase strength by solid-solution hardening and grain refinement as a result of lowering the transformation temperature. This in turn enhances the precipitation-hardening effect of columbium (niobium) and vanadium in ferrite."

Mill equipment

"The importance of the mill capability to roll according to the criteria outlined above is well documented, especially by Suzuki. The criteria include the capability for heavy passes during roughing of thick slabs, for relatively rapid cooling during holding periods, and for high reduction during the last finishing passes at low temperatures - at least as low as 700°C. (1290°F.) and in plate thicknesses to about 30 mm (1.2 in.)."

"Similarly, continuous hot-strip mills must be capable of the desired critical rolling reductions at temperatures below those normal for strip-mill rolling. The high-columbium (about 0.10%) approach to high strength offers an alternative possibility for producing reasonable high strength with good toughness without requiring low-finishing temperatures and hence, permitting lower mill loading. The toughness of welds produced with high-columbium steels is still under investigation."

Processing choices

"...In conjunction with the steel chemistry and available mill equipment, subsequent processing is designed to optimize the mechanical properties. Primarily, the effect on strength and toughness is obtained through control of grain size, though phenomena such as precipitation hardening and transformation are influenced as well. The choice of processing normally includes normalizing, controlled rolling, and controlled cooling. The effect of normalizing is maximized by vanadium plus nitrogen. In controlled rolling, vital roles are played by variables such as slab reheating, percentage of reduction at given stages, and finishing temperature. When finishing below the A_r3 temperature, additional strengthening by dislocation hardening is possible. In strip rolling, aging during slow cooling in the coil is important. High strength may be developed also by quenching and tempering."

"The steelmaking process must be adjusted to the mechanical-property requirements, mainly by control of the sulfur level and the type of sulfide inclusion. This may involve some type of special desulfurization and modification of the sulfide from plastic to re-

fractory. If very low carbon is required, overoxidation of the bath is a hazard. This may be alleviated by the use of low-carbon alloying agents or the use of vacuum-carbon deoxidation, if vacuum-degassing equipment is available.

"The mechanical properties of the formed pipe are influenced by the forming process. The existence of the Bauschinger effect is well known, and forming and alloying techniques have been developed to minimize it. Finally, the properties in the plate or strip must take into account the tensile-testing procedure and the testing orientation with respect to the rolling direction.

"Current developments are concentrated on controlled-rolling techniques for ferrite-pearlite steels, properties of very-low carbon acicular or copper precipitation-hardened steels, and the quenching-and-tempering process."

D. Availability of alloying materials

By definition, microalloying employs only very small amounts of alloying elements, mostly below 0.1 per cent.

The absolute quantities of steels produced, however, show rapid growth. At this stage 6-7 per cent of the steels produced in the United States are of HSLA-quality. (12) In Europe and Japan the percentage could be even slightly higher.

Therefore consumption of microalloying elements, particularly vanadium and niobium, is substantial and constitutes 90 and over 80 per cent respectively of the worldwide usage of these elements. This is not true for titanium, where other applications are far more important.

While the supply of all alloying elements in use or under consideration for HSLA steels is at this time more than adequate, consideration must be given to the fact, that the supply of several of them lies concentrated with a limited number of countries and/or mining companies.

Temporary disruptions of supply and corresponding price increases are conceivable. Fortunately several microalloying elements can be used interchangeably; similar properties can be achieved with modification of alloy content and processing variables.

Vanadium (13)

Vanadium is chiefly recovered as a by-product or co-product. Close to 80 per cent of total world output is derived from titanium-bearing iron ores; the vanadium, with grades of 1-2 per cent in iron ore, is recovered by treating blast furnace slag. Other sources of vanadium are uranium ores, primarily in the United States, which account for some 15 per cent, and base metal deposits (Namibia).

Vanadium-containing iron ores are exploited in South Africa, the Soviet Union, Finland, Chile and other countries.

Total world production in 1979 is given at about 38,000 tons. The leading producer is South Africa, accounting for about 33 per cent of world production, followed by the Soviet Union (27 per cent), China (17 per cent), the United States (13 per cent) and Finland (7.5 per cent). Vanadium reserves are even more concentrated than production. Out of 16 million tons of vanadium reserves, 95 per cent is estimated to be in two leading producing countries, South Africa (49 per cent) and the Soviet Union (46 per cent).

Vanadium is initially recovered in the form of vanadium pentoxide (V_2O_5). The oxide is converted to ferrovanadium, the most common commercial product for use in steelmaking. The vanadium content in ferrovanadium ranges from 38 to 80 per cent, with varying quantities of carbon, silicon, and other elements.

Ninety per cent of the total use in the United States is for low alloy steels. Consumption patterns in other countries are thought to be similar. Vanadium used in steels may be interchangeable with various other elements, such as niobium, molybdenum, titanium and tungsten. The substitution between them depends on the relative costs, their availability and technical performance.

Niobium (14)

In the United States this element is known still as columbium. Substantial technical usage started only after the development of two large pyrochloric ore bodies in Brazil and Canada in the early 1960s.

These two countries supply over 90 per cent of present niobium consumption. Further sources are the minerals tantalite, columbite and tin slags.

Total world production in 1980 is given at about 16,000 tons. The leading producer is Brazil (85 per cent), followed by Canada (7.5 per cent), and Nigeria (3.6 per cent).

The economically recoverable reserves for niobium are given at 17 million tons.

Niobium is initially recovered in concentrates of either pyrochlore, or columbite or tantalite and also from tin slags with a content of about 60 per cent niobium pentoxide (Nb_2O_5).

The oxide is converted to ferroniobium for steelmaking and into high purity metallic and nonmetallic products for other uses. Over 80 per cent of the total niobium use is for low alloy steels. As with vanadium, substitution of niobium in these steels is possible.

Molybdenum (13)

Close to 60 per cent is derived from mines which exclusively or predominantly produce molybdenum, and most of the remainder comes from copper mines; a small amount is also produced as a co-product of tungsten and other metals.

Sixty-one per cent of global output in 1980 came from the United States; the balance came from Canada (13 per cent), Chile (12 per cent), Soviet Union (10 per cent). Total world production that year was about 106,000 tons. Molybdenum reserves are given at about 8.5 million tons; with about half in the United States and about 30 per cent in Chile. Molybdenum is added to steel in the form of molybdenite (MoS_2), the product of concentration through flotation, molybdic oxide (MoO_3) which is produced by roasting of molybdenite concentrate, in metal form, and as ferro-molybdenum. The most important being the oxide. Forty-six per cent of molybdenum used is for alloy steels. Molybdenum can in part be substituted by other alloying materials, specifically tungsten.

Manganese, silicon (15)

Mine production of manganese ore in 1980 was 22 million tons. Major ore producers were the Soviet Union (41 per cent), South Africa (20 per cent), Gabon (9 per cent), India (7 per cent), Australia (6 per cent) and China (5 per cent).

World production capacity for ferro-manganese, silicon-manganese and ferro-silicon, the main alloying constituents for steel plants, is geographically very widely dispersed. The same is true for silica, the raw material for silicon production.

For example, of the 1980 production of 5.2 million tons of ferro-manganese, about 10 per cent was produced in America, 30 per cent in Western Europe, 17 per cent in Asia, 10 per cent in South Africa and about 33 per cent in various countries of Eastern Europe.

Production capacity for these alloys exists in most steelmaking countries and the production source for their consumption depends mostly on political and economic considerations. Sufficient supply appears virtually everywhere guaranteed.

Other alloying elements

For titanium, aluminium, nickel, copper, chromium and similar elements, alloy steels constitute less than 15 per cent of their total consumption.

Therefore also for these elements no important availability problems can be expected, particularly as substitution for this application is easy.

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Current Awareness

A. News items

This section is in the nature of an experiment. The Technology Programme would like to know whether the readers of the Monitor would like more space to be given to such a section in future issues.

New alloy materials

"New alloy coatings have been developed to protect coal gasification equipment parts from corrosion and erosion by the Lockheed Palo Alto Research Lab for DCE. A coating of chromium and aluminum alloyed with iron nickel, or cobalt and a small amount of hafnium protects the heat- and corrosion-resistant alloys from oxidation and sulfidation. Improved corrosion and erosion resistance are imparted to equipment parts by fusion either under a laser beam or in a vacuum furnace. The critical laser-process parameters of both pulsed YAG lasers and continuous wave CO₂ lasers are power density and interaction time, which must be adjusted to melt the coating with minimal heating and melting of substrate in order to achieve resistance to low Btu coal-gasification atmospheres containing 1% hydrogen sulfide at 1,800°F (980°C)." (NTN Energy, 3/83, p.11.)

