TECHNICAL PROGRAM AND DISCUSSION

INFACON'89

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SESSION I

April 24, 1989

Chairmen: J.G. Oxaal, Chairman INFACON'89
A. Kitera, Japan Ferroalloy Association

Introductory Address:
"Future Steelmaking and Its Impact on Deoxidation and Alloying of Steels" - E. Aukrust, Senior Technical Director, LTV Steel - United States.

*1. **"Dephosphorization of Mn Alloys with Mg"** - Y.E. Lee, Elkem Metals Company - United States.

*2. **"Dephosphorization of Manganese Alloys"** - J. Kr. Tuset, Norwegian Institute of Technology - Norway and A.N. Waernes, Sintef - Norway.

*3. **"The Establishment of a 500,00 t/a Sinter Plant at Samancor's Manatwan Managnese Ore Mine"** - W.A. Gericke, Samancor - South Africa.

*4. **"Analysis of the Smelting Process for the Production of Silicon-Calcium-Iron Alloys"** - J. Finardi, Bozel Mineracao e Ferroligas S.A. - Brazil.

*5. **"Vanadium Production and Applications"** - H. Hess, Gesellschaft fur Elektrometallurgie GmbH - West Germany.

*6. **"The Development of Vanadium Industry in China"** - T. Wang, Jinzhou Ferroalloy Works - China.

*Papers are found in Volume I of the Proceedings

Session I *Speakers (left to right): J.G. Oxaal (Chairman), E. Aukrust, J. Kr. Tuset, and Y.E. Lee.*

W.A. Gericke of Samancor in South Africa presents a paper on Samancor's sinter plant at the Mamatwan manganese-ore mine.

Registrants during the coffee break.

FUTURE STEELMAKING AND ITS IMPACT ON DEOXIDATION AND ALLOYING OF STEELS

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INTRODUCTION

We have during the last years seen a strong revitalization of the steel industry throughout the world as a result of the restructure and modernization of facilities based on state-of-the-art technology. The rate of change is, however, accelerating, and emerging is an entirely new technology utilizing direct smelting of iron ore to steel combined with strip casting and direct rolling to finished products.

On the near term the modernization is continuous with full implementation of ladle metallurgy and continuous casting for production of high purity steels both in flat rolled and bar product both for carbon and high-strength low-alloyed steels.

It is the objective of this paper to review these technological trends and to assess the implications to the steel industry as well as its ferroalloy suppliers.

Direct Iron and Steelmaking

Current concepts of in-bath smelting involve the use of a liquid pool of crude iron into which coal, and either raw or partially reduced ore, are introduced. Carbon and carbon monoxide derived from the coal act to reduce the iron oxides to liquid iron. The ore feed is preheated, and prereduced if required, in a separate vessel by means of the off-gases from the smelting unit. A schematic diagram of this type of flowsheet is shown in Figure 1. Several of the smelting concepts under investigation worldwide include post combustion of the effluent gases within the smelting vessel with injected air or oxygen. It is the intent to transfer the heat generated by post combustion back to the slag and metallic bath in the smelter. Control of the post combustion reactions and harnessing of the energy released are essential issues faced by all the organizations working on in-bath smelting methods. There have been many excellent review papers[1-7] on the major processes currently under development.

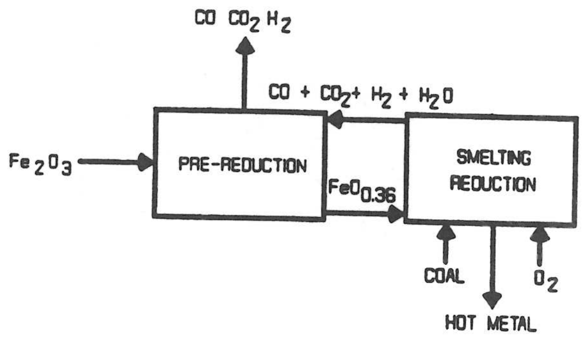


Fig. 1. Simplified flowsheet of coal + ore smelting[1].

Incentives for the New Steelmaking Process

1. High Productivity. The new processes may achieve several times the production of a modern blast furnace (per inner volume) because of the high reaction rates, and therefore the furnace can be small.

