PRACTICAL PROBLEMS IN THE MANUFACTURE OF ALLOY STEEL

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D URING World War II, when the availability of alloy steels from abroad was poor, attempts were made to have makeshift indigenous production. Pioneers in the field were the Tata Iron & Steel Co. Ltd. Tatas started making alloy steels a little over two decades back for the construction of the new Howrah Bridge, when they patented their 'Tiscor' steel — a low-alloy constructional steel with approximately 1 per cent chrome and 0.5 per cent Cu, having better resistance to atmosphere corrosion than ordinary mild steel. A major part of the steel structure of the Howrah Bridge is fabricated from Tatas' 'Tiscor' steel.

Although the manufacture of alloy steels in India was started as far back as 1930, no progress has been made towards its development on sound and stable lines. This state of stagnation may be attributed to the small demand of the various alloy steels and a large variety of them required, the serious problems that confront the manufacturers, lack of complete ancillary equipment for the manufacture and technical know-how for the same.

During World War II, use of alloy steels increased considerably, particularly for ordnance purposes. At the instance of the Government, therefore, Tatas set up a new tool and alloy steel plant having high frequency melting and forging facilities. At the end of the second war, the foreign alloy steel prices were so attractive that other small producers in India having electric steel furnaces and rolling mills also thought of manufacturing alloy steels, little realizing the technical difficulties involved in their production. Engineers and metallurgists had to work under tremendous odds for their manufacture in plants which are not suitable for alloy steel manufacture. Problems facing them were many, which I shall relate here.

One of the prime requisites of alloy steel manufacture is the purity of *raw materials*. Raw materials include scrap, fluxes and ferroalloys.

Except for major producers, who have enough good quality melting scrap from their mills, all the small producers have to depend for their scrap supplies on railways and open market. The scrap obtained from the open market is far from satisfactory. It is highly oxidized and mixed with alloy and iron scrap. Such scrap when melted presents certain unwanted elements in the liquid metal bath which are detrimental to hot or cold-working of steel and give rise to unsatisfactory physical tests of the finished material. As in foreign countries, there is no organized scrap trade in India to deal with this problem and hence producers have a tremendous task in selecting their scrap for alloy steel production. Bulk of the scrap is very light and oxidized which increases the charging and melting time. Oxidized nature of the scrap can be gauged when an addition of 0.4-0.5 per cent carbon in the form of hard coke to the charge is oxidized completely without any addition of oxidizing agent, such as iron ore or mill scale. Many a time bath opens with 0.04 per cent carbon and 0.08 per cent manganese. Such a highly oxidized condition does not produce any boil in the bath, which is a very unhealthy state in steel-making. In order to bring about a boil in the bath, carbon is added in the form of gas carbon or petroleum coke. Addition is made on the bare bath and then it is oxidized with a vigorous boil by the addition of iron ore, preferably manganese ore, in order to eliminate hydrogen and nitrogen from the molten metal as these two elements are the greatest enemies of alloy steel. All the above processes increase the time of heat, which reflects in the manufacturing cost.

Purity of fluxes is no less important in securing the proper reaction in the bath at the right time. In the electric steel furnace practice lime should be of the purest variety and free from moisture. Generally it can be said that lime standing for more than a day after burning is not conducive to quality alloy steel production. In the U.K. alloy steel makers generally use limestone chips to avoid moisture in lime.

The other very important item for the production of quality alloy steels of exact analysis is the refractory material used for the making of furnace hearth. Generally the operations that are necessary for the making of an alloy steel heat go much longer than for the ordinary commercial steel. Also the temperature required for such a heat is much higher than in the case of mild steel. Both the above conditions have tremendous influence over the operating condition of the bottom and if the dolomite used is of poor quality, it will result in frequent bottom troubles during the heat, making the slag rich in MgO which renders the slag nonreactive and the steel full of inclusions.

