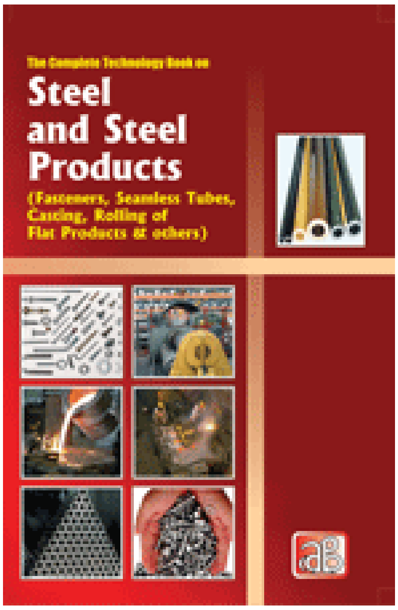
106-E, Kamla Nagar, New Delhi-110007, India.
Tel: 91-11-23843955, 23845654, 23845886, +918800733955,
Mobile: +91-9811043595.
Email: npcs.ei@gmail.com ,info@entrepreneurindia.co

Website: www.entrepreneurIndia.co

The Complete Technology Book on Steel and Steel Products (Fasteners, Seamless Tubes, Casting, Rolling of Flat Products & others)



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Iron and steel have played a leading role in the development of human civilization and their techniques. Together with its derivative, steel, iron has no real rival in its particular fields of application and has become a synonym of progress, being an essential element in mankind greatest technological achievements. It was at the origin of the industrial and scientific revolutions and at the heart of all the great discoveries which have marked the history of humanity from the manufacture of high quality swords in ancient times to today architectural wonders. Steel is an alloy that consists mostly of iron and has carbon content between 0.2% and 2.1% by weight, depending on the grade. Carbon is the most common alloying material for iron, but various other alloying elements are used, such as manganese, chromium, vanadium, and tungsten. Rolling is a metal forming process in which metal stock is passed through a pair of rolls. Rolling is classified according to the temperature of the metal rolled. Steelmaking is the second step in producing steel from iron ore. Processing of steel results in special steel product with required properties, for example; vacuum treated steel for forging ingots; pre strengthened stress relieved elongated steel, metallurgical addition product, forging powder alloy steels, etc. Fasteners are used to join and hold two or more pieces of metal either temporarily or more pieces of metal either temporarily or permanently. Some of the most common are bolts, screws, nuts, rivets and pins. Packaging steels differ from other sheet products particularly in terms of their thickness, mechanical properties and coatings, together with their aptitude to satisfy specific industrial and marketing requirements related to high production rates, design factors etc. Small gage welded tubes have an extremely wide range of applications, including metallic roof frames, mechanical construction in public work and industrial engineering sector, agricultural machinery, fluid distribution circuits, piston, etc. India is among the top producers of all forms of steel in the world. Easy availability of low cost manpower and presence of abundant reserves make India competitive in the global setup. The steel industry in India has witnessed an increase in demand due to expanding oil and gas sector, huge spending on infrastructural facilities coupled with growth in housing, consumer durables and auto sectors.

This book basically deals with structural changes in steel during hot rolling, structural changes during reheating, kinds of grain restoration process, dynamic restoration process, static restoration process, effect of initial grain, size of static re crystallization, effects of temperature and micro alloying, fundamental principles of the metal rolling process, preparing and heating the initial materials, preparations for rolling heating before rolling operations, bolt and nut manufacturing technology, casting of steel for flat products etc.

The present book covers different important aspects of steel processing with the casting method of steel for flat products, rolling of rails, wheels and rings, rolling of different steel products, production of fasteners, welded pipes, steel products for the building trade and many more.

The book is very useful for everybody who wants the thorough study on steel and steel products or wants to diversify in to this field.

Content:

Acoustic Insulation
Thermal Insulation
Solconfort Sandwich Sheets
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Typical Applications
Walling and Roofing
Facing Systems
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Conclusions

Sample Chapter:

Structural Changes in Steel During Hot Rolling

Structural Changes During Reheating

One of the consequences of reheating process is grain coarsing. The control of grain coarsing behavior of steels is an important step in the design of thermomechemical process striving to achieve fine grained products.

For microalloyed steels, the reheating temperature should be high enough to provide solubility of stable particles. If the stable particles remain undissolved, the beneficial precipitation hardening effects cannot be obtained.

Addition of aluminum, niobium, vanium, titanium, etc., produces abnormal type of grain growth (Fig. 1) which involves the growth of very few grains in relatively unchanged fine grain matrix. The abnormal grain growth occurs at the temperatures, which are significantly lower than the microalloying solution temperature. The temperature that corresponds to commencing of the abnormal grain growth is sometimes referred to as grain coarsing temperature.

The grain size distribution has a complicated dependence on the reheating temperature as depicted in Fig. 2 in application to Nb V microalloyed steel. When reheating temperature is equal to 1200ºC (2192ºF), the maximum area fraction of the steel microstructure corresponds to the grain size of approximately 0.12 mm (0.0048/in.). When the reheating temperature is lowered to 1150ºC (2102ºF), the grain size occupying the maximum area fraction is reduced to 0.06 mm (0.0024 in.). However, further decrease in reheating temperature to 1050ºC (1922ºF) produces two pronounced peaks in distribution of the grain size, one of each is at the grain size of about 0.18 mm (0.0072 in.) and the second one is at 0.022 mm (0.0009 in.).

Reheating temperature also affects a formation of so called deformation bands which play an important role during subsequent grain restoration processes. As can be seen from Fig. 3, the higher reheating temperature the smaller amount of deformation bands will be formed and with less uniformity after the same reduction.

While it does not appear that the final average austenite grain size after deformation is strongly dependent on the reheated grain size, it is likely that the distribution of the grain sizes above average is much smaller when the reheating temperature is kept below the grain coarsing temperature.

Kinds of Grain Restoration Process

Prior to the start of hot rolling, the steel microstructure consists of coarse equiaxed grains of austenite. During passing through the rolls, the austenite grains are getting flattened and elongated on the average each austenite grain undergoes a dimensional change corresponding to that of the work piece as a whole. The deformation bands may also be induced within the grains as illustrated in Fig. 4.