2. Simplification of Facilities. The blast furnace process requires stoves and coke oven batteries in addition to the blast furnace itself, but the new process(es) requires only a converter-type furnace attached to a prereduction vessel, because coal and the prereduced raw materials are best charged directly.

3. Flexibility of Raw Materials. Because coal is added directly without being converted to coke, non-coking coal can be used, i.e., without the need for coking coals. However, high heat value coals are needed for these processes. Substantial quantities of scrap can be introduced to displace ore units.

4. Operation Flexibility. The processes being developed elsewhere are for making pig iron but it appears that a "semi-steel" is possible. Further development work in the U.S. will be directed to complementary desulfurization and decarburization processes.

5. Scrap Melting Flexibility. The energy generated in the process can either be used for iron ore smelting or for melting of scrap, a flexibility of great importance in the U.S. An immediate spin-off from involvement in these development programs would be the broadening of conventional BOF capabilities.

The specific future steelmaking process being developed by the American steel industry is shown in Figure 2.

Thin Slab Casting

Thin slab casting in the 40-50 mm thickness range has reached the commercial stage with

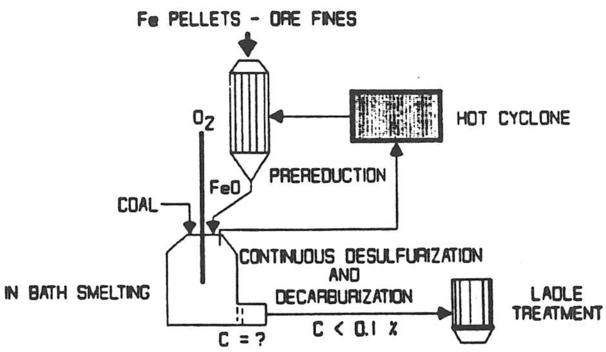


Fig. 2. General flowsheet of the direct steelmaking process under development by AISI.

the building of Nucor-Crawfordsville facilities. The plant is in the startup phase at the time of this INFRACON 89 conference. The SMS thin slab casting process builds on known slab casting engineering principles perfected during the last 20 years, i.e., oscillating casting mold, submerged pouring tubes, mold fluxes, etc. Innovative engineering design by SMS has extended the use of this basic continuous casting process to the casting of a thin slab section in the range of 40-50 mm with corresponding reductions in rolling requirements. Much higher casting rates are also being projected, with a design casting speed of 4.5 m/min for the Crawfordsville plant, and even higher speed indicated to be feasible.

A different casting precept is adopted with the twin belt processes of Hazelett, Sumitomo and Kawasaki and others. Using a moving, rather than oscillating casting mold, it is possible to increase the casting speed even further. The Kawasaki-Hatch KH process has been reported to reach 15 m/min.

Strip Casting

The moving mold is inherent to all strip casting concepts. To achieve commercially viable rates of production of tonnage carbon steel of strip in the thickness range of 1-5 mm, casting speeds one order of magnitude higher than those considered for thin slab casting would be required. This is perceived possible only through solidification of the metal in direct contact with moving molds which can take the form of rolls or belts. The principal designs under consideration are shown in Figure 3.

Most progress has been made with the single roller principle, and this is the only approach which has reached commercialization. The single roller approach has, however, some very specific limitations. The maximum thickness being cast is in the range of 1 mm, which with further rolling results in foil products and low volume applications.

For thicker strip or sheet, twin roller or twin belt machines of various combinations of belts and roll design are being considered. The engineering design related to direct casting of strip is still unresolved, and the search for a functional strip casting machine is still continuing.

An understanding of the process fundamentals has, however, been achieved and the relationship to the critical issues of surface quality, strip contour, and as-cut strip quality. The question can then be asked:

What does a viable strip casting process require?

1. The process must generate a defect-free cast surface which does not require any conditioning during subsequent processing. This depends on achieving (a) a stable meniscus of the liquid steel against the mold, (b) uniform chill surface texture, (c) clean liquid steel in the casting pool, and (d) no stream impingement.

2. The contour of the strip must be good. This requires (a) two-sided casting, (b) uniform thickness, (c) undistorted chill surfaces, and (d) square edges.