"Aluminum may develop into the 'wonder metal of tomorrow', according to Lockheed research scientist L. Langerbeck. Aluminum-lithium alloys will provide component weight-savings of 10-20 per cent over conventional aluminum alloys, making them competitive with composites and significantly less costly to produce. If applied to current subsonic aircraft, such a weight saving could reduce fuel consumption by millions of gal/yr. New high-temperature aluminum alloys will raise maximum possible operating temperatures 100+ per cent from 300°F to 650°F, while at the same time reducing weight 20-30 per cent for specific components. This would make the aluminum alloy competitive with titanium for supersonic and hypersonic aircraft. Metal matrix composites made of aluminum and silicon-carbide have produced a material 100 per cent stiffer than either unreinforced aluminum or titanium. The superplastic behavior of some aluminum alloys already permits easier fabrication of complex shapes and low-cost tooling." (Flt Intl, 2/12/83, p.398.)

"Aluminum Co of America has developed 3 low-density aluminum-lithium aircraft alloys formulated to maximize damage tolerance or strength. The alloys may contain up to 15 per cent lithium, aluminum and other undisclosed metals. Replacement of 160,000 lb of aluminum used in commercial jet liners could reduce their weight 12,000 lb, cutting fuel consumption 220,000 gal/yr/plane." (C&E News, 5/30/83, p.24.)

"New stainless steel without nickel or chromium for marine applications is discussed by R.Wang and F.H. Beck of Ohio State U. Dept. of Metallurgical Engineering's Fontana Corrosion Center (Columbus). Alloy Fe-30Mn-10Al-Si has good marine corrosion resistance and good cavitation erosion resistance. Its hardness and tensile strength properties are better than those of brass, the normal choice for propellers for seagoing vessels. The metallographic structure of the alloy in the as-cast condition is based on an austenitic matrix. Based on the results, the alloy was selected for a propeller made by the Qing-dao Institute of Mechanical Engineering (China), the first being installed on a fishing vessel launched in 8/80. Modification of the alloy should bring about more improvements in mechanical properties and corrosion behaviour. Research is continuing." (Metal Prog., 3/83, p.72-76.)

New products

"Aluminum Co. America and Continental Can jointly plan to produce a 2-piece recyclable aluminum food can that could be commercially produced by mid-1984. Alcoa (Pittsburgh, PA) said \$6 million is being spent on capital equipment to get the project going. The first cans could be ready for testing by vegetable packers in 2nd-half 1983. Equipment that was built by Stille Co. (Sidney, OH), a wholly owned Alcoa subsid, will be installed in a Continental Can Co. (Stamford, CT) plant. Developmental steps critical to the project's viability: alloy development, coatings and structural can design. The can uses 5042 aluminum alloy that allows producers to go down to a 0.009 gage, vs the 0.010 gage possible with 5352 alloy. Another element is Alcoa's patented Electro-coat process, a high speed, sanitary coating process for 2-piece aluminum cans with cost and energy savings advantages. The technology has been adapted from established electrophoretic methods used by the automakers and other manufacturers to coat metal with paint in an electrically charged, water-based solution. Another element is the structural can design, offering a lighter weight product." (Am Mtl Mkt, 2/4/83, p.1,16.)

"Kobe Steel's (Japan) new aluminum alloy stock for 2-piece can bodies has a higher strength and workability than present aluminum alloy stocks. Features of the 'KS3004-H191': it can be thinned down to 0.12"; the strength including pressure resistance and bend resistance of the can bodies is higher than present aluminum stocks; it has a corrosion resistance the same as JIS A3004; the composition satisfies the standard of A3004; the yield point of baked can bodies is 36 to 40 kg/in² at 0.12" thick; and the work hardening features are better than the present A3004-H19." (Light Mtl, 2/83, p.34).

"Kobayashi Shipbuilding's new all-aluminum alloy fishing boat is 30 per cent lighter and cuts fuel consumption 20 to 30% vs fiber reinforced plastic ships, although it cost 20% more to produce. The 14 grs ton Shinko Maru was built using Kobe Steel Ltd. technology in aluminum welding, forming and processing. The ship has a durability of 20+ years, excellence in corrosion resistance, and lower costs in maintenance such as painting, and can be sold for scrap. Japan now has 264 aluminum alloy ships with most of them being built in the past few years." (Am Mtl Mkt, 2/11/83, p.6.)

"Ford Motor's (Dearborn, MI) new concept in steel bumper design reportedly rivals conventional aluminum bumpers in weight and costs less than aluminum or soft-fascia bumpers. The firm said an experimental all-steel Fairmont bumper using the SS design concept was developed for comparison with the production bumpers on Fairmont models, which use aluminum. The steel bumper came within 1 lb of the aluminum unit. Chrome-plated steel bumpers using the select strength design have not yet been used in any production by Ford, but the principal components of the fascia-covered bumpers on Ford's 1983.5 Thunderbird are steel beams using the SS design. The Thunderbird beams cost a few dollars less to produce than steel beams of conventional design and provide savings over aluminum beams of similar strength. The T-Bird bumpers use high strength, dual phase steel with an 85,000 psi tensile strength supplied by US Steel Corp (Pittsburgh, PA), and are formed at Ford's own bumper plant in Monroe, MI." (Am Mtl Mkt, 2/14/83, p.15.)

New processes

"New methods for casting metal alloys are a key area of study in the General Electric Research and Development Center's expanded Metallurgy and Ceramics Building ...

"An experimental spin-casting apparatus is used to produce sample quantities of an advanced "rapidly quenched" alloy. The casting process involves squirting molten alloy onto a cold copper wheel spinning at speeds of up to 110 km/hr. In less than a thousandth of a second, the alloy hardens into a long, thin strip exhibiting unique properties.

"The result of cooling from a white-hot molten state into a room-temperature solid in a fraction of a second is the formation of materials with unique atomic structures. Solids with amorphous forms resembling glass have also been formed. The materials have higher strength, superior corrosion resistance and, says the company a "host" of other unique properties." (IAMI, 5/1983, p.16.)

"Battelle Memorial Institute will study applications of its new fast-rate electro-deposition (FRED) stainless steel coating technique. The process, covered in a recent patent application, would provide iron-chromium-nickel alloy coatings of commercial quality previously only available through cladding techniques. Potential substrate materials might include any electrically conductive surface, most likely such materials as copper and ferrous alloys like low carbon steel. Stainless steel clad or coated parts would be less expensive to produce than components made from a stainless steel alloy, which is often difficult to machine." (Tech Fore, 4/83, p 5,6.)

Conference News

- An International Conference on Technology and Applications of High Strength Low Alloy Steels was held at Philadelphia, United States, 3-6 October 1983, in conjunction with the 1983 Metals Congress. Over 100 technical papers were presented at the Conference and most of them are now available as individual reprints from the sponsor of the Conference, American Society for Metals, Metals Park, Ohio 44073, United States of America.

- An International Conference on Structure and Properties of High-Strength Low-Alloy Steels will be held from 20-24 August 1984 at the University of Wollongong, Wollongong, New South Wales, Australia and co-sponsored by AIME. Further information is available from Dr. T. Chandra, Department of Metallurgy at the University of Wollongong.

B. Information sources

A comprehensive resource of metallurgical information is an annual Bibliography Series. Each year more than 4,000 technical papers, based on theory and practice, enter the METADEX data base; over 500,000 are computer-searchable, covering over 1,200 journals, plus the international conference and technical book literature. The cost of each bibliography is \$50 or £27,50, and can be obtained from:

Metals Information
American Society for Metals
Metals Park, Ohio 44073 U.S.A.
(216) 338-5151 TELEX: 980 619

Metals Information
The Metals Society
1 Carlton House Terrace
London SW1Y 5DB England

The cost of each bibliography for an ASM or Metals Society member is \$45.00 or £25.00.

The Metals Information Catalogue lists the other services provided by these two societies. Titles of some bibliographies are given below.

Melting/refining/reduction

101 - Deoxidation of molten metals

Ladle refining in iron and steelmaking: effects of deoxidation on machinability, brittle fracture resistance and surface quality/the use of complex deoxidizers; effects of rare earth deoxidizers on sulfide inclusions; and the kinetics of removal of deoxidation products.

106 - Iron and steel desulfurization

Effect of manganese; injection of alkali-bearing slag powder; injection of magnesium; boundary layer concepts; influence of lanthanides; effect of synthetic slags; submerged lance technology; influence of slag refining; reactor models; effect of steel scrap quality.