The three following kinds of restoration process are associated with hot rolling

1. Dynamic restoration process-This process starts and completes during deformation.
2. Metadynamic restoration process-This process starts during deformation and completes after deformation.
3. Static restoration process-This process starts and completes after deformation.

Dynamic Restoration Process

When steel is deformed in the austenitic state at high temperature, the flow stress rises to a maximum and then falls to a steady state as shown in Fig. 5a.

Dynamic restoration process includes dynamic recovery and dynamic recrystallization.

Dynamic recovery is a reduction of work hardening effects without motion of large angle grain boundaries. It occurs in a range of strain less than that for peak stress.

Dynamic recrystallization takes place in the range of strain that corresponds to steady state of flow stress. Role of dynamic recrystallization of austenite in practical rolling of C Mn steels is small. It is due to the fact that a critical strain required for achieving the steady state of the flow stress is very large, even at high temperatures. The grain refinement of these steels is usually achieved by static recrystallization.

Static Restoration Process

The microstructures developed by dynamic restoration are not stable and at the elevated temperatures are modified by metadynamic and static restoration processes. The latter processes may include static recovery, static recrystallization and metadynamic recrystallization as shown in Fig. 5b.

In hot rolling, static recrystallization may start spontaneously. Nuclei of recrystallization take place preferentially at elongated grain boundaries and interfaces of deformation bands.

Softening by static recovery and recrystallization occurs at the rates which depend on the prior deformation conditions and the holding temperature. The recrystallization curves generally follow an Avrami equation of the form.

Fundamental Principles of the Metal Rolling Process

The chief departments of a metallurgical plant operating on a complete ore to finished product cycle are the blast furnace, steel making and rolling departments (Fig. 1).

Almost all the steel that is produced in the steel making department passes through the rolling department only a small portion is used for making castings and forgings. The rolling process, in which the finished product is produced, is the concluding stage of metallurgical production.

The finished product of such a plant is rolled stock of various types, designed for various purposes, such as rails beams channels angles round, square or strip steel special purpose shapes, plate the sheet tubes, etc.

The initial material supplied to the rolling mill is the ingot, which may be either square or rectangular in cross section. In certain cases round ingots are employed (in the production of tubes, wheels and types).

The rolling process in a modern metallurgical plant comprises two stages 1) rolling the ingot into the semi finished product and 2) rolling the semi finished into the finished product.

It is not expedient to roll small blooms or billets in heavy blooming mills since this lowers the productive capacity and considerably increases power consumption of the mills.

A blooming mill can operate efficiently if it rolls ingots into blooms of large cross section, from 200 × 200 to 350 × 350 mm in size. These blooms are subsequently rolled into billets of various sizes (to suit the production schedules of the mills rolling the finished product) in billet mills.

Billet mills are usually located adjacent to the blooming mills. This arrangement enables small billets to be rolled from heavy ingots in a single heating. This is obviously good practice from the economical point of view.

The rolling of billets in two mills has proved to be highly efficient. The larger the final cross section of the bloom, the higher the blooming mill output will be. On the other hand, the smaller the cross section of the billet supplied to the mill rolling the finished product, the simpler the design of this mill will be and the higher its productive capacity. Another factor is the higher size accuracy and quality of a finished product rolled from small billets or blanks.

The breaking down department, producing semi finished products, may contain only a blooming mill or a blooming mill with a continuous billet mill. The preferable arrangement depends on the production facilities of the section rolling department.

In modern metallurgical plants, the production of sheet and plate also comprises two stages 1) rolling ingots into slabs and 2) rolling slabs into plate or sheet.

Advantages of this two stage procedure over that practiced in old metallurgical plants, where sheet and plate were rolled directly from the ingot, are

(1) Output of sheet and plate mills is increased because the billets they roll is of comparatively small thickness and because the top and bottom of the ingot are cut off after slabbing

(2) The quality of the rolled plate and sheet is improved since the slabbing mill reduces the ingot on all sides and the slabs may be inspected after rolling so that defects may be removed.

Slabs may be produced either in blooming or in slabbing mills. The ever increasing production of plate and sheet steel, in conjunction with the development of continuous sheet and plate mills, facilitated the widespread use of powerful slabbing mills, designed specially for this purpose. The chief advantage of the slabbing mill, in comparison with the blooming mill, is that the former has two vertical rolls in addition to its horizontal rolls. This enables the width to be rolled without turning the ingots on edge.

The slabbing mill is the chief breaking down or primary mill in plants designed for the large volume production of sheet and plate. However, because of their narrower filed of application, slabbing mills are much more seldom installed than blooming mills. In the majority of cases, it is necessary for the primary mill to roll both blooms and slabs. Only a blooming mill will serve this purpose.

The main requirements in rolling the finished product are

To obtain a finished product of the specified size and shape at the highest possible rate of production and the lowest cost

To obtain a finished product of the highest feasible quality concerning, not only its physical and mechanical properties, but also its surface condition.

These requirements may be met only if the processing schedule for all operations in producing the given rolled product is strictly followed.

The number of operations comprising the rolling process depends on the specifications stipulated for the shape accuracy, physical and mechanical properties, surface condition and macro and microstructures of the rolled metal. The more exacting these specifications are, the more complicated the rolling procedure will be and the more operations it will comprise.

The chief operations in metal rolling production are

Preparing the initial material for rolling
Heating the initial material before rolling
Rolling
Finishing, including cutting, cooling, straightening, removing surface defects etc.

The preparation of the initial material for rolling consists in the removal of various surface defects. This is a very important operation, especially in rolling high quality carbon and alloy steels, as it ensures a high output of proper quality with minimum rejects.

Strict observance of the prescribed conditions for heating the metal before rolling, proper determination of the temperatures at the beginning and end of the rolling process and determination of an optimum draughting schedule are of vital importance and directly influence the quality of the finished product.

The prescribed procedure to be followed in cooling the metal after rolling may be quite significant in many cases. If it is not observed, the rolled product obtained may have defects such as flakes or cracks or it may have unsatisfactory properties.

