FURNACES AND EQUIPMENT USED IN THE MANUFACTURE AND HEAT TREATMENT OF ALLOY STEELS

R. A. P. MISRA
Indian Wild-Barfield Co. Ltd., Bombay

THE types of furnaces and other equipment used at some stage in the manufacture and heat treatment of alloy steel is indeed too large to be covered in one paper. It is, therefore, proposed to only briefly touch upon the latest developments in each field.

Crucible Furnace

Historically speaking, this is a first furnace in which small amounts of raw materials can be melted to produce high grade alloy and tool steels. Until quite recently this had been the only process used for the manufacture of alloy steels which are generally required in small casts. These furnaces were generally coke-fired, although gas and oil-firing have also been used in some cases. The problem of the life and cost of crucibles which are generally made from refractory clay mixtures is a serious one. The life of the refractories which have to operate at temperatures in the region of 1600°C. is also limited. Although this process has been used for a long time in all industrial countries of Europe and America, it is gradually giving way to electric melting because of the convenience and cleanliness of working conditions.

Electric Steel Melting Furnaces

There are two main types, the arc furnace and the induction high-frequency furnace.

Arc Furnaces — The most popular type is the 3-phase direct arc type furnace first designed by Heroult. This basic design is manufactured by a number of furnace manufacturers who have incorporated their own ideas of constructional features and detailed improvements. The 3-phase direct arc furnace may be subdivided into the following three types.

Fixed Roof Rear Door Charging Type — This design is simple and the least expensive, but the maximum capacity for which it is suitable is about 3 tons, although larger capacity models have been made. If steel scrap is available in small, easily handled sizes which can be manually charged, this type may be used for sizes up to 5 tons without undue loss of efficiency.

Top Charging with the Rise-and-Swing-Aside Roof — In this design the roof of the furnace together with the electrodes is lifted and swung aside to enable the charge to be placed in the furnace from a charging basket. This design is particularly suitable where the steel scrap is available either in relatively large pieces or in the form of small swarf and turning. The latter type of charge is relatively light and takes a long time to manually charge in a furnace of the fixed roof type.

Bridge Type — This is a design which has been pioneered by the Ing. Leone Tagliaferri Company of Italy and has been proved over the last fifteen years. When charging the furnace, the shell is withdrawn from beneath a gantry bridge and carries the electrode equipment. It is more expensive in first cost than the lift-and-swing-aside roof furnace, but has certain very definite advantages in the large capacities, say, from 20 tons upward.

Constructional Features of Arc Furnaces — An Arc Furnace is an expensive piece of equipment. The smallest one with a capacity of ¼ ton costs in the region of Rs. 1 lakh. In selecting a unit, the following points must be borne in mind: The shell of the furnace must be of rigid construction with heavy cast steel reinforcing members round the top to prevent distortion, otherwise the door will not fit properly. The base of the shell must be dished on all but the smallest units to provide great rigidity and uniformity of hearth lining thickness.

The shell of an arc furnace when fully charged weighs several tons and the method of tilting any support employed must be such that no distortion takes place and no undue stresses are produced in the shell. In this connection the provision of perforated arc-shaped rockers on the base of the furnace which roll on studded machined base beams is a valuable feature. The tilting action of the furnace is like that of a rocking chair.

All parts such as slagging doors, roof ring, which are likely to be affected by excessive heat should be provided with adequate water-cooling.

Electrode Holders — Certain furnace makers have pioneered the development of remotely controlled electrode clamps. These were fitted as standard equipment as far back as 1936 and form a valuable aid to the efficient operation of the furnace. By means of suitable mechanical and hydraulic means, the electrode clamps can be clamped and unclamped by means of a push-button located on the control panel. Those who have tried to adjust bolt-retained clamps on top of a hot furnace will fully appreciate the importance of this feature.