108 - Ladle metallurgy

Desulfurization and deoxidation by ladle power injection; sulfide shape control; effects of inclusion modification on mechanical properties and machinability of steels; microalloying in the ladle; process optimization; improvement of productivity of iron and steelmaking technologies.

Heat treating/hard surfacing/surface finishing

608 - Heat treatment of alloy steels

Both high and low alloy steels/high strength and HSLA steels; chromium, chromium molybdenum, chromium vanadium, and nickel chromium molybdenum steels; manganese and silicon manganese steels; others.

Materials

1001 - High strength low alloy steels

The properties, uses, and workability of these important steels are emphasized, in recognition of their increasing importance.

1005 - Superalloys

Fabrication technology; investment casting, joining and machining; selection and testing; development of compatible coatings; production of superalloy powder; mechanical and physical properties.

1203 - Dual phase steels

Commercial development and applications; influence of dual phase microstructures on mechanical properties and formability; work hardening properties; effects of thermo-mechanical treatments.

C. News from developing countries

Regional centre for mineral exploitation in Africa

Eight African countries are to set up a regional centre for mineral exploitation. The countries are Burundi, Central African Republic, Congo, Equatorial Guinea, Gabon, Rwanda, United Republic of Cameroon and Zaire.

The aims and activities of the planned centre will cover the following:

- Collection and organization of data on each central African country's current mining and geological activities and promotion of an information exchange among member states;
- Consultation services for the launching of new mining activities, including their planning, efficient execution and evaluation of geological, chemical and physical studies;
- Acquisition of technical know-how for the identification of mineral matter;
- Assistance to technical and profitability studies for the evaluation of reserves, rational exploitation of deposits and local refining of raw materials;
- Specialized laboratory and equipment maintenance services;
- Promotion of multi-national co-operation and inter-African projects in geological and mining studies.

The idea of establishing centres to exploit mineral resources in every region of Africa was born in February 1968 during a seminar on new metals and minerals held in Addis Ababa.

An agreement between the Economic Commission for Africa (ECA) and the Congolese Government sets out guidelines for the centre's headquarters which will be in Congo.

* * *

The following article has been excerpted from Natural Resources Forum, vol. 3, No. 4 (July 1979), prepared by the United Nations.

Technical Co-operation in mineral surveys: An example from Lesotho by J.J. Reed*

The Lesotho Government is currently undertaking mineral inventory surveys of the whole country in association with the United Nations and a number of bilateral donor countries. The major programme is the United Nations Exploration for Minerals Project being executed by the United Nations and the Department of Mines and Geology, the Government implementing agency. Included in this exercise are technical experts from the Government of Lesotho, the United Nations and several bilateral donors. The Canadian International Development Agency (CIDA) is supplying airborne geophysical surveys and ground follow-up in close co-operation with the project.

Besides the sedimentary and volcanic rocks, two intrusive types of rocks are found in Lesotho - flat lying sills and vertical dykes of dolerite and circular kimberlite pipes. The former can be used as aggregate for building and road construction, while kimberlite is the host rock for diamonds. Diamond exploration has formed a major part of the United Nations project: in fact, it was previously known as the 'Exploration for Diamonds Project.'

Exploration for Minerals Project

The ultimate development objective of the project is to promote growth, increase domestic employment and establish economic independence. The immediate goal is the completion of an inventory of the mineral resources of Lesotho. If potentially economic mineral deposits are discovered, and if such discoveries are exploited according to Government mining policy, the impact on the economy will be significant.

* Project Manager, LES/73/021, P.O. Box MS 301, Maseru, Lesotho.

The inventory includes location sampling, and, where warranted, initial assessment of grades and tonnages of all minerals (metallic and non-metallic) of possible economic interest. The major targets are diamond, uranium, coal and base metals (copper, nickel, lead, zinc and molybdenum), but any mineral resource with potential use or value is being investigated. This latter group includes industrial minerals for building and road aggregates, which in many countries constitute the most important mine products. In conjunction with the exploration activities, the project aims to establish the nucleus of a national Geological Survey.

The potential benefits to the country from the project range from those that are certain, such as compilation of geological maps and institution strengthening, to those that are uncertain, such as the discovery of large exploitable mineral resources. Such discoveries could revolutionize the economy if they materialize, but, as is the case with all mineral exploration, a favourable outcome cannot be predicted.

By its nature exploration involves extensive field surveys, and these constitute the basis of the project. Probably the most important is the systematic regional geological survey of Lesotho based on map sheets of a scale of 1:50,000, together with geochemical stream sampling. This programme follows standard exploration procedure which consists of an initial screening of the country to enable selection of exploration targets for subsequent detailed examination.

Another standard exploration procedure being used for the initial screening in Lesotho is an airborne geophysical survey.^{1/} Two other major exploration activities of the project are drilling and bulk sampling. Training of Lesotho staff is another major objective of the project. It is expected that the trainees will form the nucleus of a national geological survey when the project is completed. Special attention is being paid to on-the-job training of technical assistants, and short courses are planned at appropriate institutions abroad for selected candidates.

Co-operation inputs

The Department of Mines and Geology, as the Government implementing agency, has the overall control and direction of the mineral inventory surveys of Lesotho. The department is headed by a Commissioner of Mines, who is the Government project representative and is responsible for ensuring the necessary technical and administrative support for the project and for the co-operation of other agencies involved or associated with the project. The senior geologist of the Department of Mines and Geology is the project co-manager and works closely with the project manager. He is especially charged on behalf of the Government project representative for the latter's responsibilities as they relate to the provision of counterpart personnel, services, facilities, equipment and supplies to be made available to the project, and with the co-ordination of bilateral assistance.

The major Government inputs are assignment of national staff ranging from professional staff, technical assistants, mineral examiners, draughtsmen and drivers to skilled and unskilled labourers; provision of buildings and premises; and provision of equipment and supplies. The Government also provides utilities, animal hire and local air transport and operates a local purchase and supply agency on behalf of the project.

The United Nations Department of Technical Co-operation for Development (DTCD), as the executing agency for the United Nations Development Programme, is responsible for the organization and direction of the Exploration for Minerals Project. The main technical inputs include assignment of personnel and provision of additional support. The international staff recruited by the United Nations for the project includes five professionals: the project manager responsible for the planning and execution of the project; two economic geologists; a mineralogist/petrologist and a diamond prospecting engineer. Other DTCD responsibilities include organization and supervision of a sub-contracted fracture analysis study of 7500 sq. km. of central Lesotho; provision of United Nations volunteers who are employed as field geologists assisting in the regional geological survey and geochemical stream sampling; and logistical support.

1/ D.A. Harkin, "Systematic mineral exploration," Natural Resources Forum, vol. 1, no., 1, 1976, pp. 29-37.

2/ Ibid.

CIDA has made a major bilateral contribution to the Exploration for Minerals programme. Project components provided by the Agency include the airborne magnetic and radiometric airborne survey of 4800 sq.km. of the western lowlands and geological training of nationals in Canada. CIDA initially provided two field geologists who were attached to the project for the regional systematic geological survey and geochemical stream sampling. However, following the encouraging results obtained from the airborne magnetic survey they were replaced by a separate team of two geologists and a geophysicist who are undertaking field follow-up of the airborne magnetic anomalies.

A particularly valuable contribution to the Exploration for Minerals project has been the assignment, through the UNDP, of associate experts from various donor countries, principally Belgium, the Netherlands and Denmark. These associate experts have worked primarily as field geologists on the systematic regional geological surveys and geochemical stream sampling.

The Project is making maximum use of the opportunity provided by the presence in Lesotho of a relatively large number of experienced international personnel.

Conclusion

The Exploration for Minerals Project in Lesotho is an example of multi-donor co-operation in mineral inventories and may encourage similar co-operative efforts elsewhere. Attention is drawn particularly to the association between the United Nations and CIDA, and to the valuable contribution of various donor countries in the provision of associate experts. The sum of the co-operative inputs has been considerably greater and more effective than if they had been provided separately and piecemeal.

* * *

The following items are based on information which originally appeared in "The Developing World" column of the publication Iron and Steel International and appears here with the kind permission of the publishers. The date given in brackets after each item indicates the issue of Iron and Steel International in which the item was published originally.