3. The as-cast quality must be good, i.e., (a) no surface or internal cracks or voids, (b) internal cleanliness and uniform grain size and structure.

From these requirements one can answer the question of:

What does a viable strip casting process look like?

1. The process needs to be a two-sided casting process,

2. have variable thickness capability at least up to 1/4 in. thickness,

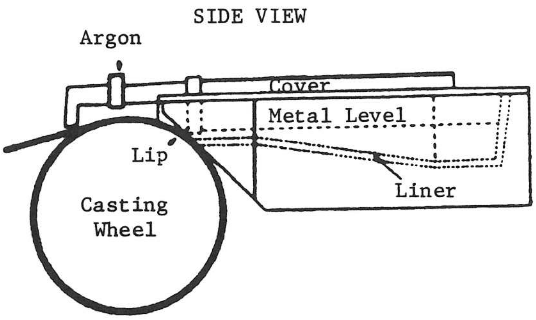
3. have vertical pool with no stream impingement,

4. provide an extended solidification length -- for high productivity, and

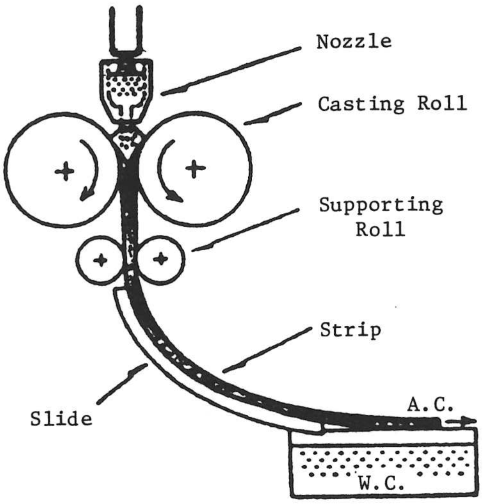
5. it needs to be a practical device.

The engineering requirements to achieve these goals are formidable, however, significant progress is being made. It is expected that strip casting will be commercialized before the end of the century.

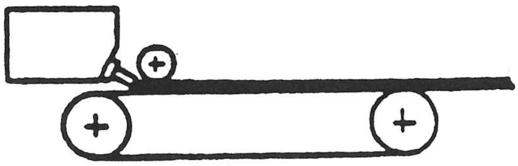
Our projection is therefore that the 21st Century will bring a new era of steelmaking. As the BOF, continuous caster and hot strip mills replaced the prevalent ingotmaking and hand mills a generation ago, the direct steelmaking process, in combination with strip casting and with in-line rolling, will become the steelmaking technology of the future.



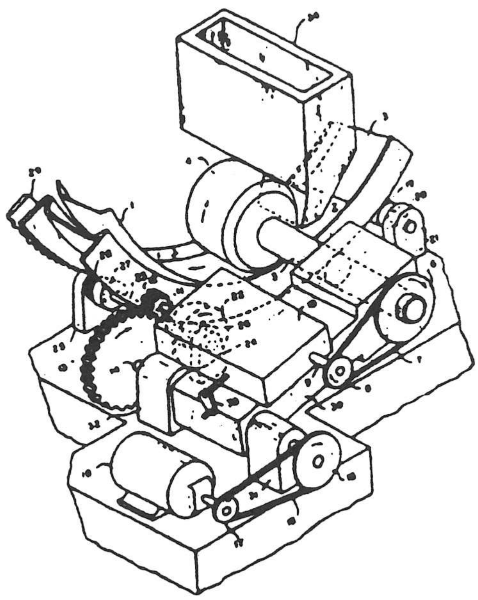
(a) Schematic diagram of single roll caster.



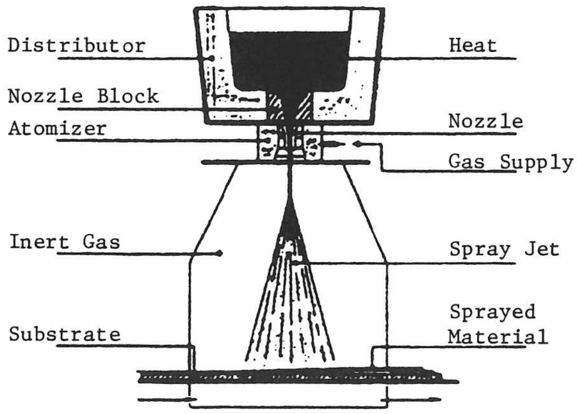
(b) Schematic diagram of double-roll caster.



