THE ROLE OF FERRO-ALLOYS AND THE DEMANDS ON THEM IN THE MELTING AND REFINING OF STAINLESS STEEL

By D. A. A. Reeves*
(presented by Mr. Reeves)

SYNOPSIS

The paper outlines the position of the stainless steelmaking industry as a major consumer of ferro-alloys, the vulnerability of the industry to the disruption of ferro-alloy supply and describes the significant changes in stainless steel production methods of the last decade, centred on the introduction of the AOD process.

The influence of the AOD process on the use and choice of ferro-alloys is examined in the light of the AOD vessels extremely good decarburisation efficiency, bath purging and slag-metal mixing. The need for consistency of supply and the careful control of quality of ferro-alloys is shown through the effects of these variations upon steelmaking production performances and yields.

The effect of modern steelplant raw materials handling equipment and operating practices on ferro-alloy sizing and properties is reviewed and finally, a computer based "Least Through Cost Mix" system for furnace charge design and the realisation of full raw materials value is described.

Stainless steelmaking as a consumer of ferro-alloys

The steel industry is the world's major consumer of ferro-alloys in general; certain particular alloys are used predominantly and others significantly in stainless steel production, in spite of the relatively low output level compared to that from bulk steelmaking. The British Steel Corporation uses some 300k tonnes of ferro-alloys per year, with a value (in 1979) of about £ 200 million. BSC Stainless used about 25 % of this intake, within a total raw materials bill for scraps and alloys of approx. £ 60 million.

There are two major groups of stainless steels, namely ferritic and austenitic steels, the former typified by type 430, a 17 % chromium steel and the latter by type 304, and 18 % chromium - 9 % nickel steel. Stainless steels derive their resistance to corrosion from a very thin chromium oxide film formed on the surface of the metal and chromium is therefore the base to these steels on which their continued existence rests. In the austenitic steels, nickel enhances the properties of the oxide film and improves corrosion resistance. The major alloys, other than iron, chromium and nickel, contained in these steels are manganese, silicon, molybdenum and

* BSC Stainless, England

titanium. If necessary, in times of supply disruption, nickel and manganese can be interchanged to some extent and this is the basis of the 200 series stainless steels, which are suitable for quite wide application. However, no economic substitute steels are available to counter a scarcity of chromium and such a scarcity would have serious consequences for many industrial sectors, including the nuclear and chemical industries, aircraft and higher temperature applications in addition of course to less critical domestic applications.

A look in a little more detail at the production and supply position of three of these alloying metals, shows the close link between ferro-alloys and stainless steel production. Some 60-70 % of chromite mined goes into the production of ferro-chromium for metallurgical use and at least 65 % of the ferro-chromium produced goes into stainless manufacture. Of the order of 55 % of all nickel produced goes into the steel industry of which some 45 % goes to stainless production. An examination of molybdenum usage, shows of the order of 80 % going into the steel industry, of which about 20 % is used in stainless steels.

These few facts serve to illustrate the very close link between our two industries. The growth in chromite mining and ferro-chromium production is undoubtedly linked to the growth in use of stainless steels and for other ferro-alloy producers the requirements of stainless steelmaking are commercially very important.

Since 1970, the world stainless steel market has grown at about 5 % per annum and although there has been some equalisation of usage over the last ten years, today the per capita usage of stainless steel in the industrial world still shows large differences from country to country with the U.K. at an average of 1.79 kg/capita and Sweden for example at 5.93 kg/capita. A view of the past and the present therefore, shows a continuing opportunity for further growth towards an equalisation of usage, the effect of which will vary country to country.

A look in the crystal ball for accurate future sales forecasts, would lead to the expectation of expanding usage of stainless steels in the coming years, for the contribution they can make towards savings in conservation of resources, energy, product life, maintenance and replacement costs. It is worth noting that the known reserves of iron, chromium and nickel ores are amongst the largest known reserves of the world's metaliferrous ores, which in the longer term could be expected to reflect in availability and price of stainless steels compared with copper for example. However, beyond the short term the crystal ball would probably fade, for the use of stainless is very much tied to the process engineering industry on the plate side of the business and to public taste and "money in the pocket" on the sheet and coil side of the business. Both areas of opportunity are intimately tied to the world economy and the health of individual countries' economies. Since the energy crises of the 70s, old trade cycle patterns have largely disappeared making future projections of market growth very difficult. There can be no optimistic forecasts for the alloy producers who look for predictions of the stainless market on a world wide basis but in the U.K., a growth of about 5 % per annum could be expected.