Bilateral co-operation and technical aid

Africa

Algeria - India to have more co-operation

India and Algeria have identified specific possibilities for collaboration in steel plant construction, commercial vehicles and engineering. India is to assist in the setting up of a design and consultancy bureau in Algeria's steel sector and two-way trade between the countries will be expanded. (April 1983)

Nigeria discusses help from USSR

Last year talks were held on further Soviet participation in the construction of the Ajaokuta steel plant which is well underway. Initial production at the plant is estimated at 1.3 million t/a and full production capacity will be over 5 million t/a. At present the USSR provides building equipment and helps train personnel for the plant. (February 1983)

SAIL training for Nigerians

The Steel Authority of India Ltd (SAIL) has entered into an agreement with Metallurgical and Engineering Consultants (India) Ltd (MECON) for the training of personnel from the Delta Steel Company of Nigeria. The Nigerians will be trained in various fields of specialization at the SAIL plants and the duration of the training will be about 23 to 25 weeks. SAIL has been training foreign nationals, particularly those from developing countries, in various aspects of steelmaking for some time. So far, more than 500 technical personnel from Afghanistan, Burma, Federal Republic of Germany, Indonesia, Iran, Nigeria, the Philippines, the Republic of Korea, Sri Lanka, and Viet Nam have been trained by SAIL. (April 1982)

East Asia

China's steel works: help from Japan

Japan has signed an agreement to lend China the equivalent of \$1.37b to finance continued construction of China's massive Baoshan steelworks near Shanghai and a petro-chemical complex in Daqing. (April 1982)

Latin America

Mexico - Aid from Japan

Atlatx SA of Mexico are to receive technical aid from a Japanese steel corporation. The agreement calls for operational guidance and advice on a special steel bar manufacturing plant. The contractor will also accept Atlatx trainees at its works. Facilities at the plant will include electric furnaces, an intermediate (billet) rolling mill and a bar rolling mill. Its capacity will be expanded to 150,000t a year by 1983 and further to 500,000t by 1988. (April 1982)

Production and export

General - Developing world spurs increase in consumption

Steel consumption in the Western world will rise at a rate of about 1.7 per cent annually to the year 2000 - in contrast to the 1.4 per cent growth projected for East European countries - according to analysts at SRI International, California, United States.

This 1.7 per cent growth rate represents an averaging of anticipated growth in the Western industrialized nations, where steel consumption is expected to show a modest upward trend of about 1.0 per cent annually, and in the developing countries, which should enjoy nearly 4.0 per cent average annual increase.

While developing countries have historically depended on imported steel to supply substantial portions of total steel consumption, they will gradually become more self sufficient in this area, forecasts the manager of SRI's Metallic Mineral Programme.

Thus, steel production is likely to increase nearly 6.0 per cent annually during the 1982-2000 period in the developing countries, and the incremental increase is 'virtually certain' to outpace the absolute gain in developed countries by a significant margin. (October 1982).

Latin America

General - ILAFA forecasts slight growth

As a result of the region's recessive economic performance in the last two years the Latin American iron and steel industry has regressed.

In 1981, production fell by 7 per cent and in 1982, it stagnated at 27 million tons. But these performances are encouraging compared with a fall of 13 per cent in the industrialized countries and of nearly 40 per cent in the United States. Raw steel consumption in the region decreased by 8.4 per cent in 1981 and according to preliminary estimates, in 1982 it ought to remain stationary, at around 34 million tons in terms of ingots. Apparent consumption per capita was of the order of 99 kg, against the 1982 peak level of 110 kg.

Brazil accounted for nearly 49 per cent of the Latin American total steel output in 1982, Mexico was second with around 7 million tons, followed by Argentina (3 million tons) and Venezuela (2,5 million tons). These four countries produced nearly 95 per cent of Latin American steel.

The trend towards modernization was clear. Basic oxygen furnace steel production amounted to 13 million tons, accounting for nearly 50 per cent of the total production and continuous casting had a 40 per cent share. A decade ago, these processes accounted for only 19 per cent and 15 per cent of total steel production, respectively. Direct reduction output increased from 800,000 tons in 1972, to nearly 5 million tons in 1982.

Against the background of an uncertain world economy and balance of payment and inflation problems, it is estimated that the region will grow at best at a rate of 2-3 per cent in 1983 and of 4.5 per cent in 1984. The 37 million tons 1980 record level of apparent consumption will be recovered only around 1984-1985. Crude steel production, if conditions are favourable, could be of the order of 30 million tons in 1983, surpassing the peak level attained in 1980.

Latin American steel production (million tons).

	1972	1981	1982 *
Iron ore	83.5	120.5	-
Pig iron	9.5	16.9	16.7
Sponge iron	0.8	4.4	4.8
Crude steel:	15.4	27.0	27.0
Electric furnace	4.3	10.5	10.7
Open hearth	7.6	3.2	3.1
Converters	3.5	13.3	13.2
Rolled products:	13.0	22.4	22.9
Flats	6.4	10.5	10.9
Non-flats products	6.0	10.9	11.0
Seamless tubes	0.6	1.0	1.0

* Estimated figures

Source: Latin American Iron and Steel Institute (ILAFI)

- No data

South-East Asia

Indonesia - Import changes cause concern

Procedures for the import of steel and other products have been changed so that steel importers will now have to obtain government approval on every import. Japanese firms are concerned about the change in import procedures in connection with moves by state-run Krakatau Steel to purchase hot coils en bloc.

Restrictions on imports of billet and wire rods began in 1981 and Krakatau already serve as the only channel for billet imports. It is now generally thought that hot coil imports will be transferred to a collective purchasing formula to be undertaken by the same company. (February 1983)

Malaysia - Bar import ban severely criticized

The total ban on steel bar imports, imposed by the Malaysian Government in November 1982, was because Malaysia's minimal tariff and non-tariff barriers have made the country an easy dumping ground.

Local steel mill stocks were reportedly a record 90,000 tons in October 1982 with foreign imports reaching 100,000 tons that month.

Malaysia currently produces about 350,000 tons of bars a year but this is expected to double next year when the country's two biggest manufacturers complete expansion projects. (April 1983)

Republic of Korea - POSCO plans increased output

Pohang Iron and Steel Corporation (POSCO) is planning to increase rolled steel production by about 32 per cent in 1985 compared with 1981. According to government sources, POSCO's production capacity will stand at 9.6 million tons for crude steel in 1985, up 12.9 per cent on 1981, and 8,536,000 tons for rolled products, up 6.2 per cent. Production capacity of cold rolled sheets will increase by 94.3 per cent but those of wire rods, plates and hot rolled sheets will remain unchanged at 446,000 tons, 1.8 million tons and 5.1 million tons respectively.

Exports are projected at 2,695,000 tons, a slight increase of 0.2 per cent over 1981. By item, wire rods and plates are projected to decrease 5 and 31.6 per cent, respectively, to 190,000 and 650,000 tons while hot coils and cold rolled sheets are forecast to increase by 17.7 and 31.4 per cent to 1.33 million tons and 460,000 tons, respectively. (October 1982)

Singapore - Scrap ban lifted

A ban on the export of steel scrap has been lifted by the Singapore Government. A statement from the Ministry of Trade and Industry said an agreement had been reached between the national iron and steel mills and the Government to discontinue the price control on steel and the protection against imports in times of over-supply in international markets. (February 1983)

Western Asia

Saudi Arabia - Trade mission talks on Spanish steel

A nine-member Spanish trade mission sponsored by the Instituto Nacional de Fomento a la Exportacion visited Riyadh earlier in the year to promote Spanish steel.

Spain hopes for a greater dialogue with Saudi on two levels - outlets for export and joint ventures. (April 1983)

Research and testing

Africa

Nigeria - DR plant passes tests with flying colours

Africa's first natural gas-based direct reduction unit, located in the Delta Steel integrated complex at Ovwian-Aladja, has successfully completed its performance guarantee test.

The Midrex Series 600 Module exceeded production requirements by about 10 per cent during the 15-day test. The plant produced 22,830 tons of direct reduced iron at 96 per cent metallization and operated at 97.6 per cent availability, surpassing the 95 per cent availability guarantee. Energy consumption was 1.9 per cent and satisfied the operating specifications of the steel mill. (April 1983)

Latin America

Brazil - Energy optimizing concept test

A company from the Federal Republic of Germany is testing a new energy optimizing furnace as an alternative to the traditional blast furnace for molten iron production at its Companhia Siderurgica Pains SA subsidiary in the state of Minas Gerais.