(c) Schematic diagram of belt-roll caster.



(d) Schematic diagram of inside-the-ring caster.



(e) Schematic diagram of spray caster.

Fig. 3. Principal designs of strip casting processes[8].

Ladle Metallurgy and Continuous Casting

For the near term continuous casting and ladle metallurgy are fundamentally changing the basic steel industry's deoxidation and alloying systems. Continuous casting is rapidly being implemented across the board, with its requirements for killed steels. Ladle metallurgy is being equally widely adoped. A much improved steel quality has resulted from these process changes.

The deoxidation of steel has traditionally been achieved with bulk additions of Al, Si, and Mn alloys during tapping. To achieve better compositional control and cleaner steel, a wide range of ladle processes has been developed. Key features to the ladle metallurgy include:

1. Temperature control by scrap cooling or full temperature adjustment capabilities with ladle furnaces.

2. Compositional adjustments by trimming of ferroalloys.

3. Deoxidation and inclusions removal by argon bubbling and slag rinsing.

4. Modification of the morphology of the inclusions by calcium treatment.

5. Decarburization and hydrogen removal by vacuum treatment.

The ladle step requires stirring of the liquid; the mode of stirring, e.g., inductive or gas driven, depends greatly on the specific ladle treatment requirements. A significant implication to the ferroalloy industry is the reduction in chemical deoxidants and ferroalloys as a result of the very high alloying recovery achieved with vacuum treatment. Except for the most reactive elements such as aluminum and calcium, the recovery is close to 100% for most alloying elements.

Clean Steels

The elimination of sulfur has been one of the most difficult struggles throughout the history of steelmaking. This "war" has now been won as a result of the advances of hot-metal and steel-desulfurization treatments. Calcium treatment has replaced the use of rare earth and zirconium for final sulfide shape control and modifications of inclusions. The calcium approach has overcome the earlier problems with subsurface inclusions which were inherent problems with rare earth and zirconium treatments.

With the capability of producing low-carbon low-sulfur steels with clean steel practices, the elimination of nitrogen becomes a critical next step for improving the quality of steels. The control of nitrogen in steelmaking is particularly difficult because of the ease by which nitrogen is absorbed in liquid steel when exposed to air. Practices have now been developed such that liquid steel is shielded from the atmosphere in such a manner that the nitrogen content of the steel can be kept to 0.003%. With this control capability in steelmaking, it becomes important to avoid any unpredictable or uncontrolled pickup of nitrogen from the ferroalloys.

Continuous annealing requires low interstitial steels. The grain growth required for deep-drawing properties is impeded during annealing by the presence of fine carbide and nitride precipitates at the grain boundaries. The control of carbides and nitrides to the 0.003-0.005%, range, is highly desirable in order to process deep-drawing steels by the new continuous annealing processes.

The next step in this evaluation of increasingly higher quality steels is the production of virtually pure iron, where alloying elements and precipitates are re-introduced to the steel in a predefined and controlled manner to achieve a steel product with properties specifically selected to achieve a given objective. We are well on the way to achieving these goals today. By applying (a) hot metal and steel desulfurization and dephosphorization, (b) BOF combined blowing, and (c) ladle treatments in a protective atmosphere with vacuum degassing, reheating and compositional adjustments; steels with a total composition of C, H, P, S, O, and N of 50-100 ppm are being produced.

These pure steels with alloying elements properly added have greatly enhanced forming properties and made possible the production of steels with greatly improved uniformity in all physical properties.

Microalloyed High-Strength Low-Alloy Steels

The strengthening mechanism of Ti, V, and Cb in microalloyed HSLA steels is well understood. To achieve the desired physical properties, it is essential that not only the composition of the steel is controlled to specified limits, but also that side reactions are not allowed to occur. For example, when titanium is used for precipitation hardening, sulfur must be removed prior to alloying to avoid sulfur-titanium reaction which would remove the titanium from the steel and make it unavailable as a strengthening element. To obtain uniform properties in HSLA steels, one would, in addition to tight control of the microstructure, also require a high degree of process control in the subsequent thermomechanical treatment. Finishing and coiling temperature on the hot-strip mill, as well as cold reduction and annealing control, are prerequisites for achieving ultimate uniform properties.