The U.K., in common with many other free world countries, has to import virtually all the ores or alloys which it uses in steelmaking. Before examining the usage of ferro-alloys in stainless manufacture, it is worth noting the disposition of critical ore-bodies throughout the world and the strategic concern which this rightly engenders in stainless producers, when considering how best to ensure continuity of their ferro-alloy supplies. Of the order of 96 % of the world's chromite reserves are in South Africa and

Rhodesia and whilst in the past some 86 % of the chromite conversion was spread through seven countries throughout the world, as I will outline, the steelmaking methods adopted during the 1970s have hastened a concentration of alloy conversion, as well as mining in Southern Africa. The Cordillera areas of North and South America hold over 70 % of the world's reserves of molybdenum and five mines are presently responsible for about 90 % of the world's suppliers. Cheap power is all important in the production of ferro-silicon, which has a total power requirement of about 9,500 KWh per tonne of 75 % FeSi produced and this for the U.K. has placed a heavy reliance on supplies from Norway, who supply something like 60-70 % of U.K. needs. Developing countries have very strong stakes in ore reserves and in mining and ferro-alloy production. Nickel is very much a case in point, with important reserves in New Caledonia, Indonesia, Cuba, Dominica and Botswana. Brazil is also sitting on by far and away the world's largest reserves of niobium.

Whilst the strategic considerations are not necessarily the same for all steelmakers, with the general move underway for alloy conversion to concentrate in the countries holding the ore reserves, the stainless producer must plan to safeguard his supplies and where possible cover the market, transport or political disruptions, which could foreseeably arise.

Some countries, such as America, Germany and France have protected their industries by setting up national strategic stockpiles. The justification for this in the case of the particular alloys chosen, the costs of doing it, the Government backing and the managerial/control problems which go with such stocking, are outside the scope of this paper but it must be recognised that such stocks could represent a production cost or business advantage for one world stainless supplier over another.

Changes in stainless steel production methods

In the late 1960s, dramatic changes started to take place in the methods of production of stainless steel. These stemmed from the successful development of processes which were able to decarburise chromium bearing melts with oxygen at low effective pressures. By so doing, carbon removal was made to occur preferentially to chromium and the other oxidisable metals in the melt, iron and manganese. The first process exploiting such a technique was vacuum oxygen decarburisation (VOD) developed at Witten and announced in 1968 and the second process was argon oxygen decarburisation (AOD), which arrived on the steelmaking scene, as a commercial process, in mid 1969. Both processes achieve their results by reducing the partial pressure at which the primary reaction production CO forms, the former by using vacuum, the latter by using argon. Other attempts have been made to utilise this simple chemical concept but the AOD has proved such an outstandingly successful process, not only for decarburisation but also in the way it can handle all the concomitant operations of high quality steelmaking, that it now dominates stainless production in the western world.

At present, only ten years after its first introduction, of the order of 80 vessels have been installed in the steel industry. Something like 65 % of the free world's stainless steel production is now produced through AOD vessels and in the U.S.A. and the U.K. this figure is about 85-90 % of production. Vacuum steelmaking systems handle about 24 % of free world stainless steelmaking and it can be seen how this when added to the AOD capacity has given such a radical change to the steelmaking scene, away from the traditional conventional arc furnace steelmaking methods. This change has had fundamental effects upon ferro-alloy usage in the industry.

The AOD process, as has been said, encourages the decarburisation of the steel preferentially to the oxidation of iron, chromium and manganese. The oxidation of a proportion of the metals cannot be avoided but whereas in conventional arc furnace steelmaking up to 45 % of chromium charged is oxidised to the slag during carbon removal, in the AOD vessel, this is typically no more than about 10 % of the chromium charged. Decarburisation is therefore extremely efficient and as a result of the reduced oxidation of metals, less heat generated and lower temperatures appertain during the blow, compared with the extremely high temperatures of conventional decarburisation, which put such extreme demands upon furnace and refractories. This has allowed the steelmaker to contemplate handling start blowing chemistries as high as 3.0 % carbon, whereas in conventional arc furnace steelmaking he was limited to about 0.8 % carbon maximum, due to excessive chromium losses, temperature build and flame evolution above this level.

With modern steelmaking and processing facilities stainless steel producers have improved their process yields significantly, by of the order of 6 %, with consequential reductions in own arising scraps. Over the same period of time, the steel users have improved their process yields and the combined effect of these factors has meant that the steelmaker can expect not much more than 40-50 % scrap in his furnace charges. In countries which rely heavily on exports of stainless steel, such as Japan, and Finland, this might be as low as 35 % scrap input.