The new system allows for the use of up to 60 per cent cold-charging of scrap, direct-reduced iron or pig iron. (October 1982)

Mexico - Rolling mills for Mexico

Mexico has been supplied with a number of laboratory rolling mills. These "Two in One" mills carry both plain and grooved roll sets in the one roll stand and are used to demonstrate the principles of both flat stock and shape rolling. Mills already supplied range from the Two in One mill to a larger, more sophisticated machine designed for metal forming research work. Under a World Bank loan, the Mexican authorities are constructing 90 new colleges for the training of technicians. (February 1983)

South Asia

Pakistan - Success with local ores

The Pakistan Council for Scientific and Industrial Research Laboratories, Lahore, has succeeded in enriching the Kala Bagh iron ore as well as the Nokkundi iron ore mined at Baluchistan. The concentrate pellets produced by the blend of ore from the two places can successfully be substituted for the imported lump-ore used in the Pakistan Steel Mills, Karachi. (October 1982)

Industrial zones

South-East Asia

Indonesia - Industrial zones open in north-west Java

A 500-hectare industrial zone, designed to become a centre for Indonesia's basic metals industries, was opened last year in the Anyer-Cilegon Delta region in north-west West Java. The Anyer-Cilegon industrial zone is expected to gradually develop into the largest site for iron and steel-based industries in Indonesia.

The presence of state-owned P.T. Krakatau Steel in Cilegon has also contributed to the development of industrial services and infrastructure in the area, which will accommodate industrial companies, including machinery, engine and machine tool-making ventures, whose operations are related to Krakatau's steel industry.

Industrial plants currently operating in Cilegon under P.T. Krakatau's auspices include a 150,000-ton capacity reinforcing rod unit, an 85,000-ton capacity profile iron unit, a 25,000-ton steel wire unit, a 1 million ton capacity sponge iron mill, a 540,000-ton slab iron mill, a 220,000-ton wire rod plant and a 65,000-ton steel-pipe unit.

Other integrated steel facilities under construction include: a hot-strip mill, a cold-rolling mill, a 1 million ton slab iron mill, a 1 million ton capacity iron sheet mill and an expansion to double the capacity of the sponge iron unit to 2 million tons. (April 1982)

Cilegon to open more units soon

State-owned P.T. Krakatau Steel should have completed two new units at its complex in Cilegon, West Java, in the first quarter of 1983.

The new units, a 1.1 million ton per year slab plant and a 1.1 million ton capacity hot-strip mill, form the second-phase development of Krakatau Steel's integrated steel industry complex. A company from the Federal Republic of Germany is building the units under a DM 1.9 billion contract awarded in late 1978. The slab plant will feed the hot-strip mill which will produce hot steel strips 2 to 25 mm thick.

These strips will be processed into sheet by a cold rolling mill joint venture between Krakatau, P.T. Kaolin Indah Utama (a privately-owned Indonesian company) and a Luxembourg company.

The cold-rolling mill, which will cost an estimated \$800 million, is in the final stage of preparation at Cilegon. It will be owned and operated by P.T. Cold Rolling Mill Indonesia which is 40 per cent owned by P.T. Krakatau, 40 per cent by P.T. Kaolin Indah Utama and 20 per cent by the Luxembourg company.

Stated to start production in 1986, the cold-rolling mill will manufacture steel sheets for auto bodies, pipes and tubes. (April 1983)

Orders and contracts

Africa

Algeria - Output boost with new furnaces

Société Nationale de Siderurgie of Algeria has awarded a contract for the design and supply of two 32-ton furnaces.

The furnaces will increase Algerian steel production by 100,000 t/a. (April 1982)

Angola - Iron ore production to be revived

After a seven-year break, Angola hopes to resume production of iron ore this year. The country has signed a contract with an Austrian company to revive the Cassinga mines in the province of Huile.

They aim to produce 1.1 million t/a of high grade hematite. In 1973, the last normal year of production before independence, Angola exported 6.3 million tons of iron ore, mainly to the Federal Republic of Germany and Japan.

Angola's biggest hopes for ore development are pinned on the Kassala-Kitungo deposits north of Kwanza river which could yield 2 million t/a of ore. (December 1982)

Egypt - Alexandria National Steel Co. to be formed

An agreement to set up a joint venture to build a direct iron reduction process-based integrated steel mill near Alexandria has been signed with a Japanese group.

The mill will be built in the El Dikheila district on the outskirts of Alexandria. 60,000 t/a of DRI will be produced by the mill using local natural gas. It will consist of electric furnaces, continuous casting units, and bar and wire rod mills. Completion is slated for 1985. The project will cost \$835 million. (December 1982, April 1983)

Nigeria - Turnkey rolling mill from Italy

Nigeria has signed a contract with QUA Steel Products Ltd, Eket, Nigeria, for the turnkey supply of a semi-continuous 100,000 t/a capacity rolling mill for sections, round bars and wire rod. This \$42,000,000 contract is one of the most important ever obtained by an Italian private company in Nigeria.

Included in the contract are the civil works and auxiliary systems (such as the electric power plant) and the erection, start-up, after-sales services and training of local personnel. The complex also will produce electrically welded-wire mesh for the building industry and this will represent considerable help to the industrial expansion of this Nigerian state.

Start-up is scheduled for January 1984. (April 1982)

East Asia

China - New plant for Beijing mill

A Japanese shipbuilding and engineering company signed an agreement with China's Shoudu Iron and Steel Co. providing for construction of a \$3.7 million blast furnace top pressure recovery turbine power plant.

The new plant was to be installed at a steel mill facility located in Beijing. Operation of the new plant was to start at the end of 1982. (April 1982)

Seamless pipe order

Three Japanese companies were to supply about 250,000 tons of seamless pipe to China in the first half of this year. This is in addition to an earlier order for 1,087,000 tons of ordinary rolled steel products, to have been delivered by June. (April 1983)

Buying know-how on castings and forgings

A Japanese steel company is to provide China with technology for the manufacture of large steel castings and forgings. A five and a half year contract, signed with the China Machinery-Building International Corporation, includes production, quality inspection and control technologies. The contractor will also design the remodelling of two Chinese factories, send engineers to China for technical guidance and accept Chinese trainees. (April 1983)

Roll grinders for new Chinese steel mill

A new Chinese steel mill has ordered £4 million worth of automated roll grinders. The mill, to be built at Baoshan near Shanghai by 1987, will have a capacity of 2.25 million t/a (April 1983).

Modernization of Anyang steelworks

China Metallurgical Import and Export Co. have signed a contract with an Italian company for the modernization of the Anyang steelworks and rolling mill complex. Valued at approximately US\$ 2.2 million, the order includes the supply of the plant, to be installed into the existing continuous mill (originally built by the Chinese), know-how and technical collaboration, supervision of the installation and start-up of the rolling mill. Also included in this contract is the training of some 10 Chinese technicians in Italy. (February 1982)

Latin America

Argentina - First CC unit built for slabs

Sociedad Mixta Siderurgica Argentina (SOMISA) is currently erecting Argentina's first continuous caster for slabs. The two-strand machine will have a capacity of over 1,000,000 p/a.

An international consortium won the contract. Start-up is scheduled for spring 1984. (February 1983)

Brazil - £14 million contract awarded

A contract valued at approximately £14 million has been awarded by Aco Minas Gerais SA (ACOMINAS), of Belo Horizonte. The contract, which includes the supply of steel rolling mill plant and civil co-ordination, is for an extension to the ACOMINAS bloom and billet mill scheme at present under construction at Ouro Branco.

Billet mill stands, shear and turn-over cooling bank are included in the new equipment. Some modifications will be made to existing equipment. All this will enable ACOMINAS to produce longer billets and a wider range of sizes. The mill is planned to start production later this year. (October 1982)

Electromagnetic stirrer contract

Usinas Siderurgicas de Minas Gerais (USIMINAS) has placed an order for two electromagnetic stirrers with Concast/ASEA.

Stirring equipment, mechanical adaptation of the CC machine and services up to the commissioning of the equipment are included in the contract. The order consists of a Brazilian portion (60 per cent) and an imported portion (40 per cent). Start-up is scheduled for early 1984. (February 1983)

Mexico - Iron ore pelletizing plant at Lazaro Cardenas

A \$26 million contract awarded by Sicartsa, a wholly-owned subsidiary of SIDERMEX, Mexico City, covers the design, engineering and procurement and construction management liaison of an iron ore pelletizing plant to be located at Lazaro Cardenas, 165 miles north of Acapulco.

Scheduled for completion in 1983, the plant will produce 3 million t/a of direct reduction quality iron ore pellets and will incorporate slurry receiving, filtering, balling and pelletizing indurating equipment.

Feed for the plant will be received via a slurry pipeline from a new concentrator to be constructed at the mine site approximately 28 km from Lazaro Cardenas. (June 1982)

Sicartsa order gears worth £1 million

A new plate mill transmission package worth £1 million has been ordered from a British company by Sicartsa for the heavy plate mill which is being constructed at Las Truchas, on Mexico's South Pacific coast.

The mill is an extension to the Sicartsa steel works.