It is necessary as well to observe the prescribed conditions for all of the remaining finishing operations, which ensure a finished product of the specified quality.

Fig. 2 shows a flow diagram of rolled stock production from the ingot to the finished product in modern rolling departments. It represents the production of ordinary and quality carbon steel and alloy steel stock.

Proper control over the rolling process and quality control of the finished product are of primary importance.

One quality control procedure practised in modern rolling mill departments is melt inspection on the basis of which the quality of the steel is determined and the melt is assigned for rolling. The scope of this inspection depends upon the requirements made to the grade of steel under consideration.

Melt inspection begins in the steel making department where samples of the melt are taken to determine the average chemical composition of the steel in each melt. Usually two samples are taken from each ladle. The second sample serves to additionally check the chemical analysis. This is done in cases when it is necessary to check the content of certain elements or if such inspection is stipulated by special requirements of the customer. In certain cases, the samples for this analysis are taken in the rolling mill department from the billet or the finished product. In the last years, many elements are determined by spectrographic analysis, which has become one of the most widespread physical methods of determining the chemical composition of metals and alloys.

Further melt inspection may include determining the quality of the melt by its macro and/or microstructure and longitudinal fracture determining the grain size of the steel determining the mechanical properties and hard enability and other tests. For this purpose one or two control ingots are selected. In the latter case, one ingot is selected from the first tap and the second from the last tap. Control ingots of high quality steels are selected from each tap. These ingots are rolled into billets (and sometimes into finished products) either separately or together with the ingots of the whole melt.

Samples for melt inspection tests are selected from bars rolled from the steel just under the top of the control ingot. In certain cases, samples are taken from bars rolled from definite sections of the ingot in height, for example, from the top, middle and bottom sections.

Macrostructure inspection of steel enables gas holes (not permissible in killed steel) to be revealed as well as shrinkage cavities, porosity, segregations, hairline cracks, flakes and other defects. These defects are evaluated by standard scales.

Longitudinal fracture enables the degree of slatiness and the grain size to be determined it reveals such defects as seams, shrinkage cavities, porosity, inclusions, stone like appearance, naphthalene appearance and other defects that can be seen by visual inspection.

The microstructure inspection, the amount of nonmetallic inclusions, grain size, depth of the decarburized layer and other factors are determined.

The second type of control is over the rolling process. It should ensure proper heating procedure for the initial materials, proper observation of the pass schedule for rolling the given section within the specified tolerances and proper finishing of the rolled material.

The marking on the initial material must be carefully checked in the storehouse before charging it into the heating facilities.

The temperature of hot ingots should be measured before placing them into the soaking pits. This will prevent thermal cracks. Processing instructions usually list the minimum permissible temperature of the ingot surface and the maximum soaking pit temperature. The heating temperatures and flame temperatures are checked during heating by appropriate instruments.

In rolling metal it is necessary, first of all, to check the initial and final rolling temperatures, as well as the pass schedule. The setting of the rolls is checked continuously by measurements of the rolled sections the condition of the roll grooves and roll gear is also checked frequently. Lately much attention has been paid to determining the pressure on the rolls and the torques applied in rolling by means of load cells and other instruments. This enables the available power of the mills to be utilized more correctly and fully.

Mechanization and automation of rolling mills allow the rolling speed to be considerably increased, particularly for continuous mills, and enable more attained in cold rolling sheet steel in continuous mills, for example, became possible only after instruments were developed for contactless continuous gauging of the strip. Such instruments include radiation strip thickness gauges based on the use of gamma or beta radiation. Radioactive isotopes are utilized as the source of energy. By means of a strip thickness control system, these instruments actuate the roll adjusting and strip tension devices. In the very latest installations, computers and television have also been applied.

Steels for Magnetic Applications

Electrical steels metallurgy and properties

Introduction

Together with nickel, cobalt and a few other elements, iron is one of the rare ferromagnetic metals. This property is intimately related to the electronic structure of the iron atom and a detailed explanation can only be given in terms of quantum mechanics. However, the consequence is that the spins of certain electrons are aligned, resulting in an overall magnetic moment, which is in the same direction throughout small areas of the crystal structure. Iron and the ferrite steels are, therefore, composed of small saturated magnetic domains, each corresponding to a microscopic magnet. The magnetization is not always obvious on a macroscopic scale, due to the fact that the magnetization directions of individual domains tend to compensate one another. The magnetization directions of adjacent magnetic (Weiss) domains are different, and often opposite, and they are separated by bound aries called Block walls (Fig. 1). When an external magnetic field is applied, the magnetization directions tend to reorient and domains more favorably oriented tend to grow at the expense of the others by movement of the Block walls, so that the individual magnetic fields no longer cancel out. In magnetically soft materials, the microstructure is such that displacement of the Block walls is facilitated, enabling the metal to respond rapidly to external excitation, and to transmit the magnetic flux with minimum power losses. On the contrary, in magnetically hard materials (magnets), the aim is to conserve a strong macroscopic magnetization (remanent induction) with a high coercive force or coercivity (the external field necessary to overcome the remanent induction). Figure 2 shows the typical shape of a hysteresis curve, illustrating the fundamental parameters Bs (saturation induction). Br (remanent induction or remanence) and He (coercivity). The magnetic permeability, which reflects the ability of the metal to transmit the magnetic flux, corresponds to the slope of the initial magnetization curve. A good electrical steel sheet must have a high permeability and minimum coercivity, together with other properties, which will be described in detail later.

Utilization and Property Requirements

Transformer sheets are sold in the finished or semi finished conditions and are used in the form of lamination stacks, mainly in electric motors, alternators and compressors, depending on their properties. The stacks form the magnetic core of the apparatus concerned. The sheets must satisfy several, sometimes contradictory, requirements, whose priorities depend on the specific application, such as high magnetic permeability, low hysteresis losses (i.e. low power consumption) and ease of cutting to shape.

Electrical steels come in two principal categories, the oriented and non oriented grades.