Electrode Control Mechanism — There have been a good deal of claims and counter-claims made by various furnace manufacturers who adopt a particular type of system. The electro-hydraulic system of electrode control with gravity return for the electrodes has stood the test of the time. Its simple construction, high sensitivity plus and minus 1 per cent and rapid response one-seventh of a second ensure satisfactory operation, positive control and elimination of electrode breakage, etc. One important feature to be considered in selecting plants suitable for India is that highly skilled maintenance is not easily available in all places and, therefore, the control system selected should be such that all routine maintenance and overhauls can be carried out by mechanics and electricians of average ability and knowledge. In the electro-hydraulic system, all moving parts in the regulator box are continuously operated in a bath oil and maintenance required is negligible.

Furnace Tilting and Roof Raising System — This can be of the mechanical, electrical or hydraulic type. It has been the general experience of engineers that where large forces have to be accurately controlled, the hydraulic system is the only real answer. The water pressure for the system is usually provided by a centrifugal pump driven by an electric motor and to prevent shuting down of the equipment because of pump failure duplicate pumps are normally installed. As an additional safeguard an hydro-pneumatic reservoir is supplied which can give a reserve of power after a complete electrical failure.

High-frequency Induction Furnace

In this type of furnace, the furnace part is relatively simple and consists of an H.F. coil which is normally composed of a copper tube through which cooling water is circulated. The coil is embedded in a refractory lining which is rammed *in situ* with a fabricated steel former which is melted out when the furnace is first started after slowly drying out the lining. The furnace case work is made from electrically inert material like compressed asbestos board. Large furnaces are usually arranged for lip axis tilting.

Power-factor Connection — The electrical characteristics of the furnace with a varying charge have to be carefully matched by means of condensers which can be brought into play at will. The most expensive part of an H.F. furnace is the motor-driven alternator, and a furnace with a capacity of 200 lb. of steel per charge would require an alternator of 100 kW. delivering 800 volts, single-phase, A.C. supply of 2000 cycles per second at 3000 r.p.m. Due to the very fine clearances used, a high degree of maintenance is required particularly of the bearings and the motor generator must be located in a separate dust-proof room and provided with necessary fresh air inlets and outlets. The above furnace would cost approximately Rs. 1½ lakhs which is much more expensive than a direct arc 3-phase electric furnace of a similar capacity.

Choice of the Most Suitable Type

When alloy steel has to be melted, one is often called upon to decide between an induction and an arc furnace. The correct choice depends upon the raw materials available and the finished charge required. If selected scrap of known analysis is available, such as in the works of a tool steel maker, to which known quantities of alloying additions can be made and it is desired to produce alloy steels of the highest grade of purity and controlled composition in small casts, the answer is the induction furnace in spite of its higher capital cost.

If, however, only normal commercial scrap is available which is to be corrected after an analysis of the melt, then an arc furnace is indicated.

It should be clearly understood that it is not possible to carry out refining in an induction furnace. It is essentially a furnace for melting down and alloying known constituents. The arc furnace, on the other hand, is capable of carrying out a refining process to give the required alloy from a raw material which is not accurately to specification to start with. The arc furnace is slightly the more efficient thermally since the lining is so much thicker than that on the induction furnace.

One disadvantage of the arc furnace must be mentioned which does not apply to the induction furnace, and that is load fluctuation on the supply system during the melting-down period. An arc furnace with a normal rating of 500 kVA. may peak to 1000 or even 1500 kVA. momentarily. This is, however, not a serious disadvantage if the furnace is connected to a large system on H.T. supply of 6000 or 11,000 volts, but the largest size of arc furnace which can be safely connected to the 400 volts, 3-phase, 50 cycles power supply has a capacity of 500 lb. and with a normal rating of 150 kVA. It is not advisable to connect arc furnaces of a larger size than this on 400 volts supply.

Submerged Arc Furnaces

This type of furnace is used for the production of ferro-alloys such as ferro-manganese, ferro-silicon, ferro-chrome, etc. This type of furnace is also used for the production of calcium carbide and pig iron. These furnaces, sometimes called electro-blast furnaces, are normally of the non-tilting type consisting of a heavy circular steel shelve fitted with tap-holes. A roof is provided only when gas recovery is required. The charge is hand-loaded into small furnaces and mechanically charged in the case of larger types. The operating platform is usually arranged to be flushed with the shell top. In some furnaces, a rotating hearth which completes one revolution in about 24 hr. is used to avoid the formation of dead pots and ensure uniformity of the products.