Helical and bevel/helical units of high torque capacities, designed specifically for the type of mechanical handling machinery which will be employed in the roughing and finishing sections of the new mill, form the main part of the order. (April 1983)

Large contract for weighing equipment

One of the largest individual weighing equipment contracts ever has been awarded for the second stage of the Sicartsa Steel Mill in Mexico. A total of 48 different weighing systems will be supplied to a value of about £900,000.

Deliveries will include weigh feeders, scale cars, weigh hoppers and platform scales, along with microcomputer-based control systems and VDU terminals. The equipment forms part of a materials handling systems for extension of the steel mill, where a new type of electric arc furnace will be used to melt and refine the charge in the same furnace. When completed in 1985, the extension will raise the production capacity of the Sicartsa mill by 2 million t/a. (April 1983)

Mexican international joint venture project

A 40-ton electric arc furnace, two 60-ton holding furnaces and other materials handling and related facilities for a Mexican casting and forging mill project are being supplied as part of an international joint venture which includes the Mexican National Development Bank (NAFINSA) and the Mexican Steel Corporation (SIDERMEX).

Annual production capacity of the electric arc furnace will be 85,000 tons - 20,000 tons each for castings and forgings and the rest for other purposes. Start-up of the facilities is planned for the summer of 1985.

The overall project is an integral part of the Mexican Government's economic development plan, which is based on the structuring of an industrial base including steelmaking and petrochemicals as well as the development of the Las Truchas area. (April 1983)

South-East Asia

Indonesia - 4-strand unit for Master steel

An Italian firm has negotiated a contract for the supply of a 4-strand continuous casting machine to P.T. Master Steel Mfg. Co., Djakarta. The machine, which will be supplied entirely from Italy, will be equipped to cast billets from 80-160mm² and incorporate the CEDA Automatic Mould Level Control system. (February 1983)

Coil centre looks likely

A Japan-Indonesia joint project to construct a coil centre in Indonesia was tentatively approved by the Indonesian Government's Industrial Ministry in 1982.

The joint firm is to be capitalized at \$3 million, 70 per cent of which will be shouldered by the Japanese company and 30 per cent by local interests. (October 1982)

Malaysia - Malayawata-Hyundai supply contract

Malayawata Steel Bhd has agreed to supply steel bars of various sizes worth a total of \$36 million to Hyundai for the construction of the Penang bridge. This is the biggest single sale ever for Malayawata. Hyundai will use the bars (of 10-32mm diameter and total weight 36,500 tons) for prestressing of concrete beams.

Local procurement of the bars by Hyundai is significant because steel bars on the world market currently enjoy a price advantage, averaging \$80pt less than Malayawata's quotation. The lower price of imported bars, the result of a world-wide glut, is in spite of the imposition of a \$180pt import duty by the Government. Hyundai's decision to obtain the steel bars on the domestic market further fulfills the local content requirement of the \$525 million Penang bridge contract. (December 1982)

Singapore - Walking beam furnace bought by NISM

An Italian company is to supply a walking beam reheating furnace (oil fired, 55 tph) to the National Iron and Steel Mills (NISM) new rolling mill. The mill, which will be built by another Italian company, will produce rods and bars. (February 1983)

Western Asia

Bahrain - AISCO order

Arab Iron & Steel Co. provisionally ordered an iron ore pelletizing plant from Kobe Steel Ltd. last year. Completion of the Bahrain facility is scheduled for 1984.

Direct reduction steel mills, now being built in the Middle East, will provide a market for the 4 million t/a capacity pelletizing plant. (June 1982)

Iran - Commitment to buy Indian ore

Now that the Ahwaz steel plant is nearing completion, Iran has informed the Indian Government that it intends to start buying iron ore from the Kudremukh project in 1984.

Initially the ore from Kudremukh was to serve Iran's new steel complex on an exclusive basis. When the Ahwaz plans were delayed, Iran was forced to cancel the delivery schedule, leaving India with a huge surplus of iron ore concentrate.

India has now found alternative buyers for part of the Kudremukh output. Romania, for example, has agreed to buy 3 million tons until 1985. (April 1983)

Czech mill train delivered

Czechoslovakia's foreign trade company has delivered 14,500 tons of equipment for a section-rolling mill train in Iran. The train is part of the new sections of a metallurgical plant in Isfahan being supplied by the Soviet Union. (April 1983)

Projects in the pipeline

Latin America

Brazil - Special steel plants

Companhia Siderurgica de Corumba is planning to build a \$70 million steel mill to produce 250,000 tpy of special steels. (October 1983)

Delay in iron ore project

Due to the crisis in the world steel industry, the Carajas iron ore project is to be delayed by one year.

The project entails a 5 million t/a iron ore sintering plant to be built at San Luis, the loading port of the prospective Carajas iron ore. It is estimated to cost about \$200 million and is designed to sinter the Carajas iron ore to meet the Brazilian Government's request for increasing the value of Carajas iron ore for exports. At approximately \$US5 billion, the Carajas development is believed to be the biggest project of this type underway. Eventually the project is intended to produce 35 million t/a of ore. According to Cia Vale do Rio Doce, Brazil's state-run mining company, Carajas is now scheduled to come on stream in July 1986. An output of 5 million tons is planned for the second half of that year. The situation will be reviewed again, however, if the expected upturn in the international market does not occur this year.

This postponement means that virtually all major development projects in the Amazon have been set back. (October 1982 and April 1983)

Mexico - Second HYL III plant nears completion

The world's second HYL III Plant, the 3M5 in Monterrey, is in the final stages of construction and due to come on stream this year.

3M5 is a scaled-up version of the 2M5 plant, which has now put in two full years of commercial scale operation. The new plant will have a moving bed reactor with a 500,000 t/a capacity, replacing the four fixed bed reactors currently in operation. This retrofit will increase production capabilities by about 80,000 t/a.

A new heater design will be incorporated to improve energy consumption, while the original reformer will remain in operation. (April 1983)

South-East Asia

Malaysia - Hot briquetting process for direct reduction plant

The first facility in the Far East (Sabah Gas Industries' (SGI) plant) exclusively devoted to exporting highly metallized, premium quality direct reduced iron to the rapidly growing steel industries of the Association of South-East Asian Nations (ASEAN) and the Far East will incorporate a proprietary hot briquetting process. It will be incorporated in a direct reduction (DR) plant being constructed on Labuan Island, Sabah.

The plant should commence product shipments by mid-1984 and will employ over 150 people. The site can accommodate a second DR plant and a steel mill at a future date. (December 1982)

Plans for integrated steel complex

Heavy Industries Corporation of Malaysia (HICOM) is to participate with a six-company Japanese consortium in the construction of a sponge-iron and billet plant. Designed to increase Malaysia's self-sufficiency in galvanized and cold rolled sheet supplies, the mill is the first stage in Malaysia's plans to build a state-controlled integrated steel complex in Trengganu. With an annual capacity of 600,000 tons the mill is scheduled to begin production in 1985. (June 1982 and April 1983)

Philippines - First integrated steel complex to be built

The Government has adopted several measures to facilitate the implementation of plans to build an integrated steel complex, the first of its kind ever to be built in the country. With the present domestic demand for steel products of over 1 million t/a, and the total domestic demand expected to exceed 2 million t/a by the time the 1.5 million t/a steel mill is operational, the Government sees the establishment of the mill as imperative. The mill will have ironmaking, steelmaking and rolling mill facilities. Estimated cost of the whole project is \$1.2 billion. (October 1982, February and April 1983)

Republic of Korea - Integrated steel mill plans

A integrated steel mill will be built at Kwangyang Bay. Plant construction is due to begin in 1985. Major features of the mill will be a coke plant (1.5 million t/a); an iron casting plant (2.8 million t/a), a steelmaking plant (2.7 million t/a), a hot rolling plant (2.8 million t/a) and a continuous casting plant (2.8 million t/a). (October 1982)

Western Asia

Saudi Arabia - HADEED nears completion

The Saudi Iron and Steel Company (HADEED) is nearing completion. It is being set up in Jubail as an integrated plant, consisting of a Midrex direct reduction unit, a steel plant with continuous casting facilities and rod and bar rolling units, along with two berths for the unloading of ore ships.

The \$705 million plant has been designed to produce reinforced rolling rods and bars from which wires, nails, net, crossbeams and similar items will be made for the domestic market.

The company signed two \$50 million contracts for the import of quality iron pellets; the first was with Companhia Vale Do Rio Doce of Brazil (1981); the second with a Swedish Government-owned company for 202,500 tons of Swedish iron ore.