IMPLICATIONS FOR THE FERROALLOY INDUSTRY

The production of liquid steel on a large tonnage basis of purity levels which only could be produced in a few laboratories, and referred to as "pure iron" just 15 years ago, have major implications. The trend is to manufacture steel from this pure iron by re-introducing alloying elements at very precise, predesigned levels in order to achieve steels with specific engineering characteristics in regard to strength, fatigue, ductility, and other physical properties. The ferroalloys to be used in this new steelmaking approach must be compatible with the new steelmaking processes as well as meet the compositional restraints for the steel products.

Some principal requirements of the ferroalloys are:

Statistical Process Control

SPC information for production of ferroalloys is still available and utilized only on a limited basis by many steel plants. This is probably because the ferroalloy quality has not yet become the primary focus. Most ferroalloys are bought based on generalized specifications and one analysis will accompany the bill of laden. This one analysis might represent a full barge load and provides no information on compositional variation within the shipment. Consequently, the steel plants can do very little with this information.

This will have to change greatly as the developments we discussed in this paper are being implemented and the trend toward purer steel continues.

In continuous casting plants, the quality of aluminum is being controlled in a far more rigorous manner. Suppliers provide weights and chemical analysis on a lot-by-lot basis and this information is being verified by the steel plant. Suppliers are being qualified and eliminated on basis of the quality of their products. I believe we will see an increasing trend toward the application of similar control procedure across the board on ferroalloys.

We are becoming increasingly aware of situations where impurities in ferroalloys can impact the property of the steel product. However, with the many process variables involved, it is difficult in most cases to identify a single cause-effect relationship. Our awareness and demand for higher purity for alloys will undoubtedly increase and so will the sophistication of SPC procedure by the ferroalloy producers. The integration of ferroalloys and steel plant SPC procedures will be the next step in this field.

Uniformity in Size and Composition

With the tolerance band in composition of the steels being reduced to one-half and, in many cases, one-quarter of AISI grade tolerances (which were accepted commercial ranges just a few years ago), it becomes mandatory that the variability in physical and chemical properties of the ferroalloys be equally reduced. The presence of fines in alloys designed for bulk addition to the steel ladle during tapping is clearly unacceptable. The steel plants require assurance that all specifications for the ferroalloys are met at all times. Standard operating practices and monitoring procedures need to be adopted throughout the ferroalloy production cycle.

The casting process in the manufacturing of ferroalloys needs to be re-examined. Segregation during solidification is very severe in many alloying systems. Large and variable pick up of oxygen and nitrogen does also exist in flat-bed casting operations. Further oxidation as well as adsorption of moisture may occur in storage and during distribution of the materials. Granulation of ferrosilicon has been successfully used to produce a more uniform product, but additional work needs to be done on the development of improved casting processes for a wide range of ferroalloys.

Control of the Gaseous Content of Ferroalloys

Many ferroalloys have concentrations of oxygen and nitrogen in the range of 0.2%, which is unacceptable when used for superclean steels with a total impurity level of 0.005%. Particular attention needs to be placed on the reduction of nitrogen content in the ferroalloys. With modern ladle metallurgy procedures, it is relatively easy to eliminate oxides from the liquid steels. However, nitrides are far more difficult to remove. The steelmaking approach in keeping nitrogen under control is to produce the steel with a nitrogen concentration of 20-50 ppm, and then to shield the steel from the atmosphere during ladle treatment and continuous casting. Approximately 30% of the nitrogen can be removed during vacuum treatment of low-carbon steels; however, in most steelmaking operations, any nitrogen introduced in the steel stays with the product. Thus, nitrogen contamination from the ferroalloys needs to be avoided.