Thorough deoxidization and correct finishing temperature are other contributory factors in the production of quality alloy steels. Here again the finishings, i.e. the ferro-alloys used, should be free from moisture. Generally they are heated up in a small furnace before addition. Any hydrogen introduced into the steel at the finishing stage will be held by the steel producing deleterious effect in the finished product. Different grades of steel require different

finishing temperatures, and unless proper checks are adhered to, all the good qualities of steel produced after careful furnace operations are brought to nought. Furnace refractories and ladle refractories should also be of proper quality and refractoriness to ensure cleaner steel during pouring.

Size and shape of the alloy steel ingots and their casting temperatures are other problems in steel-making which have to be solved properly for ensuring quality products. Size and shape of the ingots of different qualities of steel vary within wide limits from plant to plant, depending on ingot-shaping equipment of the plant and the size of the finished products, and consequent changes are made in teeming temperatures from plant to plant for the same quality of steel. Like ordinary commercial steel, alloy steel is much more sensitive to the rate of pouring or teeming. It is general knowledge that all ingots of the heats cannot be poured at the same temperature and hence the rate of pouring is so adjusted that there is least variation in teeming temperatures from ingot to ingot. This fact demands careful selection of the size of nozzle in respect to size of heats, which will give optimum rate of pouring with minimum variation of temperature. In some alloy steel factories in foreign countries a great importance is attached to this phase of ingot production, so much so that even during teeming operation sizes of nozzles are changed twice to ensure uniform pouring rate with regard to temperature and ferrostatic pressure in ladle. Optical pyrometers are used to guide the steel-pourer to determine the size of nozzle to be used. In others, two ingots are cast at the same time through two nozzles fitted in the ladle to reduce the casting time thereby maintaining least variation of temperature. The above practices are followed in respect of top casting of ingots.

In order to ensure equal rate of pouring some steelworks prefer to cast the ingots uphill, but here again they take proper precautions that the metal reaching to all ingots through the runners is at the same temperature and the metal is hot enough in the hot tops to give a sound feeding of the ingots. Also it should be borne in mind that the pouring refractories should be of such high refractoriness that the metal does not wash away the refractory material giving rise to harmful inclusions and making it dirty. By uphill casting method, on the one hand, uniform pouring rate and temperature are assured, but on the other, there is risk of making the steel dirty due to erosion of runner material.

Cooling rate or solidification rate is as much of great importance as that of pouring and necessary precautions are taken to cool certain qualities of alloy steel at a very definite rate, to ensure proper isothermal changes of the different constituents of the steel. Here again it is guided by the size and shape of the ingot and each plant has its own schedules according to the nature of facilities available. Careful handling of the cast alloy steel ingots is imperative as they cannot be knocked about like ordinary commercial steel. Generally all alloy steel ingots have to be cooled down to room temperature before cogging.

The first operation on an alloy steel ingot is to convert it into billet by a process known as cogging. This is usually done by hammering, pressing or rolling. Highly alloyed steel ingots, like high-speed steel, cannot be cogged satisfactorily in a rolling mill and these qualities are, therefore, hammered, whatever the ingot size. Low-alloy constructional steels are generally roll-cogged. The operation accomplishes a reduction in the cross-section, a refinement of the structure and shaping of the metal in a desired form. The flow of the metal is continuous and almost entirely in longitudinal direction. Therefore, any segregates in the ingot are usually simply elongated by rolling and not broken apart. It is for this reason that hammering has an inherent advantage over rolling or pressing for more highly alloyed

type of steel, for in hammering the segregates are broken up by the kneeding action and not merely elongated in the direction of greatest flow of material. Low-alloy steels, which are usually not highly segregated, are generally rolled resulting in a bar that compares favourably in physical properties with forged bars. But many alloy steel makers prefer forging all of their alloy steel ingots for the simple reason that the intensity of hammer blow can be controlled to a nicety, and the ingots which have been made from steels that are highly subject to the formation of coarse, columnar structure on solidification can be reduced by hammering with a much smaller loss in corner cracking than can be had from the same ingots by rolling.