HADEED hopes to meet more than 70 per cent of domestic iron and steel requirements. (October and December 1982)

Start-up

Africa

Nigeria - Katsina rod and bar mill inaugurated

Government-owned Katsina Steel Rolling Co. Ltd. (KSRC) has inaugurated its 210,000 tpy steel wire rod/bar rolling plant, completed recently by a Japanese company.

The development of Nigeria's steel industry is the main element of the country's Third Five-Year plan. The plan envisaged one integrated steel mill using the direct reduction method and three rolling plants to be dispersed evenly throughout the country to provide equal employment opportunities in all areas.

A 1,000,000 million t/a direct reduction plant has already been completed in Warri in the southern part of the country, and two other rolling plants are under construction by firms from the Federal Republic of Germany.

KSRC's rolling plant, comprising a wire rod/bar mill, a reheating furnace, a transformer substation and other utility facilities, has the capacity to produce 170,000 t/a of wire rod and 40,000 tons of bar, both for construction use. Billets, the semi-finished products, are supplied by the steel mill in Warri.

The contractor has trained 94 Nigerian operators at its steel works and other facilities in Japan and will provide operational guidance for three years following the start-up of the plant. (February and April 1983)

Steelworkers paradise?

In 1982 Africa's largest and most advanced steel plant at Aladja, near Warri in Bendel State was commissioned.

Aladja, a DR-based plant, will have a peak production of 2,500,000 t/a. It will use iron ore imported from Liberia and Brazil. Domestic steel demand in Nigeria is so great that the slump in the world market does not worry Nigerian producers at all.

Even with the Aladja plant and the Ajaokuta blast furnace plant, which is presently under construction, the Nigerians believe that they will still be importing steel in 1990 to meet the estimated 9 million t/a demand. (June 1982)

Latin America

Brazil - 360 million tons of reserves at Capanema mine

The iron ore mine of Minas de Serra Geral SA (MSG) at Capanema, some 50 km south-east of Belo Horizonte, became operational in August 1982.

Proven reserves of hematite and soft itabirite iron ores averaging 61 per cent in Fe content at the mine are estimated at some 360 million tons. These deposits are located in the heart of the Minas Gerais 'iron ore quadrangle district'. The project cost approximately \$125 million.

MSG, based in Belo Horizonte, is a joint-venture firm formed in late 1976 by a consortium which includes Companhia Vale do Rio Doce, Brazil.

All ores mined from the reserves will be delivered in the run-of-mine form over an 11 km conveyor line to Rio Doce's nearby ore deposits at Timbopeba where they will be crushed, washed and screened.

Rio Doce will ship some 2 million tons of the screened Capanema ores 650 km over land by rail to the 3 million t/a integrated steel plant of Companhia Siderurgica de Tubarao in the State of Espirito Santo, following the plant's start-up in mid-1983.

The remainder will be exported after blending with ores from other Minas Gerais mines. (October 1982)

Successful start-up for billet caster

Companhia Siderurgica Pains (Divinopolis) has successfully started up another billet caster. Their new unit, which provides for the future addition of a third strand, produces 120 mm square billets from 30 ton heats from an open hearth furnace.

A new simplified withdrawal and straightening unit is incorporated in the caster. The machine was manufactured in Brazil and is based on imported technology and design. (February 1983)

Guyana - BACIF open new plant

In October 1982, the commissioning of new plant and the opening of a new centrifugal casting section of the Brass Aluminium and Cast Iron Foundry (BACIF), Georgetown, Guyana, took place.

The plant is intended to modernize BACIF's floor moulding section which produces short length ferrous and non-ferrous tube for jobbing repair work in the sugar refinery and ship repair industry.

The new centrifugal casting machine will provide the versatility of jobbing or high volume production of high quality tube lengths up to 20 inches long. It will be possible to produce this length of tube every 4-6 minutes, allowing the foundry to cope with the annual

surge in demand during the 4-6 week shut-down period used by the sugar industry for repair work. BACIF hopes to export to similar industries in the Caribbean and Central American states. (February 1983)

Mexico - Experimental meltshop for industrial research

Mexico's first meltshop for industrial research has begun operations at HYL's research and development installations in Monterrey. The new facility will be used for applied research in metallurgical systems and processes which will enable the company to widen its capabilities in iron and steel technology.

The objectives are more efficient levels of energy utilization, superior quality control and better anti-pollution systems.

The experimental plant features a half-ton capacity electric furnace, charge and discharge mechanisms, smoke and dust control equipment, measuring and control instrumentation and computerized systems to analyse solid matter. This installation will allow HYL engineers to simulate industrial conditions that will yield realistic test results.

The facility initially will be used for tests aimed at boosting productivity and lowering operational expenses in integrated steel mills. At a second stage, to be initiated in 1983, research will be carried out in continuous casting operations and modernization of present systems and equipment. (April 1983)

South Asia

Pakistan - Raw materials plant operational

The raw materials preparation plant (RMPP) of the Pakistan Steel Mills, inaugurated last year, is designed to remove various gases from dolomite, limestone, and other minerals used in the steelmaking process. It comprises two sintering machines with a total annual capacity of 1.5 million tons. (December 1982)

South-East Asia

Indonesia - Pipe plant inaugurated

The biggest steel pipe plant in South-East Asia, belonging to Bakrie Brothers, was inaugurated last year. Located in Bekasi, the plant is one of 26 steel pipe plants which have been built in Indonesia.

The plant was completed at a total cost of Rp 15 billion, comprising 40 per cent from Bakrie Brothers and 60 per cent from Bank Pembangunan Indonesia (Bapindo).

The plant will have a production capacity of 100,000 tons of line pipes for the channelling of oil and water and piling pipes for construction. It is the second pipe plant belonging to the Bakrie Brothers, the first having been built in 1959.

According to the President Director of Bakrie Group, the company is planning to produce seamless steel pipes in co-operation with P.T. Krakatau Steel.

The scheduled plant is expected to be completed in 1985 at a total cost of \$300 million. (October 1982)

Philippines - Developments in raw materials production

A dolomite mine on Cebu Island, with an estimated annual production of 360,000 tons, was opened in October 1981 by the Philippine Mining Service Corporation. Feasibility studies conducted after mining rights were obtained confirmed reserves of 15 million tons and estimated reserves of 215 million tons of high quality dolomite. (April 1982)

Western Asia

Saudi-Arabia - Al-Babtain aim at domestic market

Production has begun at the Al-Babtain galvanizing factory in the Riyadh industrial zone. The \$90 million plant was launched to meet the growing demand for galvanized poles which last longer than painted poles in the climatic conditions of Saudi's coastal areas.

At present, the domestic market is supplied with imports from France, the United Kingdom, the United States and other countries. (December 1982)

New steel fabricating shop opened in Al-Jubail

NKK Arabia has expanded its operations in the Middle East by opening a new steel fabricating shop in Al Jubail, Saudi Arabia, in July 1982. Already the shop has received orders for steel products amounting to 3000 tons with a much larger volume expected in the near future. Demand for steel products in the area is expanding rapidly due to the increasing number of on-going construction projects. These include oil refineries, petrochemical plants and steelworks. (April 1982)

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Information on UNIDO's work in the iron and steel sector

A. Technical assistance programmes in 1982

Whilst production of crude steel in some of the developed countries has been static over the past years, production in developing countries during 1981 amounted to more than 15 per cent of the global steel output, as compared to about 7 per cent in 1974. Demand for steel in the developing countries is rising steadily, with the requirement/consumption at around 145 million tons in 1981. As a result of the changing pattern in world steel production, the iron and steel industry continued to receive the largest proportion of technical assistance deliveries from UNIDO.

Three projects in the iron and steel subsector were started in 1982 in India, comprising: standardization of melting technology of sponge iron; design development of a concurrent top and bottom blown reactor for steel-making; and design development of an experimental blast furnace. Other projects under implementation included: continuous assistance to the Chimbote steel plant (Peru), with special emphasis on electrical and utility services distribution systems; and an expert mission to Uganda to survey the iron and steel subsector and establish a preliminary programme for its development. The Companhia Industrial de Fundação e Laminagem plant in Mozambique received further assistance for upgrading the efficiency of the merchant steel rolling mill.

Preparatory assistance provided to the Arab Iron and Steel Union comprised advice on the introduction of a computerized information system to help solve various technical and managerial problems in promoting the expansion of the iron and steel industry in Arab countries. In Democratic Yemen activities comprised the techno-economic appraisal and preparation of a project report for a mini steel plant, incorporating casting and rolling operations based on steel scrap melted by electric arc furnace. For Yemen a detailed project report for the establishment of a mini steel plant was also prepared.