Low-Carbon Ferroalloys

Carbothermal reduction leads to carbon saturated alloys which are refined to low carbon levels by oxygen blowing. Process developments aimed at reducing the carbon content of medium-carbon ferroalloys are highly encouraged. In stainless steel production, the majority of the chromium is charged as high-carbon ferrochrome, and only a small amount of high-purity ferrochromium is used for compositional adjustment in the ladle before casting. One would expect this trend to expand to other steel alloying systems. This would suggest the use of high-carbon grades for the charge, low-carbon grades for trimming, and less use for alloys with medium-carbon compositions.

Phosphorus Control

Phosphorus is used as an alloying element in a few grades. However, by and large, phosphorus is deleterious to the properties of steel and needs to be reduced. There may be a possibility, as new continuous steelmaking processes are developed, to smelt high-phosphorus manganese ore as part of the steelmaking process. The concepts being explored involve the oxidation of phosphorus in such a manner that good recovery of the manganese is still maintained. Short of such new steelmaking developments, the steel industry is largely dependent on the use of low-phosphorus raw material. In view of the strategic importance of low-phosphorus manganese ore, research and development on the dephosphorization of ferroalloys is highly encouraged. The driving force for this work would be the development of a cost-effective process for manufacturing of low-phosphorus ferromanganese from high-phosphorus ores, and thus make us less dependent upon the strategically limited supply of low-phosphorus manganese ores.

Improved Dissolution Rates of Ferroalloys

The thermal requirements and the rate of solution of ferroalloys need to be understood precisely for the steel plants to optimize the alloying practices.

The major methods for additions of alloys to steel include:

1. Bulk additions to the steelmaking furnace or to the ladle during tapping.

2. Powder injection by dense or dilute phase transport to the ladle.

3. Wire feeding to the ladle or the tundish and even, in some cases, to the casting

mold.

Bulk additions of coarse material will continue to be the first choice of the steelmaker provided good recoveries can be achieved in the operation. Materials and equipment costs favor this approach. Advanced techniques for achieving slag-free tapping have greatly reduced the risk for reoxidation when the ferroalloys are added to the ladle during tapping. The ferroalloys have to be sized such that the material can dissolve within the time of turbulent mixing generated by the tapping stream. The buoyancy effect makes bulk additions of light-reactive alloys to the ladle after tapping unattractive in most cases.

Submerged powder injection in the steel bath has inherent good heat- and mass-transfer characteristics, and can be used effectively for additions of virtually all alloying elements. Reoxidation may render this technique ineffective where substantial quantities of reactive furnace slag are present. Other considerations are the relatively high capital costs for reliable and flexible injection systems.

Steel-encased alloy wires are clearly more expensive than other forms of ferroalloys. Consequently, this method for alloy addition is only used for highly reactive elements such as calcium or for microalloying close to the casting operation. Wire feeding is also attractive because of the simple equipment involved and the highly reproducible results. There is also very little possibility for losses of the alloys due to oxidation by any furnace slag in the ladle. Because of these features, wire feeding of aluminum has been widely adopted.

We have, in the previous discussion, highlighted the process considerations which will determine whether bulk addition of coarse alloys suffices or whether injection or wire feeding might be required. With the trends toward cleaner steel, the foremost consideration is higher-grade ferroalloys with lower contamination of sulfur, phosphorus, nitrogen, oxygen and hydrogen. Uniform size distribution specifically chosen to satisfy individual steel plant practices is also important.

CONCLUSION

With improved process control in steelmaking and with the separation of the desulfurization, the deoxidation and the alloying steps, it might be appropriate to reconsider alloying systems which in the past gave unreproducible results due to the multitude of various competing reactions taking place. For example, as titanium has a strong affinity for oxygen, nitrogen and sulfur, it is not surprising that it was difficult to achieve reproducible strength level in microalloyed steels when the titanium alloys were added during tapping. As titanium reacts with the oxygen, nitrogen and sulfur, only a limited and uncontrolled amount of the original addition would be available for the microalloying, which was the principal purpose for its use. However, with modern ladle metallurgy stations, it is possible to desulfurize, deoxidize and control the nitrogen content in the steel before titanium addition, thus assuring that the desired microalloying effect of titanium is achieved.

It is predictable that the reactive alloying elements such as titanium and boron, which are cost-effective as strengthening elements for steel, but which have been difficult to utilize reproducibly in the past, will achieve new applicability with modern secondary refining systems.