In the absence of stainless scrap, the steelmaker turns to the cheapest sources of ferro-alloys, which for many are the natural first stage high carbon reduction products. In the past, the restricted ability of the arc furnace to cope with high carbon burdens reined him back but the advent of the AOD process completely changed this.

To take advantage of this and what was seen in the early 70s as a rapidly expanding market for stainless steels, steelmakers around the world have built new melting shops or squeezed new vessels into existing shops, to give steelmaking facilities based on arc furnace melting and AOD refining. In many instances these melting facilities have been linked with continuous casting which gives an important contribution to yield improvement. BSC Stainless have followed this process route and our production is now based upon three melting shops operating with Arc/AOD combinations of 120T, 45T and 15T, the first also using a single strand, curved mould concaster capable of taking the full flat product output of the melting shop of up to 6000 tpw.

The influence of the AOD vessel on ferro-alloy usage

What effect has this superior ability for decarburisation in steelmaking had on the ferro-alloy producer ? In the ferro-chromium field, there has been a natural and dramatic switch from low carbon ferro-chromiums to the cheaper higher carbon ferro-chromiums. In the early 1970s, of the order of 60 % of the ferro-alloy chromium units purchased for stainless steelmaking within BSC were as low carbon alloys but today these alloys represent only about 2 % of our intake. This move to higher carbon materials brought the cheaper very high carbon South African charge chrome to the fore, which is a first stage reduction product made from the lower grade South African chromite ores. In turn, the large ore and coal reserves of this country in the face of rapidly escalating energy costs have been prime movers in concentrating ferro-alloy conversion, even more so, in South Africa.

Parallel with the moves on ferro-chromium, there has been a change to a greater usage of high carbon ferro-manganese and in addition carbon containing ferro-nickels are now readily used. Ferro-nickels in general have also come more strongly into their own, at the expense of pure nickels, being an attractive coolant material for use in temperature control during blowing of the AOD vessel and at the same time contributing valuable iron units.

The advantages of the present steelmaking methods and their effect on the alloy producer, do not solely arise from an improved ability to handle higher carbon contents in steelmaking. By "melting only" in the arc furnace, the introduction of a secondary refining vessel significantly increases the working pace of the shop and therefore raises its capacity and improves its conversion costs. As previously mentioned, the high decarburisation efficiency of the AOD process has the complementary effect of reducing oxidation of metal during the blow. This, coupled with excellent slag/metal mixing from the vigorous stirring brought about by bottom gas injection in the vessel, has reduced the requirements for reductants and simultaneously significantly increased through yields of iron, chromium and manganese. Silicon used for reduction in the arc furnace was at least 20 Kg/tonne of steel produced, for the Arc/AOD route this is now typically only about 9 Kg/tonne. Where chromium and manganese yields of 86 % and 60 % were normal on the arc furnace route, through yields of 93 % and 75 % respectively are typical today, with yields of 98 % and 93 % respectively in the AOD vessel itself.

Within BSC Stainless, the effect of these improved yields has shown itself, at a fixed scrap input level, in a decreased usage of alloy units from ferro-alloys per tonne of steel produced. In the early 1970s, at the 50 % scrap input level we were using of the order of 107 Kg of chromium from ferro-alloys per tonne of steel produced, whereas today this has decreased to 95 Kg of chromium per tonne. Similar improvements have been obtained on silicon and manganese.

It should not be overlooked, that the combined effect of the improved alloy yields has been an improved metallic yield in steelmaking, which, when combined with other process yield gains, from continuous casting and cold rolling heavier coils for example, has led over the past ten years to significant reductions in the steelmake required for each tonne of good steel sold.

There are other advantageous features of the AOD blowing stage. The flushing action of the inert gases passing through the liquid metal and the oxidising conditions appertaining during the decarburisation step, normally reduces the hydrogen content of the steel down to absolutely safe levels. This reduction reflects in improvements in steel quality and yield through the avoidance of pinholes and hydrogen cracks, and for many steel producers this has allowed the final elimination of alloy roasting facilities, installed in the past to reduce the moisture content of alloys, water being a strong source of hydrogen.

After the reduction step in the steelmaking operation, it is normal to have a desulphurisation step before final additions are made and the vessel tapped. The excellent slag/metal mixing available to the steelmaker, from inert gas stirring, gives the facility for quick slag chemistry adjustment and rapid desulphurisation. The ease of desulphurisation allows the handling of higher sulphur burdens, which in turn gives a greater degree of freedom in the choice of raw materials, whilst still eliminating the long hours spent on the arc furnace bringing down the sulphur level. Low sulphur levels together with low oxygen levels obtained as a result of good reduction and the flushing out of oxide inclusions by the inert gas injected, gives good and consistent product cleanness. Although there are cost debits associated with handling higher sulphur levels through steelmaking, the steelmaker now more readily entertains off grade higher sulphur ferro-chromium, alternative ferro-nickels and other materials, when these can be obtained at an overall cost or supply advantage to him.