The electrodes are of the continuous forming Soderberg type and dip deeply into the charge and lower voltages than those normally employed with arc furnaces are used with consequent heavy secondary currents. A complete installation usually includes the building designed specially to accommodate the auxiliary equipment allowing space for the manufacture of electrode shells which can be welded to existing electrodes while the furnace is in operation. A hoisting mechanism for electrode control is usually provided. The transformers are similar to those employed with the normal arc furnaces, but no reactance is required and the tap changer is of the 'onload' type.

The electrical load provided by this type of furnace is reasonably steady and does not fluctuate much.

The term small or large furnaces for this type of plant is merely relative and a furnace of 2000 or 3000 kVA. would be considered small and the usual size of an economic unit is from 8000 to 12,000 kVA. A furnace alone with its electrical equipment of 8000 kVA. would cost about Rs. 15 lakhs, but a complete plant consisting of two such furnaces, buildings, etc., and all other ancillary equipment may cost in the region of Rs. 13,300,000 (one crore thirty-three lakhs of rupees).

Indirect Arc Type Furnaces

In this type of furnace the arc is struck between a pair of electrodes forming the axis of a refractory-lined drum which is rotated. Due to the lower temperatures attainable, this type is used for melting cast irons and non-ferrous metals but not steel on a commercial scale. Another disadvantage is that the furnace requires a single-phase supply and the load is not balanced unless three furnaces are operated at the same time. The electrodes are often manually controlled on small sizes, although automatic arc control is the rule on larger sizes.

Basic Open-hearth Furnace

Where alloy steel casts are required on a tonnage basis the open-hearth furnace can be used. The operation of this furnace is well known and covered in detail in technical literature. So no further remarks are necessary.

Soaking Pits

These furnaces are storehouses for large ingots which are kept (as a rule underground) at a uniform temperature after casting until they can be handled by the mill. They are, as a rule, gas-fired.

Due to the lower tonnage handled in the case of alloy steels and the smaller size of ingots cast from the smaller electric furnaces, soaking pits are not used if the ingot size is small but allowed to cool down.

Billet Reheating Furnaces

If ingots or billets have to be reheated for reduction in a mill or under a hammer or press, fuel-fired furnaces are used. They are generally gas or oil-fired, but pulverized coal is also used where the large size of the furnace makes its use economic. Apart from the cast of the pulverizing equipment, even the finest pulverized coal particle has to travel about 20 ft. in a straight line before combustion is complete. This is because the coal particle is like a football compared to a $\frac{1}{16}$ in. ball when the ball represents a gas molecule.

The design of the furnace depends on the nature of the charge and the output required. Heavy blooms and billets are generally heated in batch type furnaces of the fixed hearth type with mechanical handling of the billets. Very heavy charges like turbine rotors, ships propeller shafts are heated on bogie hearth furnaces to facilitate mechanical handling of these large charges which are, as a rule, forged under large hydraulic presses.

Where a large number of small or medium size billets have to be heated continuously to feed a rod mill, they are pushed through the furnace on water-cooled skids located in the hearth of the furnace by means of a mechanical or hydraulic pusher. The operation of the discharge door is interlocked with the pusher. As a rule, the billets progress through the furnace in a line at right angles to their own axis.

Forging Furnaces

As alloy steels are mostly used for their high strength, they are often used as forgings or stampings. As a rule, gas or oil furnaces are used for heating the general run of forging billets, although induction heating has been used successfully in special purpose installations for doing such specialized jobs as forging the mouths of shells. Direct resistance heating of the material is also practical in certain applications like forging the heads of valves for I.C. engines.

Choice of Fuels

Coal (Solid)—*Advantages*: Cheapness, easy availability in industrial areas, luminous flame which is an advantage in some types of work.

Disadvantages: Lack of proper temperature control; proper grade of coal must be used as many of the cheaper grades do not burn well in the solid state. Labour required for handling fuel; storage problem and smoke problem.

Coal (Pulverized) — *Advantages*: Same as solid coal. Most of the disadvantages of solid coal firing are overcome. Temperature control is made possible by control of firing. Lower grade coal can be burnt satisfactorily thus effecting economy. No labour required for charging furnace. Smoke problem can be overcome through control of combustion.