It should be noted that modern steelmaking technology requires less deoxidant per ton of steel. Improved control of the steelmaking refining reactions by combined oxygen-inert gas blowing has reduced the oxygen content of the steel at tap; extended use of carbon-oxygen deoxidation with partial or full vacuum treatment will further reduce the oxygen level of the steel. However, in most cases, deoxidation is completed by chemical means, principally with aluminum.

The alloying of steel will be done in such a manner that the active alloying elements are not lost by reoxidation or reactions with sulfur or nitrogen. We will, therefore, have higher or more reproducible recoveries of ferroalloys but will be more concerned about their purities. With the low level of impurities present in the liquid steel after ladle refining, the purities of the ferroalloys might indeed be the limiting factors regarding the cleanliness of the steel being produced. Nitrogen and phosphorus control of the ferroalloys warrant particular attention.

Close collaboration between the ferroalloy producer and the steel plants they serve will continue to be required to provide alloys specifically suited to fit special plant practices. In general, the trend toward production of purer steel will continue. At the same time, simplification in the steelmaking process will be sought to decrease costs.

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SESSION I - DISCUSSION

"FUTURE STEELMAKING AND ITS IMPACT ON DEOXIDATION AND ALLOYING OF STEELS"

Q. W. F. Porter, Shieldalloy Metallurgical - USA. Can you give us any idea on the timing you feel the steelmaking process could require between now, and say, commercialization?

A. E. Aukrust - We are starting to see the impact of these technologies already today. For example, the Decorex process, which is only dealing with one of the objectives I have indicated here, namely iron-making, is in the demonstration phase in South Africa. There are certain processes, for example, CRA announced their collaboration with Midrex and Colby which are also aiming for a demonstration project. The big effort, by the Japanese national project and the American national project is broader in scope, dealing with research and development. I think we are going to see that going through development in the coming three to five years, and commercialization within ten years.

Q. F.R. Sadler, Frank Sadler Associates - USA. Are the raw material specifications for coal, ore and scrap more critical or less critical than what we have in the conventional process of today?

A. E. Aukrust - They are different. Of course one of the key things we want to find out is what are the most critical aspects in these raw materials. In regard to coal, the one that we will particularly work on, will need a high fuel value. So, of course, a low-grade coal is not applicable. We do not need, however, a coking coal, for example. That opens up new and broad avenues for a different selection of coals. In ores we do not feel that the lower gangue content, that has been dominant for prededuction, is going to be an extra critical element. In scrap, I think the major issue is going to be preparation and size control.

A. Saraf, Ferro-alloys Corporation - India. I have only a few observations to make. One is in regard to the phosphorous content of ferroalloys, which is going to play a very critical role as was already mentioned. In India the phosphorous content in the ferroalloys of manganese is very high. We have got to find out the methods of dephosphorization of these ferroalloys. With regard to making the special steels, such as stainless steel, we have got to reduce the phosphorous content in these steels which we can do only if we reduce the phosphorous content in the input ferroalloys, namely ferrochrome. So we have to find out methods of dephosphorization of the ferrochrome or the dephosphorization technology for these special steels.

"DEPHOSPHORIZATION OF MANGANESE ALLOYS"
"DEPHOSPHORIZATION OF MN ALLOYS WITH MG"

Q. J.G. Oxaal, Chairman - INFACON'89 - USA. What is the yield based on magnesium or how much magnesium is required to reduce the phosphorus from, let's say, a .3 to a .1%?

A. Y.E. Lee, Elkem Metals Company - USA. Roughly based on the residual magnesium content and the phosphorus removal I can estimate about 30% or 40% of magnesium recovery. With that number an estimate can be made of the magnesium required to remove a certain level of phosphorus.

Q. J.G. Oxaal. It is surprising that the solubility of magnesium in high-carbon ferromanganese is closer to carbon saturated iron than it is to carbon saturated manganese. Do you have an explanation for this?

A. J. Kr. Tuset, Norwegian Institute of Technology - Norway. I don't, in fact, it is also a bit surprising to us that it turned out to be like that. I have a comment on the question to Dr. Lee about the consumption of magnesium. One can of course calculate consumption from what is needed by the stoichiometry of the reaction, but in addition to this there is a fairly high content of magnesium in the metal which will also consume magnesium. The product alloy, as we can see from the results of Dr. Lee, contained somewhere in between .5 to 1.5% magnesium which is a fairly high quantity.