The AOD vessel is a very predictable and controllable steelmaking tool and with the two steelmaking units now involved in the operation, the opportunities for chemistry adjustment using cheaper high carbon ferro-alloys, are increased and the need for final additions of low carbon finishing alloys, to bring the steel into specification, very much reduced. This is an added advantage to that of being able to handle higher carbon contents and has furthered the reduction in usage of low carbon alloys. For arc furnace steelmaking, chromium additions, as low carbon ferro-chromiums used for final finishings, were typically 10 % of total chromium units added, whereas today this is only 0.1 % of total chromium added. Similar improvements in nickel, manganese and other alloy usage levels have been obtained.

An important proportion of these finishing additions savings has arisen in the production of extra low carbon (E.L.C.) stainless steels. On the conventional are furnace route, the chromium level present during blowing had to be restricted to 3-6 % Cr, to allow the carbon to be reduced and to control temperature, necessitating very heavy low carbon finishing additions after blowing, to bring the steel into specification. In present day secondary refining vessels, the carbon can be quite easily reduced to ELC levels in the presence of 18 % Cr and the finishing additions are therefore not normally required. A further contribution to the reduction in the level of finishings has been derived from the improved analysis control which these vessels have given, allowing some reduction in aim points and working ranges and therefore material conservation.

The quality control of raw materials

The constant demands on steelmakers to improve speeds of working and yields, and the introduction of more controllable processes, has led to the introduction of extra and more accurate weighing equipment and main frame or micro processor type computer systems. This equipment now allows a measurement of the yields obtained through the process with greater accuracy and checking back on the chemistry of materials charged. With the high value of raw materials used in stainless steelmaking, more and more steelmakers are also using small re-melt facilities to determine check analyses on materials supplied, albeit a technique more normally applied to scraps than alloys. The upshot of all this has been an increasing attention to the accuracy and consistency of analysis of alloys supplied and certainly on our part, this has brought us much closer to the alloy suppliers in discussions about what they see as being attainable and their methods of chemical analysis. The consistency of analysis is important for easing the bulk handling of materials and for steelmaking control.

A whole variety of different analyses creates problems with segregation, in storage and usage, if the value of materials is not to be wasted and operating speeds and analysis control in steelmaking, are at greater risk with too many parcels of alloys of different analyses in the system.

The quality control and quality assurance of raw materials is an area receiving increasing attention from the steelmaker, on the whole range of material properties, for the same reasons of yield, speed of working and consistency of performance. On the ferro-alloy front, material sizing control is required to avoid physical handling loss from fines or mechanical damage and jamming of plant with excessive lump sizes. Water and slag contained obviously represent a lost value to the steelmaker, if they are not accurately known when the alloys are purchased. When charged to the furnace, these items require energy to drive off the former and energy plus fluxes to handle the latter, both giving a yield loss in processing. It should be noted that unexpected yield losses from these or any other sources, apart from carrying a direct processing cost debit, can also, through reduced tapped weights, lead to scrap, short weight slabs or ingots. Hence the desire for consistency and accuracy of knowledge of the level of contaminants.

Materials handling and the implications for ferro-alloys

As with all production processes, as output rates increase and manning levels reduce, to retain a competitive position, equipment design alters to suit and becomes more automated. In the modern stainless steelmaking shop, raw material handling equipment design is a key factor in obtaining high speeds of working, whilst retaining the flexibility in usage of different materials in terms of size and physical form. Our large melting shop in Sheffield illustrates the trends in design and can be used as a model to highlight the remaining and continuing raw material handling problems.

On the input side of the shop, apart from capital constraints which preclude exotic design answers, there are no easy new technological answers to scrap and alloy handling. The wide variety of physical form, the fact that many materials used in stainless steel production are non-magnetic, limits the handling solutions available. As far as is possible, scraps and alloys are received in bulk, predominantly by road, tipped into storage pens after weight checking and visual inspection for non-stainless material, sampled for full chemical analysis validation and finally loaded by mechanical shovel or grab into bulk storage areas or into identified skips.