In cogging, either by forging or rolling, ingots are carefully heated to a predetermined temperature in a reheating furnace fired either by producer gas or by oil. Generally producer gas is preferred for better control of temperature than is possible with other fuels. Heating furnaces are equipped with recording pyrometers and in some plants they are even fitted with automatic oxygen recorders to control both temperature and atmosphere. The rate of heating of the ingots is a very important factor in successful rolling of the ingot. It should be very slow so as not to cause large temperature gradient throughout the ingot which would undoubtedly lead to cracking. It is a general practice to preheat those ingots which have been allowed to cool throughout to an intermediate temperature, to prevent serious stresses from arising when the ingot is charged in a hot furnace. From this preheat the temperature is gradually increased until the forging or rolling temperature is reached. The upper limit of the temperature at which the cogging may be performed is determined by the solidus temperature of the alloy, i.e. lowest point of lowest melting constituents. No sooner the point is reached than the ingots crack on cogging. In forging, the sudden blow of hammer will cause a rise of temperature in the outer portion of the bar, which will always have to be considered in selecting the upper limit of the forging temperature. This rise is of greater magnitude in hammer operations than in rolling due to limited contact time thereby lessening the dissipation of surface heat.

The soaking time, that is to say, holding time, of ingot at temperature is largely governed by the tendency of the particular steel to surface decarburization. Theoretically, the time should be of such a duration that the centre of the ingot is brought to the operating temperature, and this often takes many hours. Prolonged soaking, no doubt, gives better plasticity of highly alloyed steels, but surface decarburization and grain growth take place, which suggests a limiting time at temperature. Loss of metal due to heavy scale formation should also be taken care of. During cogging, the scale forming on the surface should be continually swept away in order to prevent its burial and the formation of surface imperfections, especially in forging process.

One can readily imagine that when liquid steel is poured in a mould from top, the surface of the ingot cannot be very smooth. There is always a certain amount of splashings and motion which produce certain imperfections on ingot surface. This is true for bottom cast ingots as well, though to a lesser degree. When the ingots are rolled into billets, these surface imperfections are stretched out along the length of the billet into defects. Some defects are also produced during rolling or forging process. Hence these defects must be removed before the billets are further processed in order that sound finished material is produced.

Four methods are employed for doing this, namely (1) chipping, (2) grinding, (3) rough turning, and (4) deseaming.

For efficient chipping and grinding operations it is essential that the defects on the billets are made visible by pickling. All the visible defects are then chipped off by pneu-

matic chisels or ground off by swing grinders. Here again great attention has to be paid that the chipper does not make too deep a hole to remove certain defects which on subsequent processing may give rise to further defects, or by prolonged grinding overheat the surface of the metal and thereby produce new cracks which under the action of thermal stresses may well propagate and travel completely through the billet. Grinding operation is generally employed for highly alloyed steels and in certain cases the steel is preheated or perfectly annealed before grinding. As the grinding operation cannot be as selective as the chipping operation in most cases, the billets are ground all over. For low-alloy constructional steels chipping is generally employed for the removal of surface defects after pickling. Experience and skill are required to carry out the above operations perfectly.

Sometimes it is desirable to completely remove the surface from the billets and for this purpose the billet is rolled round instead of square. These are annealed and straightened and then put through the roughturning machine that removes the entire surface of the billet. In certain qualities of steel even ingots are made round and roughturned before cogging into billets. Deseaming process is also being employed for entire removal of the surface.

After surface-conditioning, the billets may be finished to desired shape by hammering or rolling. Generally they are finished by rolling. Even those grades which do not lend themselves readily to be rolled in ingot form can now be rolled from prepared billets with very little difficulty. But this rolling should be done on a tool and alloy steel rolling mill which is very different from rolling mills used for ordinary commercial quality merchant bars of mild steel. An alloy steel mill reduces the cross-section of the billet very slowly and about twice as many passes through the mill are required to reach a given size. Pass designs are also quite different to ordinary mild steel.