Grain oriented sheets are obtained by a complex processing cycle and give excellent results in terms of permeability and core losses in certain conditions, particularly in unidirectional fields, such as in transformers. The particular feature of these materials is their microstructure consisting of very coarse grains, oriented with the cube edge parallel to the rolling direction (110) (the so called Goss texture). The crystallographic direction is a direction of easy magnetization, so that when the sheet is magnetized in the rolling direction, its permeability will be very high and its coercive force very low. Figure 3 shows the magnetic anisotropy of iron and illustrates the advantage of having a direction parallel to the exciton field. In contrast, because of their planer anisotropy, grain oriented sheets have much poorer performance in rotating machinery, such as motors, where the excitation field rotates in the plane of the sheet. They are difficult to blank because of their large grain size. In France, they are manufactured by the Ugine S.A. company.

Non oriented sheets are produced by a much more conventional process, and can be subdivided into two categories

Fully processed grades are delivered in the finished condition and are alloyed with silicon. They are continuously annealed at high temperature, and sometimes varnished. Although their magnetic properties in the rolling direction are not as good as in grain oriented sheets, they are much less textured, making them better suited for use in rotary fields. They have good blankability, which depends on the silicon content, the grain size, and possibly on the coating.

Semi processed grades are continuously annealed at a lower temperature and are delivered after a significant skin pass reduction (several %). They have good blankability, but must be given a final annealing treatment by the user to develop their magnetic properties. This treatment has several effects. Firstly, it produces a coarse grain size, due to the critical strain (1 5%) imparted by the skin pass, leading to relatively few recrystallization nuclei, enhancing the magnetic properties. Secondly, decarburization is promoted by the use of a controlled atmosphere. Thirdly slight oxidation, producing a bluish tinge, provides electrical insulation between the laminations in a stack, limiting the formation of eddy currents in alternating current machines. The uses of semi processed grades are similar to those for fully processed materials, even though the clients are often different. Todays top semi processed grades are roughly equivalent to mid range fully processed products.

Optimization of Magnetic Properties

The remainder of this article will concentrate on semi and fully processed non oriented sheet.

Among other characteristics, a good electric motor must have a high maximum speed (or torque) and high efficiency. The magnetic circuit design and the choice of metal have a decisive influence on these properties. Power losses, which affect the efficiency, have two major sources, resistive losses in the copper windings, and core losses due to induced eddy currents and magnetic hysteresis. The resistive losses are proportional to the square of the induction current, and can be decreased if the coupling between the stator and the rotor is increased, i.e. if he core has a high permeability.

Hysteresis Losses

The applied fields associated with alternating currents are sinusoidal, so that the hysteresis cycle is repeated 50 times per second at the normal mains frequency. The energy consumed by this process alone is equal to the area inside the hysteresis loop. The hysteresis is caused by internal magnetic friction associated with the movement of the Block walls. To reduce the losses, it is necessary to lower the coercive force, which correlates to high domain wall mobility. This can be done by eliminating as far as possible all precipitate particles, particularly cementite, requiring extremely low carbon contents. The fully processed grades are decarburized either in the melting shop or by strand annealing after cold rolling. The semi processed grades are decarburized by the user during final annealing after cutting to shape.

The very low solubility of carbon in ferrite at room temperature makes these steels highly sensitive to magnetic aging, which can lead to increased power losses due to the natural precipitation of fine carbide particles. The final carbon content must therefore be less than or equal to 20 ppm. Figure 4 shows the percentage increase in power losses with carbon content after simulated aging in a fully processed grade. Manganese sulfide and aluminum nitride particles are less detrimental, due to their large size (induced by appropriate metallurgical control).

Another way of reducing hysteresis losses is to decrease the coercive force by increasing the grain size, since grain boundaries are effective obstacles to the movement of domain walls. In non oriented grades, cold rolling is performed in a single reduction of about 70%. Fully processed steels are continuously annealed at high temperature to obtain coarse grain sizes of the order of 4 to 8 ASTM (20 80 um). Semi processed sheets are given a slightly smaller cold reduction, followed by strand annealing at lower temperature and skin pass following corresponding to a strain of less than 10%. Critical strain recrystallization during the final high temperature annealing treatment carried out by the customer gives typical grain sizes of about 0 to ASTM (80 300 um), strongly diminishing hysteresis losses. The skin pass reduction enables the blankability to be optimized. The electric motor manufacturers or blanking shops usually prefer YS/UTS ratios greater than 0.85 in order to improve productivity and reduce tool wear. The amount of cold work required to obtain such ratios is always a few percent higher than the critical recrystallization strain. Figure 5 shows a typical example of the variation of YS/UTS ratio with skin pass reduction. The accompanying micrographs illustrate the as annealed grain sizes. For low strains, recrystallizaion does not occur and the grain size remains fine, while strains of a few percent lead to coarse recrystallized grains.

The density of dislocations and other mechanical defects is also important. Semi annealed sheets are annealed after blanking and therefore have very low dislocation densities. In contrast, fully processed sheets can contain local regions of high strain after blanking. This is particularly true at notches in the stator, where the deformation is most severe. Since the purpose of these notches is to transmit the magnetic flux from the stator to the rotor, certain users perform a stress relieving treatment at about 800ºC to produce local recovery or even recrystallization.

Finally, another useful way to reduce hysteresis losses to modify the texture, enhancing the density of (100) and (110) planes, which significantly raises the low flux density permeability and sharply lowers the coercivity. The texture can be modified by adapting certain stages of processing, but the operations involved are relatively complex.

Eddy current losses

The other important source of core losses is the resistive heating associated with induced eddy currents. The latter are caused by interaction between the magnetic field and the conduction electrons of the metal. The losses due to this phenomenon are proportional to the square of the frequency and the thickness of the sheet (the current loops appear in the sheet section perpendicular to the magnetic flux, and create a counter field which opposes the induction field). Apart from reducing the working frequency, which is rarely possible, there are three ways of decreasing this effect.

Decreasing the sheet thickness is common practice, since magnetic cores are generally composed of stacks of thin sheets, less than 1 mm thick. This approach is limited by productivity considerations.

Efficient inter lamellar electrical insulation, generally obtained by oxidation (bluing) in semi processed grades, at the end of the final annealing treatment performed by the user, and by varnishing for fully processed products. The latter technique is much more effective.