Disadvantages: Increased cost of pulverizing apparatus and attendant mechanical complications. Coals of very high ash contents cannot be used successfully.

Coke (Solid) — Generally same remarks apply as in the case of coal with the exception that coke ensures general freedom from smoke, but since the calorific value is lower than coal, larger grate area is required for a certain heat output.

Oil — Where this fuel is available at economic prices it is a serious competitor to coal owing to the easier control of combustion as no labour is needed for firing. Oil burners require either a forced draught of air or steam to atomize the oil from the burner to ensure combustion of heavy oils. Heaters are sometimes employed to preheat the oil to reduce the viscosity to enable heavier fractions to be utilized with consequent economy.

One great advantage of oil-firing in metallurgical furnaces is the luminous flame this fuel provides which enables the rapid heat transfer to take place to the work being heated and this is of special importance where steel billets are heated to high temperature for forging etc.

Gas — This may be divided into several varieties:

(a) Coal gas or town gas
(b) Producer gas
(c) Blue water gas
(d) Natural gas
(e) Cracked oil gas.

Coal Gas — Owing to the relative scarcity of high quality gassing coals in India, the development of the gas industry in this country has been very tardy and India may be virtually said to have skipped the phase of gas development and arrived at the electric era. Most iron and steelworks, however, have their own coke ovens and, in addition to the supply of metallurgical coke, they have supplies of gas and valuable byproducts of distillation.

Producer Gas — This has a rather low calorific value and unless enriched it requires specially large burners, ports and passages to enable the furnaces to be brought up to heat-treating temperatures within reasonable time. To attain higher temperatures preheating of air blast is almost essential.

Blue Water Gas — This gas has higher calorific value than producer gas specially if coal is used in place of coke in the producer bed. The calorific value and the content of methane CH_4 is much lower than coal gas.

Oil Gas — This is an excellent fuel of a very high calorific value, almost double that of coal gas. Owing to the higher cost of oil as compared with coal, this system has only been used for small-scale plants for laboratories etc.

Electricity — The choice of the right fuel depends upon the availability and economy of the particular fuel, but apart from considerations of economy technical suitability plays an important role in determining the best fuel. The first cost of the furnace, the running fuel cost, supervision charges, maintenance charges, all must be taken into account and compared with the relative convenience of using a particular fuel before a correct choice can be made. When comparing the cost of various fuels, efficiencies of utilization must be taken into consideration to arrive at a fair assessment. For example, it is much cheaper to buy B.T.Us. as coal than in the form of electricity, but the efficiency may be only 5-10 per cent in case of coal-fired furnace with a separate fire-box and 86-88 per cent in the case of a well-designed and insulated electric furnace. In the case of liquid and gaseous fuels higher thermal efficiency can be achieved with proper design than with solid fuel fired furnaces, because the fuel and air mixture can be arranged to burn inside the furnace chamber; even so it is not usual to find an efficiency higher than about 15 per cent even with recuperators and heat exchangers to preheat the incoming air for combustion. Other factors such as the ease with which automatic temperature controllers and time-controlling switches can be arranged to bring the furnace into operation or switch it off also influence the choice of the fuel. Whereas these features are more easily incorporated in electric furnaces, it must now be imagined that automatic temperature control cannot be provided with gas and oil-fired furnaces. Generally speaking, these furnaces do need personal supervision when they are lighted, although automatic switching off can be arranged.

As a rule, the electric furnace is more suitable and convenient for all heat treatment operations due to the precise temperature control possible and reasonable working costs. In the case of very large installations, however, the lower costs of fuel in a fuel-fired furnace may justify this installation.

Normalizing Furnaces

This design depends on the nature of the charge and output. For small and medium outputs the batch type is preferred, but where output justifies the higher capital cost a rotary hearth or walking beam furnace may be found suitable.

Hardening Furnaces

The same remarks apply as for normalizing furnaces except that the work is quenched instead of being air-cooled.

Tempering Furnaces

Modern practice is to use electric furnaces of the forced air circulation type which are usually vertical. The centrifugal fan which has been pioneered by some manufacturers ensures absolute uniformity of temperature in the range up to 700°C. where radiation is not very effective in producing temperature uniformity.