On the input side, the problems arise with the significant tonnages of material which come in drums, bags, baled pigs, ingots and a host of other forms. These create a variety of difficulties, for apart from the use of fork lift trucks and drum tipping devices, manual effort is still required to open or break down these packages. Continuing thought and discussion with suppliers is being given, to useful ways of altering packaging or changing to bulk delivery of these items. One novel development which has arisen, is the supply of nickel pillows in bags, which can be lifted by crane or fork lift truck over receiving hoppers, slit and their contents discharged without spillage, so avoiding the problems of handling drums.

From the storage areas, our materials are routed either for basket charging to the arc furnace for melting or into a conveyor system for feeding to storage hoppers, ready for use at the arc furnace for trimming additions or AOD vessel for coolant or finishing additions. All materials destined for the basket are handled to that point in skips for subsequent tipping by overhead crane. The movement of scraps and lump alloys gives no significant handling difficulties but ferro-alloy fines contained in bulk alloys present problems with physical loss, starting with wind and rain losses on the bulk pile, followed by spillage in multiple handling through to the basket or loss through the basket clam shell joint. Even if some of these fines can be recovered, it requires manpower to do it, which is not an acceptable solution. For these reasons, granular ferro-alloys are somewhat less desirable for the basket charging route.

The use of conveyors, overhead storage, weighing and controlled feeding, is a necessity in the melting shop of today, if speeds of working, low manning levels and tight process control are to be maintained. The first requirements for a material to go through such a system, are that it will not jam hoppers or damage plant and that it will stay on the belts. This dictates that the lump size must not be excessive, that the fines content should be low and that the material must not roll too freely on the belts. There is still scope for rapport between the alloy producer and the steelmaker to optimise and minimise the number of lump sizes available, leading to the operating and cost advantage of both.

The ferro-alloy industry is obviously well aware of these trends in plant design and consequent demands on alloy form, and their solutions are legion, including broken lumps, broken pigs, cast cones, briquettes, pillows, granules, flutes and others - they cannot all be correct. There is useful discussion going on between suppliers and users, which I am sure will eventually lead to solutions which are the best for both parties.

This range of physical forms can be slotted into three main groups, granulated, cast and pressed. The granulated materials do demand under cover storage, particularly in the U.K. climate, to avoid moisture pick up but they are most attractive from a handling point a view, giving high packing densities, fast handling, less storage space and good flowing properties. These advantages apply from the dockside, starting with ship unloading, through warehousing, to final usage in the melting shop. Spherical granules are of doubtful benefit due to rolling and spillage off conveyors, but irregular granules, provided they do not tangle, can be superb. The only potential draw back with granulated materials such as granulated ferro-chromium as opposed to ferro-nickel, is in the high fines content (less than 4 mm) of 10 % to 25 % arising from granulation or degradation, which on top of the previously described physical losses in handling can give additional losses into gas extraction systems on the furnaces.

Cast alloys, cover the broken lump alloys, which still form the greatest tonnage of deliveries, and cast shapes. Lump alloys will probably be a growing embarrassment to the alloy producer, due to the labour involved in breaking up cast alloy beds and in segregating according to size. For the steelmaker, lump friable alloys can still carry a high fines content and are not infrequently porous and contaminated with slag. For the future, an increasing movement from lump to granular materials could be expected. With respect to cast shapes, for the alloys which lend themself to this sort of finishing operation such as nickel or ferro-nickels, a small cast cone of the order of 50 mm in height appears to be ideal, above this size impact damage in hoppers can become a problem. If there is a panacea in terms of ferro-alloy form, which would give the flexibility in use to basket, arc furnace and vessel, I would choose material of this size and form. However, granulation may not achieve this particle size and certainly not without fines, whilst casting is prohibitive due to the cost of the operation for many alloys. My single alloy size may probably therefore remain a dream.

The pressed alloys are mainly nickel and nickel oxides. With this form of material, the shape of the product can cause problems. Thin flutes break and create fines and similarly, sharp corners or edge fash created in pressing can be chipped off and present a potential costly physical loss. The absolute strength and abrasion resistance of these materials is therefore very important and in these respects significant differences can be seen in the products from different suppliers, there being obvious scope for further improvement. Whereas these materials are a useful source of alloy units, which can be handled on conveyor belts to limit losses, and form a proportion of the materials used in temperature control or as finishings on the AOD vessel, wherever possible bulk handling of these materials to the arc furnace basket is avoided to prevent the physical losses.