The use of alloying elements such as silicon, phosphorus, aluminum and manganese has the advantage of considerably increasing the resistivity. This significantly decreases the intensity of the eddy currents and the associated power losses. Silicon can be incorporated in the steel in appreciable amounts, up to 3.5%, with appropriately adapted processes. Beyond this level, excessive brittleness prevents cold rolling. Furthermore, silicon reduces the saturation induction of the steel, and hence its permeability at medium and high flux densities. Steels and hence its permeability at medium and high flux densities. Steels with more than 0.5% silicon have various technological disadvantages. After continuous casting, the slabs must be transferred hot to the rolling mills, due to their tendency to crack on cooling, and silicon containing sheets are difficult to weld. However, in spite of these drawbacks, the functional benefits of silicon containing electrical steels have led to their widespread use, due to the critical importance of low power consumption, especially in large motors.

Type of electrical steel

Classification

Non oriented electrical steel sheets are covered by three French standards, depending on whether they are semi or fully processed. Semi processed products are described by the C 28 925 and 28 926 standards, while NF C 28 900 treats fully processed sheet. It all cases, only the magnetic properties are guaranteed, particularly the total specific losses at a given magnetization level and the induction level for a given applied field, in both the transverse and rolling directions. For semi processed sheet, after a reference heat treatment, the metal must guarantee a power consumption less than a specified value, together with a minimum induction level for a given applied field. The reference heat treatment corresponds to annealing for two hours at 790ºC in a decarburizing atmosphere. The apparatus used for the measurement is called in Epstein frame and is described by the NF C 28 911 standard.

The designations of different steel grades according to these standards reflect the maximum power losses in watts for one kilogram of the metal concerned and an induction of 1.5.T. Since these losses depend on the thickness, the designation includes the standard thicknesses (0.5 and 0.65 mm for the semi and fully processed produces. plus 0.35 mm for fully processed materials). For example, the FeV 660 50 grade corresponds to a material with a thickness of 50 hundredths of a millimeter, for which the guaranteed total losses must not exceed 6.6 W/kg measured in a standard Epstein frame. The difference between the two semi processed product standards NF C 28 925 and 28 926 concerns the amounts of alloying elements, the first applying to unalloyed steels (0.5 wt. % Si) and the second to alloyed grenades (according to the NF EN 10 020 standard). The designations are differentiated by two letters. HD for unalloyed semi processed grades, HE for alloyed semi processed materials and HA for the fully processed sheets. The NF C 28 900 standard mentions certain requirements concerning magnetic aging, the packing factor (volume increase on stacking) and magnetic anisotropy.

Steel Grades

Usidecoupe

Although not really electrical steels, these XC grades are used for the manufacture of small motors for very infrequent utilization (e.g. kitchen mixers, electric automobile window drives, etc.), for which the efficiency is of little importance. Although their magnetic properties are never guaranteed, their mechanical characteristics are severely controlled. Their blanking capacity must be excellent and invariant.

Semi processed grades

Four grades are presently available, in different thicknesses. They cover all the requirements of the domestic appliance and small industrial motor markets. The differences concern the guaranteed maximum power losses, and are essentially related to the amount of alloying additions in the steel. The latter include the four main elements which increase the resistively, i.e., silicon, aluminum, phosphorus and manganese. Table 1 gives the guaranteed magnetic properties of these grades, compared to those required by the standards, together with their typical mechanical characteristics.

The trend in semi processed steels is towards more efficient decarburization during melting. This improves their intrinsic quality, but most of all, simplifies the process for the end user, by eliminating the need for decarburizing, increasing the productivity of the grain coarsening furnace. Moreover, modern stacking techniques, such as the Fastec process, become accessible to the semi processed grades. Since assembly is performed immediately after blanking, decarburizing is not possible. However, in these applications, varnishing of the coils becomes essential. This development enables the steelmaker to differentiate between semi and fully processed grades at a much later stage in the manufacturing cycle, significantly simplifying internal product management.

Fully Processed Grades

A large number of fully processed grades are available on the market. For a given thickness, it is possible to choose from a wide range of different power loss levels. Various types of varnish can be applied to the sheets. Table 2. illustrates the extreme grades in terms of guaranteed maximum power losses for three standard thicknesses, together with their typical mechanical characteristics.

The choice of power loss level depends on the application concerned, varying greatly from a washing machine motor to a nuclear power station turbine. Metallurgically speaking, the variations are due mainly to differences in the silicon and aluminium contents and in the annealing cyles employed.

Preparing and heating the initial materials

Preparations for rolling

The initial materials (ingots and billets) are prepared to be rolled by removing various surface flaws. This is called surface conditioning and is an important operation, especially in rolling quality carbon and alloy steels intended for the manufacture of vital components in various fields of industry. The cost of preparing the initial materials will be justified in this case by the possibility of obtaining a product of the specified quality and by the decrease in the amount of rejects.

As a rule, hot ingots are charged into the soaking pits and, therefore, surface conditioning operations are performed on the billets (however, flaws may also be removed from the surfaces of the hot ingots).

Especially exacting requirements are made to the surface of alloy and high alloy steel ingots. Therefore, the cast ingots may be completely cooled, surface conditioned and then reheated for subsequent rolling (a softening heat treatment may be employed before removing the flaws). In this case, surface flaws are removed both from the ingots and from the billets.

Surface defects, subject to removal, include scabs, hair lines, cracks, rolling laps, nonmetallic inclusions, scratches, etc. All of these flaws are revealed by inspection. If all surface defects are to be removed, the billet is first pickled. Defects, enclosed by scale and therefore hidden from ordinary inspection, may be detected by acid pickling.

Chipping operations to remove surface flaws, performed by means of pneumatic hammers usually operating under an air pressure of 5 to 5.5 atm, are still in wide use. This method has a low production capacity, especially for alloy steels, and is a health hazard as far as the operations are concerned. Chipping requires the highest labour input of all rolling operations and is therefore little suited to modern rates of production. It is chiefly employed in the surface conditioning of billets and sometimes as a supplementary operation for removing certain deep flaws on ingots. These are flaws such as may remain, for example, after rough machining the whole surface of the ingot or after performing some other allover cleaning operation.