Charge Progress Recorder

With this type of furnace by suitable placing of two thermocouples and a two-point recorder it is possible not only to record and automatically control the temperature of the furnace, but also to record the temperature of the charge at any instant. This enables uniform tempering treatments to be carried out with full utilization of furnace capacity.

Salt Baths

They are particularly useful for heat treatment of steels, for hardening, liquid carburizing and heat treatment of high-speed steels. This process is specially useful where treatment has to be carried out at above 700°C. as there is no scaling and the surface finish is much better. Decarburization is also not a serious problem, but where requirements are critical, suitable salt mixtures have been developed.

Nitriding Furnaces

These are usually electrically heated with a gas-tight box or chamber which contains the work. Ammonia gas is supplied in controlled quantity and special steels are necessary. Due to the long duration of the process which requires about 80 hr. and the small case depth, about 0·02 in., the process has not found general favour. The treatment is carried out round 500°C., and no quenching is required. It is, therefore, possible to treat complicated shapes like aero-engine crankshafts which cannot be treated by other conventional methods due to distortion.

'Carbodrip' Gas-carburizing Process

Although the process of gas-carburizing is not new, it is only recently that a commercially reliable process has been developed which does not suffer from previous disadvantages. Following the success of the prepared town gas process, it is now possible to use gas-carburizing where no town gas (coal gas) is available. In the 'Carbodrip' process the carburizing atmosphere is produced by supplying a specially prepared fluid to the furnace chamber which is gas-tight and contains an electrically driven fan with special bearings and glands.

The process is reliable and quicker than the conventional box carburizing method. Very little time is required for packing and unpacking of the charge. The fluid is reasonable in cost and consumption works out to about 500 gallons per year for an installation of medium size. The capital cost of the furnace due to its special construction is a little higher, but it is a good investment in view of its high productive capacity. A large number of motor-car manufacturers are adopting this process in view of this proved ability to lower costs.

Carbonitriding

Where it is not required to produce cases of great depth and production requirements are large as in the case of self-tapping screws, a mixture of carburizing gas and ammonia can be introduced to give a case which consists of carbides and nitrides. The furnace is designed to work continuously and the work is quenched into an oil tank through a chute.

Due to limitations of space it is impossible to go into greater details or describe each and every type of furnace within the confines of one paper. The author will be only too pleased to answer any queries about any special problems regarding furnaces. Before concluding I should like to acknowledge the help and co-operation of the following companies:

(1) Indian Wild-Barfield Co. Ltd., Bombay 18
(2) Wild-Barfield Electric Furnaces Ltd., England
(3) G.W.B. Furnaces Ltd., England
(4) Ing. Leone Tagliaferri Company, Italy
(5) Aldo Tagliaferri Company, Italy
(6) Thermic Equipment & Engineering Co. Ltd., England.

PAPERS DISCUSSED

1. Segregation and Internal Weakness in Forging Ingots, by N. H. BACON.
2. The Effects of Hydrogen on Alloy Steel Production, by K. C. BARRACLOUGH.
3. Hydrogen in Steel, by A. G. QUARRELL.
4. Oxygen in Foundry Steel-making, by A. K. GUPTA.
5. Furnaces and Equipment Used in the Manufacture and Heat Treatment of Alloy Steels, by R. A. P. MISRA.

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

May I ask Mr. Bacon if he could please indicate the latest developments in continuous casting in alloy and stainless steels in the U.K. ?

MR. N. H. BACON (Sheffield)

Stainless steel slabs in the region of 3 ft. wide, 20-27 in. broad and 7 in. thick have been successfully cast continuously. However, trouble is experienced on casting smaller sections. The trouble appears to be that if the smaller sections are cooled slowly as they issue out of the mould — cooled slowly in order to obtain a good structure — the liquid drains out from the ingot leaving a cylindrical hollow. If the ingots are cooled rapidly, internal cracking occurs. All I can say is that continuous casting is still in experimental stage except for certain sizes.