At the AOD vessel, alloys can be used for coolant additions, as a reductant or as finishings. Each alloy has its own characteristic cooling effect and an operating strategy is developed to use the different materials to best effect, to control temperature. In general terms, for the present operating strategies used within BSC Stainless, charge chrome on ferritic steels and granulated ferro-nickel on austenitic steels, have proved to be the most suitable alloys for coolant use. The pure nickel and nickel oxide materials can presently only be used as coolant in smaller amounts because of their relatively large effect on bath chemistry for a given cooling effect, which is not always desirable. When pre-reduced iron is available, at the right price, we intend to use as coolant a blend of iron pellets with these nickel forms. This would overcome the present nickel usage limitations and allow the use of an infinite variety of nickel/iron mixes for simultaneous chemistry and temperature control.

Large batch additions of coolant into the AOD vessel are undesirable due to the excessive cooling which they cause. This cooling takes the liquid metal away from the carbon/chromium/temperature equilibrium it has attained and on further blowing the system returns to equilibrium by oxidising relatively more chromium. This causes a more rapid temperature rise and subsequently requires more reductant silicon to recover the metals and increases refractory wear. As the arc furnace rather than the AOD vessel normally paces the output of the melting shop, for a single arc furnace/AOD vessel combination, higher output levels can be obtained by reducing arc furnace charge weights and increasing AOD vessel coolant additions. In common with other modern plants, our overhead hopper storage and weigh system allows for batch and continuously fed additions of alloys to the vessel during blowing and the latter can be used to advantage in minimising the silicon and other debits associated with heavy coolant additions. By controlling the rate of coolant feed, the temperature rise in the vessel can be balanced, so eliminating excessive bath cooling and limiting extra silicon requirements and refractory wear.

Coolant materials can be divided into "active" and "passive" groups. The active materials like charge chrome contain carbon and/or silicon, which leads to the material giving a cooling effect when first added, related to the latent heat, specific heat and weight of material but subsequently generates heat in the bath from the extra carbon/silicon added, reducing the overall cooling effect achieved and increasing the blowing time. Passive materials, without the oxidisable carbon or silicon content, give only the immediate expected cooling effects. Dependent upon the least cost operating strategy, which normally rests on whether the order book is a full or lean one, the lower or higher furnace charge weights and vessel coolant levels options are chosen. For the higher coolant usage, higher output strategy, active coolants are used in greater amounts as they allow greater reductions in furnace charge weights.

Nickel oxide 75 sinter is used by some operators as a coolant, injected directly into the vessel pneumatically. In our experience, even when added at the best bath carbon content and temperature, there are cost debits equivalent to about 1 Kg/tonne of silicon for a 3 % nickel addition made in this way, due to the oxygen in the sinter oxidising chromium as well as carbon. The dissociation of the oxide sinter in the liquid metal also gives a strong cooling effect, which again is not always desirable. The use of this material is very much subject therefore to local consideration, on the capital cost of installing such plant, the pricing and price stability of the nickel and the debits associated with its use. Looking to the future however, it could be expected that the use of particulate injection will increase for the ease of handling and control in steelmaking which it could give.

The utilisation of full raw materials value

With a raw materials bill at BSC Stainless of approximately £ 60 m and mixture costs representing of the order of 85 % of the cost of the slab produced out of the melting shop, it is important that we make the best purchasing and usage decisions. If scrap is freely available and can be bought at an attractive price it is used to the fullest extent, if to the contrary, then cheaper ferro-alloys such as charge chrome and ferro-nickel are used.

There is a wide variety of materials available to the steelmaker; nickel forms are particularly diverse, with pure nickels, ferro-nickels and oxides. On our stockyard we can have up to 15 lots of nickels at any time and some of these in drums we prefer, for handling reasons, not to split open. On ferro-chromes and other alloys, up to 22 lots can be in stock and on stainless scraps typically up to 14 categories and possibly as many as 70 parcels of scrap.

Low phosphorus mild steel scraps are needed to balance the alloys in the charge and our wastes such as skull and swarf have to be used. In addition, exotic scraps present a usage and purchasing opportunity, if they can be fitted into charges. Exotics, are scraps containing various combinations of nickel, molybdenum and chromium, normally available at advantageous alloy unit prices because they also contain cobalt, copper and other contaminants. To use these requires a skill, in fitting them into arc furnace mixtures without breaking residual codes in final steelmaking specifications.

In addition to this broad raw material variety of analysis and parcel weights, there are useful and disadvantageous analysis variations in the alloy groups. A look again at the ferro-nickels highlights this; two of the ferro-nickels from one supplier in addition to iron units contain chromium units as well and it is obviously of value to deliberately use these instead of the more expensive chromium units from ferro-chromes. With respect to debits, the higher carbon content of some of the ferro-nickels precludes their use as finishing materials and to remove it requires greater gas usage in the AOD vessel when used as a charge material or coolant. Similarly, the higher sulphur content of two of the ferro-nickels available, brings processing cost debits in its removal in extra lime, time and refractories. The incentive to use these materials or put another way, their "value in use" is therefore a balance between the nickel unit price and the balance of other credits and debits associated with that material, the same reasoning applying to all alloys and scraps available for steel-making.