Defects are usually chipped in a direction along the length of the billet or ingot since transverse chipping may caulk such defects as cracks. The sides of the chipped groove should slope gently and its width to depth ratio must be such that no new cracks or other defects will be produced on the surface of the finished product in subsequent rolling.

Swing frame grinders are also used for surface conditioning operations. They are mounted on a special suspension device allowing them to be easily swiveled about a vertical axis and titled from the vertical position. Due to the high grinding speeds, the abrasive wheels used are of aluminum oxide with a resinoid (bakelite) bond.

In contradiction to chipping with pneumatic hammers, conditioning with a grinder is carried out in the transverse direction (on the billet) since it is difficult to detect hair lines or fine cracks, usually running along the billet, in longitudinal grinding.

Grinders have a low production capacity in surface conditioning operations and the cost is higher than for chipping. Consequently grinding finds application in removing a large amount of slight defects and chiefly for conditioning high alloy steel billets. Chipping of the latter with pneumatic hammers is extremely difficult or even impossible. In removing flaws by grinding from hard steel billets, the intensive heating of the metal and subsequent cooling may lead to the formation of grinding cracks. This can be avoided by taking lighter cuts and by selecting the grain size, grade and peripheral speed of the grinding wheel to suit the steel being processed. Grinding cracks are more liable to appear in conditioning hard steels. That were rapidly cooled after rolling, producing high stresses. Air hardening steels should be conditioned in the as annealed state to prevent the formation of cracks.

A new surface conditioning method, called flame scarifing, has come into use in the last years. It consists in burning out the flaws in the surface by means of a torch with an oxyacetylene flame.

Flame scarfing is performed either by hand or in special machines.

As a rule, hand (torch) scarfing is a localised operation in which certain definite defects are removed from the surfaces of ingots and billets. Here the tip of the torch is directed to one end of the defect and the metal is preheated to a temperature of 950° 1,000°C. This takes several seconds. The torch is held at a angle of 75° 80° to the billet surface. When the metal is heated to the burning point, the amount of oxygen supplied to the torch is increased.

This oxygen removes a layer of metal by oxidizing or burning the metal. As soon as the metal begins to burn, the torch is titled to an angle of 25° 30° to the surface. Then the jet of oxygen not only burns the metal but also blows the slag and liquid metal from the surface being scarfed.

At present, almost all types of steel are torch scarfed. All carbon and low alloy steels may be torch scarfed without difficulty. Stainless, heat resistant and other steels, with high chromium content, require the application of special fluxes and coatings, which facilitate burning and form slag with a low melting point. Frequently a special torch is used to scarf these steels. It differs from the ordinary torch in having a supplementary injector, supplied through one hose with an oxygen flux mixture, and with additional cutting oxygen through a second hose.

First, the beginning of the cut is heated, then the oxygen and flux delivery are turned on. When a sufficient amount of molten slag has formed, the supplementary oxygen injector is turned on and torch is moved along the line of scarfing.

Cracks, which may be formed in flame scarfing, are due to the thermal stresses resulting from large temperature differences along the cross section of the billet and also to stresses associated with the formation of a martensite or troosto martensite structure from the austenite. The lower the thermal conductivity and initial temperature of the billet being scarfed, the higher its coefficient of thermal expansion and the lower the ambient temperature, the higher the thermal stresses will be. The higher the austenite stability and carbon content of the steel and the higher the cooling rate after scarfing, the more susceptible the steel will be to crack formation. Stresses due to scarfing may be reduced by preheating the billet or by surface conditioning directly after rolling when the billet is still hot.

Torch scarfing is performed in a direction along the billet. The scarfed groove should have sloping sides and should be of a width at least five times its depth and of a length at least three times the width.

The production capacity of hand torch scarfing is several times higher than chipping with pneumatic hammers. Highest output is achieved, however, in flame scarfing machines where surface defects are removed by an allover burning of the surface layer with an oxyacetylene flame.

Flame scarfing machines are usually installed beyond the mill, for example, in the roller table line between the blooming mill and the shear. Here hot blooms and slabs are scarfed directly after they leave the mill. Here, the surface layer of metal is removed simultaneously from all four sides of the bloom.

The same type of mechanized allover surface conditioning is also practiced in the billet storage where billets are treated either cold or preheated. In these installations, the torch head is mounted on a truck traveling on rails along which the billets are arranged.

Other surface conditioning methods, used for billets and ingots, are 1) milling, 2) planning and 3) turning. Of these, turning is the most extensively used operation for roughing ingots and billets.

Turning is applied in roughing round ingots and billets of heat resistant, stainless and other special grade steels for the production of high quality seamless tubing. Special lathes are available at present for roughing such round ingots. These lathes are equipped with special fixtures for rapidly setting up and centre drilling the ingots. The use of several tools clamped on a single carriage effectively reduces machining time.

Alloy and high alloy steel ingots, intended for producing sections, sheet or plate, are also turned in special cases. Such ingots have a square or rectangular cross section and are machined on special tracer controlled lathes. These machine tools, called multiple cornered lathes, can accommodate ingots and billets of any cross section.

Before multiple cornered lathes came into use, square and rectangular ingots were roughed all over on general purpose and special planers. The low output and high cost have almost excluded this method from general practice.

The surfaces of ingots and billets are milled both for allover surface roughing and for removing separate defects. This operation is performed on special milling machines.

Large surface defects, of a width up to 50 mm and a depth up to 15 mm, difficult to cut out by pneumatic hammer chipping, are usually removed by a local milling operation.

Ingots and billets of mild and medium hard steels are machined without being previously annealed. Hard steels are annealed before machining.

Bolt and NuT Manufacturing Technology

Introduction

The metal working industry employs a range of different technologies. These include the casting of molten metal into moulds, fusion by welding, cold and hot mechanical working, cutting and chemical machining, technologies consist of a variety of distinct techniques for example, metal cutting technology includes amongst many other techniques turning, milling and drilling. The manufacture of nearly all threaded fasteners requires the employment of methods or techniques from more than one technology.