Missions were also undertaken to assess market/consumption demands for iron and steel products, to assist in the planning and development of the iron and steel industry in general, and to review existing techno-economic studies. A techno-economic evaluation together with laboratory investigations of raw materials for the establishment of the iron and steel industry was under implementation in the United Republic of Tanzania. The Government of Pakistan requested follow-up to the preparation of the master plan for the iron and steel industry in the form of assistance in the preparation of a study on quality control and special steel production. Assistance was continued to the Helwan iron and steel plant in Egypt, and the General Company for Iron and Steel Products in the Syrian Arab Republic. Expert assistance was also provided to the iron and steel plant in Basrah (Iraq).

The project for the establishment and operation of a centre for technical management systems for maintenance and production control in metallurgical and engineering industries became operational in Egypt and demonstration equipment was ordered. Within the framework of the UNIDO maintenance project in Czechoslovakia, in-plant group training was conducted for 21 managers, planners, engineers and computer specialists from developing countries. The

training programme which covered the development and application of modern maintenance management systems was so successful that requests were received to hold such programmes on a regular basis.

The large-scale project in the field of standardization, quality control and quality certification of iron and steel in Brazil was successfully completed. The project counterparts organized training courses in that field for Brazilian nationals, and an international seminar on steel standardization is under consideration, to be held jointly by UNIDO and the Government of Brazil in 1983. Considering the success of this project, similar projects are envisaged for other industrial sectors.

B. Special programmes

The Third Consultation on Iron and Steel Industry was held in Caracas (Venezuela), 13 to 17 September 1982. As preparation for this Consultation, UNIDO finalized the following documents:

(a) Seven scenarios, were elaborated on the basis of the elements identified by the Second Consultation, and under the guidance of a group of experts. This group of experts selected two, "low growth" and "normative", from among the seven scenarios for presentation to the Third Consultation.

(b) Within the framework of these two scenarios, issue papers were prepared on the specific problems of training manpower (including the possibility of utilizing surplus trained manpower from developed countries), of financing steel projects (including the ways of reducing the capital costs of steel projects), of the 32 countries seeking entry into the steel sector (possibly through the establishment of mini steel plants).

One of the important features of the Third Consultation was the recognition of the special problems faced by newcomers in attempting to enter the steel sector. Participants not only offered to make available their experts to help the newcomers, but also indicated that, in some cases, the services may be available without charge. It was recognized that, for the newcomer countries, the desirable route for steel development was the mini steel plant. Assistance, therefore, had to be provided in terms of information on mini steel technology. The Consultation also agreed to placing much greater emphasis on training and on seeking finances on special terms, particularly for infrastructural development.

C. Publications

Listed below in chronological order are some UNIDO publications dealing with iron and steel. Copies may be obtained free (except where a price is quoted) on request from the Editor, UNIDO Newsletter, by quoting title and symbol number. Sales publications should be ordered only from local sales outlets or from the Sales Section, United Nations, Geneva (for readers in Africa, Europe and Western Asia), or New York (for Asia and the Pacific and North and South America). The letters A (Arabic), C (Chinese), E (English), F (French), R (Russian) and S (Spanish) refer to the languages in which the document is available. Please note: a report of a meeting lists the papers presented at the meeting. Copies of publications more than one year old may only be available in microfiche from the Sales Section, United Nations, Geneva, at a price of \$US 1.65 per fiche.

Reports

Report of the Second Interregional Iron and Steel Symposium, Moscow, USSR, 19 September to 9 October 1968. ID/24. E, F, R, S.

Creation and transfer of metallurgical know-how. Report of a workshop, Jamshedpur, India, 7 to 11 December 1971, including a summary of lectures presented to the workshop. ID/103. E.

The iron and steel industry in the developing countries. Report of the Third Interregional Symposium on the Iron and Steel Industry, Brasilia, Brazil, 14 to 21 October 1973. ID/139. E

Report on the First Consultation Meeting on the Iron and Steel Industry, Vienna, Austria, 7 to 11 February 1977. ID/WG.243/6/Rev.1. C, E, F, R, S.

Report. Consultations on the Iron and Steel Industry - Expert Group on Training Problems, Vienna, Austria, 24 to 26 April 1978. ID/WG.276/5. E, R, S.

Report. Second Consultation on the Iron and Steel Industry, New Delhi, India, 15 to 19 January 1979. ID/224. C, E, F, R, S.

Report. Consultations on the Iron and Steel Industry - Working Group on Scenarios, Algiers, Algeria, 3 to 5 December 1979. ID/WG.313/3. E, R, S.

Report. Second Working Group Meeting on Scenarios of the Iron and Steel Industry's Development, Estoril, Portugal, 3 to 5 February 1982. ID/WG.363/4. E, F, S.

Report. Third Consultation on the Iron and Steel Industry, Caracas, Venezuela, 13 to 17 September 1982. ID/291. A, C, E, F, R, S.

Studies

The world iron and steel industry (second study). UNIDO/ICIS.89. 1978. E, F.

Picture for 1985 of the world iron and steel industry (contribution to the preparation of 1990 scenarios). UNIDO/ICIS.161 and Rev. 1. 1980. E, F.

New elements for the preparation of 1990 scenarios. UNIDO/ICIS.161/Add. 1. 1980. E, F.

1990 scenarios for the iron and steel industry. Part one, "The Dossiers". UNIDO/IS.213/Rev. 2. 1981. E, F.

1990 scenarios for the iron and steel industry. Part two, "Proposals for the Dossiers". UNIDO/IS.213/Add. 1/Rev. 1. 1981. E, F.

Other documents

Information sources on the iron and steel industry. UNIDO Guides to Information Sources No. 16. Sales number: UNIDO/LIB/SER.D/26. \$4. E (F/R/S/ introduction)

Information sources on the foundry industry. UNIDO Guides to Information Sources No. 5. Sales number: UNIDO/LIB/SER.D/5/Rev.1 and Corr.1. \$4. E (F/R/S/ introduction)

Technological profiles on the iron and steel industry. Development and Transfer of Technology Series No. 11. ID/218. E, F, S.

UNIDO for industrialization series. Foundry industry. PI/87. E.

UNIDO for industrialization series. Metallurgical industries. PI/83. E.

Materials technology

Development and application of new materials: a prospective view. By N.A. Makhutov. 1982. UNIDO/ID/WG.384/12. E.

Implications of new materials and technology for developing countries. A preliminary approach. 1982. UNIDO/ID/WG.384/Rev. 1. 1983. E.

New materials, new technology. By N.S. Enikolopov, S.A. Volfson. 1982. UNIDO/ID/WG.384/11. E.

Some significant advances in materials technology. by E. Epremian. 1982. UNIDO/ID/WG.384/10. E.

Policy responses to technological advances. 1983. UNIDO/ID/WG.384/3/Rev. 1. E.

Reports of working groups. Expert Meeting Preparatory to International Forum on Technological Advances and Development, Moscow, USSR, 29 November to 3 December 1982. UNIDO/ID/WG.384/14. E.

Report. Expert Meeting Preparatory to International Forum on Technological Advances and Development, Moscow, USSR, 29 November to 3 December 1982. UNIDO/ID/WG.384/16. E, F.

Report. International Forum on Technological Advances and Development, Tbilisi, USSR, 12 to 16 April 1983. UNIDO/ID/WG.389/6. E.

Abbreviations

AISE	American Iron and Steel Institute
AOD	argon oxygen decarburization
API	American Petroleum Institute
AQ	air quenching
ASEA-SKF	Allmänna Svenska Elektriska Aktiebolaget - Svenska Kullagerfabriken AB
ASM	American Society for Metals
ASTM	American Society for Testing and Materials
AWS	American Welding Society
BOF	basic oxygen furnace
CRLC	cold rolled low carbon
DH	Dortmund Hoerder
DIN	Deutsche Industrie Norm
FATT	fracture-appearance transition temperature
ft-lbf	foot pound force
HAZ	heat-affected zone
HRLC	hot rolled low carbon
HSLA	high alloy low strength
HSS	high strength steels(s)
IUPAP	International Union of Pure and Applied Physics
LF	ladle furnace
LPG	liquefied petroleum gas
MPa	megaPascal
OD	outer diameter
ppm	parts per million
ReNit	renitrogenized
RH	Rheinstahl Haeraeus
SAE	Standard Average European
TN	Thyssen Niederrhein
UTS	ultimate tensile strength
VAD	vacuum arc degassing

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We should appreciate it if readers could take the time to tell us in this space what they think of the first issue of Advances in Materials Technology: Monitor. Comments on the usefulness of the information and the way it has been organized will help us in preparing future issues of the Monitor. We thank you for your co-operation and look forward to hearing from you.