The melt out analyses on the arc furnace, which we normally obtain, are over the range of 0.9 % C to 2.5 % C with attendant silicon variations. Each arc furnace burden and subsequent melt out chemistry has associated processing costs on the arc furnace and AOD vessel. It can be seen that in order to handle this wide variety of materials, to make the best process use of them, to take advantage of the cheaper materials available in the market and to minimise the use of expensive low carbon finishing materials, something more than a normal mixtures clerk is required.

To do this and to help purchasing area management decide "what to buy and how much to pay", and against a background of price volatility, an on line computer based least through cost mix system (L.T.C.M.) is used within BSC Stainless for mixture design, operating strategy evaluations and value in use assessments of ongoing and new materials.

In principle, the system is based on a model which is divided into three parts, the mixture design, arc furnace operation and AOD vessel operation stages. The system first designs a burden for the arc furnace and AOD vessel to meet final desired aim points, by using the cheapest materials available in raw materials stockyard and using all the alloy units contained in the various materials. The non-metallic content, residual contents and restrictions, expected yield and usage restrictions of all materials are accounted for in the calculation. The mixture so designed is then evaluated on an arc furnace model, to evaluate processing cost debits and credits associated with this mix and then similarly on an AOD vessel model. A series of optimising calculations then ensue which results in a furnace charge mix and AOD vessel coolants giving the lowest final liquid metal cost in the ladle leaving the AOD vessel.

The system uses present day or "replacement costs" and not standard costs of materials, and therefore allows quick and realistic reaction to market price changes of raw materials.

The arc furnace model takes account of variable time and tonnage costs on items such as power, electrodes, oxygen and fluxes. Each burden calculated for the arc furnace has attendant and different requirements of these items dependent upon the weight, non-metallic content and chemistry of scraps and alloys charged and the desired chemistry and temperature required for transfer to the AOD vessel. The AOD vessel is set up with a variable stage to represent the first blowing stage and a fixed stage for the subsequent blowing periods, reduction, de-sulphurisation and finishing steps. For each start blowing chemistry and temperature there are attendant time, gas, fluxes, coolant and reductant requirements. From this brief description, it will be appreciated that the model follows the production practice closely, it is not however a direct mimic - it only takes into account those factors which can make a significant difference to the final liquid metal cost.

The full L.T.C.M. system has operating terminals in two Melting Shops for mixture calculation, in the purchasing department for value in use and stock assessments and in a separate establishment for system development. The large main frame scientific computer is based over 100 miles from the operating plant at a computer bureau company. A very large sophisticated programme was required to accommodate the model and to allow the handling of particular parcel weights in the charge calculation, for example ingots and drums of materials, so necessary for meaningful operation on the raw material stockyard. A machine of this type, with an integer programme facility was not available within BSC.

The raw materials area of our newest melting shop was laid out and manned to use this system to best advantage and all materials on the stockyard are identified in the LTCM stock with a weight, analysis and expected yield. A hard copy of a cast mixture is output from the system listing the materials to be used. This is interpreted into a working instruction to the raw materials team showing the scraps and alloys to be organised for the cast. When selected for an arc furnace charge, these materials are already in or are loaded to skips. All skips are identified and are marshalled by scrap handling lorries into the charging basket area in cast quantities, where they are tipped by overhead crane to the charging basket, in a predetermined order, there typically being 2 or 3 baskets per charge. The baskets are then charged to the furnace, from which point onwards basket tracking is taken over on a second process control computer system, which tracks all casts in process in the shop and generates cast logs. The LTCM system advice on coolant materials for the AOD vessel is picked up and materials organised by the steelmaking team.

In addition to mixture design, "value in use" assessments are also carried out on the system, to assist operating and purchasing decisions.

An alternative type of run can be carried out on the computer system, which generates a value in use assessment calculation. For a material on offer, this is assessed against a standard stockyard of materials, at different price levels, to determine the cast mixture cost at different usage levels of that material. From the print outs obtained, similar materials from different suppliers can be evaluated, to determine the price level which would give similar cast costs and the relative usage of alternative materials at different price levels.