In later chapters, bolts and nuts are described as being manufactured using a particular technology. It does not necessarily follow that only one technology is employed in the full sequence of manufacturing operations. Rather, the characterization refers only to the most important technology that is used in the complete manufacturing sequence.

The next section of this chapter provides an introduction to the principles involved in the manufacturing of threaded fasteners. It is followed by more detailed discussion of alternative, technologies, the ranges of alternative techniques within each technology and the types of tools and machines that are used. The descriptions of the principles and technologies are not comprehensive the purpose of this chapter is to give a reasonable idea about the nature of choice currently available and to provide sufficient information to enable the reader unfamiliar with fastener manufacturing to follow the discussion in later chapters of the study.

The three main metal working technologies used in the manufacture of threaded fasteners are cold mechanical working or cold forming, hot mechanical working or hot forging and metal cutting. In mechanical working, the processes used to shape metal include rolling, drawing, extrusion, upsetting open die forging, closed die forging, and presswork. Although mechanical working changes the shape of work pieces it does not change their volumes substantially. The processes involve the plastic re shaping or deformation of either cold or heated work pieces by the external action of special tools. Mechanical working strengthens components by drawing impurities and grains into bands along the direction of working and closing minute cavities.

Fundamentals of Mechanically working and cutting metals

Cold Forming

When metals are subjected to progressively larger loads they first deform elastically. If the load is increased beyond a certain point the metal becomes plastic. Curve A on the load extension diagram in figure 1 shows how the rate and degree of deformation can vary with the magnitude of the applied load. Stress, which is the load per unit area, is plotted on the vertical axis of the diagram while deformation, expressed in terms of strain is shown on the horizontal axis. Beyond the transition point on curve A between elastic and plastic deformation some deformation remains when the load is removed. If the load continues to be raised the metal eventually breaks.

Cold forming metal within its plastic range decreases its plasticity and this phenomenon is called strain or work hardening. Curves A and B in Figure provide a comparison of how mild steel behaves before and after cold working. Work hardening is not only associated with an appreciable decrease in plasticity but also with an increase in strength. Advantage is sometimes taken of this to deliberately increase the strength of a piece of metal by cold working it, but since plasticity decreases with cold working there is a maximum limit to the amount of cold working that may be undertaken. Advantages of cold forming over hot forging are that parts are free of surface scale, may require less raw material since they can be formed closer to final size, do not need to be pre heated and require little cool downtime after working.

Hot Forging

For each metal there is a range of temperatures in which the plasticity and resistance to work hardening is greatly increased. The forging temperature range varies from metal to metal. For mild steel it is around 1,200°C while for lead it is room temperature. The forgability of a metal is its ability to flow into the required shape without cracking and offer low resistance to the forces shaping it. Forging a metal to a given shape requires considerably less power than cold working it, but the accuracy and finish of the work piece are generally inferior.

Metal Cutting

There are several ways of cutting metal sawing, abrasive cutting off (grinding), shearing or cropping, and machining. These methods have much in common both with each other and with the mechanical working technologies all involve working metal in the zone beyond the elastic limit.

Manufacturing Technologies

In this section each of the main bolt and nut manufacturing technologies employing the principles described in Section 2 is discussed.

Cold Forming of Bolts

Four widely used methods of cold forming are shown in the top row of Figure 2. These are upsetting etc. which involves a reduction in length and increase in cross sectional area of work pieces, forward and backward extrusion which both have the effect of reducing the area and increasing the length of work pieces and thread rolling. In thread rolling the dies penetrate the surface of the blank to form the thread root, the displaced material flowing outwards and upwards to form the crest of the thread. Cropping or shearing, trimming and piercing are often carried out in association with cold forming but they employ cutting rather than forming techniques, are shown in the lower half of Figure 2. Most work pieces or blanks to be cold formed are first cut off by cropping them from wire stock. Hexagonal bolt heads are usually formed by trimming the periphery of cylindrical upset heads with a hollow hexagonal punch. Trimming removes any cracks on the edge of the heads caused by upsetting. Piercing involves the removal of a slug from the work piece to form a hole and is used in the cold forming of nuts.

One sequence of operations which can be used to produce a bolt to its final shape together with an outline of the necessary tooling is shown in the left hand side of Figure 3. In this case the heading machine cuts off and upsets the blanks in two blows. The additional secondary operations required to finish the blanks are carried out on a single blow trimming machine and thread rolling machine.

In heading machines, the end of a coil of cold drawn wire that has been precoated with a lubricant passes through straightening and feed rollers which push the wire through the cut off quill until it comes up against a stop. The blank is sheared from the end of the wire and transferred to the heading position by the cut off mechanism. During the firsts stroke in the heading station the punch pushes the blank into the die until it comes up against the ejector pin and then commences the shaping of the head by upsetting a cone. Between the first and second blow the first punch is moved aside and the second punch takes its place. The second punch forms the head into a cylindrical cheese and usually also embosses the top of the head of the blank with symbols to permit identification of the manufacture, tensile strength and sometimes of the tread forms. Once the second punch has withdrawn, the blank is forced from the die by the ejector pin and falls clear of the die before the next blank is inserted.

Two blows are needed to form the cheese head because there is a limit to the amount of metal that can be upset in a single blow without buckling the portion of the blank that is not supported within the die. In a single blow, the maximum amount that can be cold upset under control is two and a quarter diameters but most single blow heading is within the range of one to one and a half diameters. In two blow heading four and a half diameters can be upset.

There are other limitations to the lengths of material that can be headed using the methods shown in Figure 3. Ejector pins buckle if they are unsupported over a length of more than eight times their diameter which limits the length diameter ratio of formed b1they anks contained within a die. One way round this problem is to provide support to the ejector pins by using a telescopic ejector mechanism. This makes it possible to remove formed blanks with lengths contained within the dies up to twelve times as long as their diameters. For even longer parts which are upset (but not extruded) split dies are used which are made in two halves. The two halves are held together during the upsetting operation and act in a similar way to normal closed dies but are forced apart before ejection. With this arrangement blanks are inserted from the back as opposed to the front of the dies and are cut off by the back of the split dies before they close for the upsetting operation. The length of the wire for the next blank to be upset ejects the previous part from the die. The head of very long bolts can be cold formed by holding pre cut blanko in split dies during upsetting. The heads of most cold formed threaded fasteners are upset using the closed rather than the split die arrangement. The reason is that when bolts are made from wire the split die configuration requires a different set of dies for each blank length whereas only the ejector pin requires replacement when, blank lengths are altered using closed dies.