The prepared billets are heated to a predetermined temperature and then rolled to the desired size and shape. The precautions enumerated previously with respect to heating operation of ingots apply again in this case. In many cases, the finishing temperature, as the bars come out of the mill, is almost as important as the original temperature to which the billet is heated. If it is desired to finish the bar hot, the mill is speeded up, and if it is desired to finish it cold, the mill is slowed down. In order to obtain this control all tool and alloy steel rolling mills are equipped with variablespeed direct-current motors.

All alloy steel bars, either forged or rolled, have to be thoroughly annealed before they can be further worked without danger of cracking.

The bars are heated to just above the critical range of temperature and then allowed to cool down slowly to room temperature. The process not only softens the bars, but also removes the stresses and refines the crystal structure (even removes the gases from the metal!).

During annealing process, greatest care is to be taken to protect the bars from surface decarburization. Care should also be taken that the temperature does not go too high of the critical temperature, otherwise the bars subject to such prolonged treatment will not respond to subsequent heat treatment. In order to safeguard against surface decarburization bars are usually packed in large H.R. iron tubes or boxes with either charcoal powder or cast-iron filings to eliminate surface reaction tendencies. The heating cycle is generally slow and is controlled by suitable pyrometric equipment. The furnace having reached the desired temperature and time allowed for the temperature to equalize itself throughout the charge, the furnace is cooled down very slowly. The rate of cooling is usually 20°F. (10°-15°C.) per hour through the critical range. When the temperature reaches the black heat, say 400°/450°C., the cooling is allowed to take place more rapidly. The product on removal from the furnace should be in the softest possible condition with well spheroidized structure.

Having manufactured the products with all necessary care and precautions, it is likely that some of the bars still fail to come out to the desired standard. Hence it is imperative that inspection should be carried out, and upon proper inspection of these steels during and after their manufacture depends, to a great extent, the excellence of the product. Although the specific requirements of a customer will be the guiding factor in carrying out the tests on any steel, some routine tests should be and are carried out during the manufacturing process regardless of the specifications. These tests include chemical (analytical) tests, close control of heating and cooling cycle, check on accurate dimension of the bars during rolling and forging, and some others which will enable the manufacturer to produce a uniform product. In case of alloy tool steels, routine inspection of finished product will include, apart from surface inspection, hardness test, fracture test. deep acid etch test and microscopic examination of the annealed and hardened tool steel to determine the carbide distribution, the amount and distribution of nonmetallic inclusions, the grain size and decarburization. All the above precautions enumerated before are problems in a plant which is not exclusively a tool-steel plant. Workers and technicians, having been used to handling mild steel products of commercial quality, fail to realize the importance of various precautions necessary for the alloy and tool steel production and try to finish the alloy steel products in the same manner as commercial quality steel with disastrous results.

Indian Tariff Board, while submitting their report in 1951 on the continuance of protection to the alloy, tool and special steel industry, had estimated an annual demand for the protected categories of alloy, tool and special steels at 3920-4975 tons, of which alloy constructional steels formed the major part of the demand, i.e. 2500-3520 tons. With the rapid industrialization of India and setting up of automobile, shipbuilding and machine tool industries in the country, this demand is likely to go up much higher and it is in the fitness of things that an exclusive alloy steel factory be set up in India of suitable capacity to meet the home demands and thereby make the country self-sufficient in alloy, tool and special steels. It was also reported in the report of the Tariff Board that the Mysore Iron & Steel Works were planning in 1951 to set up a plant with a capacity of 1000 tons of special steels per annum and the new plant would be ready to go into operation in about two years. I do not know at what stage the new project of the Mysore Iron & Steel Works has reached today, but surely, taking into consideration the demands estimated by the Tariff Board in 1951 and the anticipated demands of the future, there is ample scope for another alloy steel plant in the country. May I request the organizers of the symposium to take this matter up with the Government of India and request them to include in the Second Five Year Plan this project, which is so vitally important to all industries in the country?