It is an extremely comprehensive system which has been found to be invaluable, where for an equipment and operating cost outlay of pence per tonne of liquid steel, there are savings of pounds per tonne to be gained. It is perhaps worth restating that there are no unique least cost mixtures which will always apply. There may be preferred analyses for particular alloys and we welcome discussions with suppliers about these; to a degree silicon for example can be useful in an alloy as it can be used to assist melting on the arc furnace. However as with mixtures, there are no unique materials which will always be used, the use of the AOD process has taken off most material restrictions and the purchase of one material rather than another depends strictly on the prices asked for these materials and their relative cost debits/credits in use.

Future trends

With the present position between stainless steelmakers and ferro-alloy producers, after the trends of the last decade, what could the next ten years bring ? To safeguard company interests in the continuity of supply, the trend for steelmakers to take up interests in ore mining and ferro-alloy conversion would probably increase, if given a free run, but government interests and particularly those of the developing countries may preclude this. Alloy producers and scrap suppliers, in addition to steelmakers, will no doubt become more sophisticated in their methods of evaluation of the full value of materials, which in turn will reduce the opportunities to the steelmaker to make cost savings relative to his competitor. In the longer term the effect of this and the stainless producers squeezing out the last of the significant processing gains to be had from modern steelmaking plant, new Sendzimir cold rolling mills and heavier piece weights, the pendulum could well swing back to the ferro-alloys area for the next significant improvements in production costs. Any alloy producer who can combine the production of alloys from major ore-bodies with low energy costs, must be in a strong position to move into stainless production. Such a move would also have great merit in energy conservation from the point of view of liquid ferro-alloy or hot pelletised feeds to steelmaking and through costs could benefit from the ready tailoring of alloys to meet production needs. Whether the position of those operators whose countries resources give this opportunity are in suitable positions to service the markets, or whether international trade and other governments policies to their own existing industries would allow it also, is a different matter.

For some time to come however, the effect of the large excess stainless capacity installed round the world and the high capital cost of new plant will favour stainless steel producers with recently installed plant, recognising that probably no-one in the industry could afford to install any large developments for at least ten years. Dependent upon the size of the home market available to each stainless steel producer, their capacity, scale and age of plant and commitment to exports, a pattern of a few large, modern plants producing the bulk stainless grades and other plants concentrating on more difficult to process or more specialised steels could be expected to emerge.

On the ferro-alloy supply front, the move to bulk supply of easily conveyored alloys and alterations in packaging of others to ease handling will continue, and materials injection into steelmaking units could be expected to develop. The discussions between alloy producer and steelmaker will continue to develop preferred analyses and material forms to the benefit of both and the many attempts by alloy producers to develop a mixed chromium/nickel alloy for stainless steelmaking will perhaps succeed in the next decade - but remember that such an alloy is of no special value to the steelmaker unless it can be sold at a price below the intrinsic value of the present day cheapest separate sources of chromium, nickel and iron.

In steelmaking, perhaps someone will show how to remove phosphorus effectively from stainless melts. We are still not clever enough to do this, even with our new vessels and new raw materials pastures are available if it can be achieved.

Whatever the trends, I expect the involvement of alloy producers and steelmakers in each others problems and expectations to widen and deepen and a conference in ten years time could usefully pick up the lively progress attained.

DISCUSSION

Mr. C.N. Harman*

Thank you Mr. Reeves for the very detailed comparison of advantages while using the AOD process and particular mention of lower yields of sulphur and residual elements like lead. I would like to know what is the impact on the yields of phosphorus while using the AOD process?

Mr. D.A.A. Reeves:

In stainless steelmaking, the problem with phosphorus removal is the presence of chromium. In the presence of chromium, even in the AOD process, phosphorus in theory will not move very much at all. Therefore, in our operation, we always design on the basis that the phosphorus being charged will come out of the process in the liquid metal. Incidentally, we have looked at the analysis of our fume dust which we collect in our bag filter house and it seems that there is some concentration of phosphorus in the AOD fume, but by weight it is small and I would not want to work on the basis that I could remove phosphorus in the process.

Mr. H. Geilenberg**

By what criteria are you selecting charge chrome versus conventional high carbon ferro-chromium?

Mr. D.A.A. Reeves:

I think the first and the main criterion, as I outlined at the end of my paper, will be the value of the chrome units that we are purchasing and then the balance of any debits and credits associated with that materials use in steelmaking. Normally the comparison between charge chrome and the high carbon 4:6 carbon ferro-chrome is such that the chrome unit price is much lower in the charge chrome than the 4:6 carbon ferro-chrome and overwhelms any process cost debits or credits associated with the comparison of these two materials.

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* Ferro Alloys Corporation Ltd, India; ** Union Carbide Europe S.A., Switzerland