MR. S. C. BISWAS (Mukand Iron & Steel Co., Bombay)

We have experienced negative segregation of 3-4 points carbon in the bloom of the top of the ingot of the feeder head in axle steels. The ingots are of $5\frac{1}{2}$ tons weight. I want to know why there is inverse segregation.

MR. N. H. BACON (Sheffield)

I have never come across such a case and I believe there is a mix-up which sometimes occurs in the shop or laboratory.

MR. E. H. BUCKNALL (Director)

Are all the troubles reduced if the ingots are cast in 4 to 6 in. size ?

MR. N. H. BACON (Sheffield)

Yes, in alloy steels very much so. At Samuel Fox, when 3 per cent Ni steel is cast in 14, 16 and 18 in. sq. ingots, the loss due to panel cracking is 10, 15 and 20 per cent respectively. In order to avoid panel cracking losses, they have found out that 11 in. sq. ingot serves the purpose best. For higher alloy steels the smaller the ingot, the better it is.

DR. S. BHATTACHARYA (Metal Factory & Steel Factory, Ishapur)

Mr. Bacon is requested to throw some light on the ingot mould wall thickness to ingot diameter ratio. While manufacturing 32 in. octagonal Ni-Cr-Mo steel ingots for ordnance purposes we experienced corner cracking along the ribs on ingots in course of forging even when the ingot was stripped hot and homogenized by prolonged annealing. This trouble could be overcome by stripping this 5-ton ingot after 3 hr. and standing it upright in a refractory-lined ingot mould of 42 in. in diameter till the ingot had fully solidified.

MR. N. H. BACON (Sheffield)

The cracking is not in any way connected with the wall thickness of the mould. To avoid cracking during forging of the ingot the ingot mould should have sharp corners. The sharper the corners, the better it is. The other causes of cracking are either that the metal is tapped too hot or teemed too fast.

MR. S. VISVANATHAN (Tata Iron & Steel Co. Ltd.)

I remember to have seen in an American paper about the use of carbon plate at the bottom of the ingot mould to reduce the basal cone in 4 to 5 ton ingot practice. I would like to know if Mr. Bacon agrees whether it is possible to avoid the basal cone.

MR. N. H. BACON (Sheffield)

I do not see how putting a carbon block at the bottom of the mould can remove the basal cone weakness. This weakness is very real and we test all heavy forging for it ultrasonically.

MR. S. VISVANATHAN (Tata Iron & Steel Co. Ltd.)

In American practice for stainless steel making inert gas is used to avoid hydrogen pick up and I do not see why the same cannot be extended to the smelting of other alloy steels, provided argon is made cheaply available by the Indian Oxygen & Acetylene Co. Talking of Oxygen Company I was rather flabbergasted that a couple of years ago Mr. Gupta suggested using hydrogen for decarburizing high-silicon heats, and I gained a sort of idea that bubbling hydrobgen inside the melts is being practised in certain parts of England. I would like to know whether anybody can confirm such practice.

Mr. A. K. GUPTA (Indian Oxygen & Acetylene Co. Ltd.)

In England a certain firm carried out experiments on bubbling hydrogen gas for a year and a half to decarburize, but now I hear that the practice has been discontinued.

MR. F. M. SCHONWALDER (Mukand Iron & Steel Co., Bombay)

The discussion of removal of hydrogen in alloy steel will not be complete without the mention of recent developments, especially in Germany, of pouring and teeming of ingots in vacuum.

MR. J. R. MILLER (Ramseyer & Miller Inc., New York)

On Mr. Gupta's paper on oxygen in foundry steelmaking I would like to say the following:

Hot metal charges in the U.S.A. have been found advantageous up to about 15-20 per cent in electric furnaces. When used over 20 per cent, total heat time is increased to an extent to make this advantage questionable. This is, however, based only on limited and occasional experience (Republic steel) and is not generally followed by U.S. steelmakers.

The Battelle Institute 50 per cent hot metal data were calculated from theoretical considerations and not from actual operating results.

The Battelle data and experience have shown that all-scrap electric furnaces (in larger size over 40 tons capacity) are superior than all-scrap open-hearth.

The development of hot metal practice in electric furnace still depends on results of actual plant experience. However, in recent two years interest in hot metal electric furnace practice has been replaced by interest in Linz Donowitz process.