PAPERS DISCUSSED

- Alloy and Tool Steel Industry in India, by K. N. P. Rao.
- Alloy Steel Industry in India Historical, by B. R. NIJHAWAN & E. H. BUCKNALL.
- Indian Alloy Steels for Engineering Industries, by B. R. NIJHAWAN.
- The Mysore Iron & Steel Works as a Major Producer of Stainless Steel in India, by J.R. MILLER.
- Manufacture in India of Ferro-alloys Used in Alloy Steel Industry, by B. R. NIJHAWAN & P. K. GUPTE.
- An Investigation into the Development of Prospective Indian Austenitic Stainless Steels, by P. K. GUPTE & B. R. NIJHAWAN.
- Practical Problems in the Manufacture of Alloy Steel, by S. C. Biswas.

DR. B. C. KAR (National Metallurgical Laboratory)

In connection with the manufacture of ferro-alloys for steel industry in India I should like to say a few words about the production of electrolytic manganese in this country. It has been found that electrolytic manganese can be used with advantage in place of ferro-manganese now used in steel industries. The only consideration which stands in the way of using electrolytic manganese is its high price. A considerable amount of work has been done on the production of electrolytic manganese from lowgrade ores at the National Metallurgical Laboratory, and the semi-pilot plant experiments on its production have been carried out successfully. On the basis of the data obtained and with reference to present Indian conditions, it has been roughly estimated that electrolytic manganese can be produced at a cost of Rs. 690 per ton whereas the price of American ferro-manganese (77-80 per cent Mn) is now about Rs. 1050 per ton at Indian ports. For similar material of English origin the cost is much higher. So it appears that the production of electrolytic manganese from low-grade Indian ores deserves careful consideration.

DR. A. LAHIRI (Director, Fuel Research Institute)

Mr. Gupte, in his paper on the manufacture of ferro-alloys, has dealt with the question of availability of suitable coke for the production of ferromanganese in blast furnace. We have in our survey found rather large deposits of coal containing 0.05-0.06 per cent P, though coals containing around 0.03 per cent P are very limited. These coals can be obtained without difficulty at standard market rates. If non-coking coal can be used, there are deposits in C.P. containing P as low as 0.003-0.001 per cent.

What is the load factor in the production of electrolytic manganese and what is the cost of electricity ?

MR. E. H. BUCKNALL (Director, National Metallurgical Laboratory)

Coming to the figures quoted by Dr. Kar I would like to point out that they were calculated at 10 tons a day layout, which is very very small. If you calculate on 40 tons a day layout, the figure comes down to Rs. 400.

Why the prices in America are so high is fairly simple to understand. Firstly, labour costs in America are enormous compared to India and, secondly, the price which is paid in America for native low-grade manganese ore is higher than the price paid in India for the low-grade manganese ore. The Rs. 400 a ton figure is based on the idea that very low-grade manganese ore can be obtained at something like Rs. 10 a ton.

The figure for load factor is 90 per cent and for the price of one kWh. 0.3 anna.

DR. A. LAHIRI (Director, Fuel Research Institute)

No, no, you can't get electricity so cheap.

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MR. E. H. BUCKNALL (Director, National Metallurgical Laboratory)

The ferro-manganese produced in blast furnace contains too high a carbon content for weldable quality 1.5 per cent manganese steel. In such cases electrolytic manganese can be used with advantage and also in some non-ferrous alloys.

DR. B. R. NIJHAWAN (Dy. Director, National Metallurgical Laboratory)

Everybody present in the meeting seems to agree that an alloy steel and ferro-alloy industries should be established in India, but there seems to be difference of opinion as regards their size and the exact quality to be manufactured. I believe that Mr. Miller's statistical approach, in absence of factual statistical data, towards statistical forecasting is probably the only way. How and where these industries are to be started requires much closer collaboration between industry, government and research workers at all levels.