Q. A. Saraf, Ferro-alloys Corporation - India. I would like to know from Dr. Lee if any work has been done with the use of soda ash for the dephosphorization of manganese? Because soda ash is used for dephosphorization of pig iron.

A. Y.E. Lee. We tried soda ash but it did not work. We believe that the oxygen potential is too high for the soda ash to work in this particular system.

Q. F.R. Sadler, Frank Sadler Associates. I would like to ask a question of either gentlemen about the cost effectiveness of reducing phosphorus from, say .3 to .1% in high carbon ferromanganese. How much can you expect to increase the cost, percentage wise, and is the steel industry willing to except such an increase?

A. Y.E. Lee. We estimate, based on the current prices, the additional cost will be something less than two cents per pound of the manganese treated.

Q. J. Elliott, MIT - USA. It is well known that oxygen, even in minuscule quantities is an enemy of the chemistry that you are attempting, and I recognize you worked in a graphite crucible. On the other hand, there may be oxides present in your magnesium additions and so on. Would you comment on the precautions you may have taken to make sure of the elimination of oxygen, and what role this might have played in your experiment or the application of the technique to the purpose you have in mind?

A. Y.E. Lee. The alloys which we employed contained about 7% carbon and about 1% silicon. We measured the oxygen potential using an oxygen sensor and found that at high levels of silicon the oxygen level is very low. Magnesium may be wasted during this reaction, but we are assured the reaction is progressing the way we designed. However, if the silicon content is less than .6 we observed that the magnesium was much less active.

"THE ESTABLISHMENT OF A 500,000 t/a SINTER PLANT AT SAMANCOR'S MAMATWAN MANGANESE ORE MINE"

Q. K. Festoy, Tinfos Jernverk - Norway. I have two questions. One is on phosphorus. You just mentioned, and we saw from the analysis here that phosphorus content of the sinter was 0.016 compared to expected 0.03. Will you comment on that? The other one is the operating time on your furnaces, on regular charge, what is that in average?

A. W.A. Gericke, Samancor - South Africa. I will answer the second question first. Standard operating time both with and without sinter on the furnace is 97.5%, and through the sinter campaign we have achieved operating time in excess of 98%. But as I indicated, I think the real benefit will come over a longer time period.

As far as the phosphorus content is concerned, .03 was a calculated value based on a simple phosphorus balance whereas the .016 was the mean of the results achieved on that specific month.

Q. A. Saraf, Ferro-alloys Corporation - India. You rightly mentioned that coke breeze crushing is of great importance in the sinter of manganese ore, as also in iron ore. What is the degree of crushing you achieve?

A. W.A. Gericke, Samancor - South Africa. The important parameter is really that the coke breeze should be 100% minus 3 millimeters and we need about 30% less than half a millimeter. Those are very important indices because this affects not only the production rate, but also the strength of the sinter.

Q. A. Saraf. Your CaO content in the sinter is nearly 16% to 17%. That means you are producing fluxed manganese ore sinter. Does all the CaO come from the manganese ore because it is carbonaceous or do you add limestone also?

A. W.A. Gericke. You are correct. The CaO comes from the ore itself. The ore contains between 14% to 16% CaO as calcium carbonate, and once you drive off the CO_2 associated with it for the calcium carbonate then the CaO content increases to the values indicated between 17% and 18%. However, in conjunction with the Wessels ore which we use, which is a silicious ore, we virtually get a self-flexing ore blend.

"ANALYSIS OF THE SMELTING PROCESS FOR THE PRODUCTION OF SILICON-CALCIUM-IRON ALLOYS"

Q. J.G. Oxaal. What do you consider the maximum calcium level that is obtainable in the production of calcium-silicon by carbon reduction?

A. J. Finardi, Bozel Mineracao e Ferroligas S.A. - Brazil. Sometimes we obtain 35% calcium, but this is not a good level. The maximum level that we should work is about 33%, and the minimum level should be 30%. This would be a good range for many users. About 30% is regular production, above 33% calcium it is so difficult that it is practically impossible to run the furnace.