After heading, the blanks are collected from under the heading machine and transported to the trimming machine. The trimming machine performs two distinct functions first it gives the head a hexagonal shape by trimming off material and second, it straightens the body and forward extrudes the end of the body in preparation for thread rolling. The headed blanks are usually deposited into the hopper of a trimming machine where they are first automatically orientated correctly for delivery into a chute at the lower end of which they are picked up and transferred to a point over the trimming die centre by a pair of fingers. The punch pushes the blank through the extrusion die as depicted in the left hand column of Figure3. Towards the end of its forward stroke the punch forces the head of the blank through the hexagonal trimming die. Once the punch is on the return stroke the blank is ejected from the die by means of a spring behind the ejector pin.

There are limitations to the amount of forward extrusion that can be carried out with a single blow. If buckling of the portion of the blank that is not supported in the die is to be avoided during extrusion, the reduction in cross sectional area resulting from a single operation must not exceed 30 per cent.

The diameter to be thread rolled could be reduced by machining rather than extrusion, but this would waste material. Another method of producing threads is to cut them but this also wastes material. Thread rolling has other advantages, however, over thread cutting. Firstly, the cold working action during rolling increases the strength of the threads since the grain of the material follows the thread contours and secondly, compressive stresses are imparted to the thread roots during rolling which offset the tensile stresses produced by tightening nuts into bolts. In flat die thread rolling, parts are threaded between a pair of flat dies, one reciprocating and one stationary. The thread shaped ridges on the working faces of the dies are inclined at the angle necessary to produce a continuous thread on the blank. A thread is rolled on one blank at a time while it rotates about its own moving axis, during the forward stroke of the reciprocating die. Thread rolling can take other forms. In planetary thread rolling, blanks are rolled between a centrally located rotating die and a stationary concave die segment. The circular die in the middle rotates continuously with the result that two or three parts can be passing between the dies simultaneously. Such machines can only roll relatively small diameter blanks. In another arrangement the blank is squeezed between two cylindrical rotating dies, which have, thread form cut round their circumferences.

Thread rolling machines, like trimming machines, are usually arranged so that the blanks are automatically fed down a chute from a hopper although, in the case of very long blanks, it is necessary to hand feed both trimming and rolling machines. Some fastener manufacturers link their heading, trimming and rolling machines by providing conveyors, which collect the blanks from under one machine and deliver them to the hopper feed on the next machine in the line. Although conveyors can reduce the amount of materials handling required between the operations they have two disadvantages. First, all the machines in a line linked by conveyor must be working on the same size of blank (when the machines are not linked up this is unnecessary) and second, overall machine utilization in a linked system can be low because when one machine stops running for more than a short period the other machines linked to it must also halt.

The heading, trimming, extrusion and rolling operations can be combined in a single specialized machine. The operations are illustrated diagrammatically on the right hand side of Figure3. The drawing shows a machine having a bank of five stations, with a cut off, four dies, and four punches. Transfer fingers move each blank along the row of dies one die position at a time between blows. Each blank receives a single blow from each punch. In the case shown in Figure 3, wire with a diameter greater than the finished shank diameter is used. By extruding the body if the bolt down to its finished shank diameter in the first dies the head can be upset in only one blow by the second punch without buckling occurring. This is possible because the section of the blank forming the head is less than two and a quarter times the diameter of the original wire compared to two blow heading there is less deformation in the head for a given bolt size. The result is a better balance of properties between head and shank with the result that normalizing of finished bolts may be necessary. The portion of the shank that is to be thread rolled is extruded in the third die and the head is trimmed in the fourth die. In some machines, the trimmed blanks pass through the centre of the trimming die and enter a tube through which they are delivered to either a pointing or then a thread rolling station or directly to a thread rolling station. The pointing operation cuts a chamfer round the tip of the body so that the start of the rolled thread is even. In other machines, a trimming punch is used and parts are allowed to drop into a collecting belt after ejection from the last die.

There are several types of cold forming machines, which represent intermediate stages between two blow heading machines and fully integrated machines. Often when parts with large diameter heads and slender shanks are required, two dies, three blow headers are used. Machines with four or five stations in line but without pointing or thread rolling stations are called either progressive or transfer headers. These machines are most often used for cylindrical parts other than bolts which would otherwise have to be machined from solid bar.

In addition to the precoated solid lubricants on the wire small quantity of oil is usually applied to the material stock to lubricate forming operations. An oily rag is often tied round the wire ahead of the feed rolls but oil can be sprayed into the tool zone where there is no risk of large quantities of oil entering the die and causing work pieces to be partially filled. The important characteristics of these oils are resistance to high pressure and temperature and the minimum emission of smoke and toxic vapours. Most cold forming wires are precoated with thin dry coatings.

Cold Forming of Nuts

Figure 4. shows a cold nut forming sequence and an outline of the tooling. Cold nut forming machines are quite similar to short stroke progressive headers. The wire stock is fed through feed rollers, the cut off quill and the cut off bush up against the length stop. A cylindrical blank is cut off and inserted into a transfer gripper which presents it to the first forming station. After forming in the first die the blank is ejected and received by a second gripper for transfer to the next forming station. This sequence is repeated until the blank leaves the last die position finished formed. During two of the transfers in the sequence shown in Figure 4 the blank is turned end on end through 180 degrees to enable the punches to work on both ends of the blank. Because of the work hardening that occurs during forming, the slug is punched out cleanly at the last station.

Nuts can also be formed in four stations cold nut forming machines which accept wire with a hexagonal cross section or alternatively by cutting off and performing cylindrical blanks on one machine, heat treating the blanks to remove the effect of the work hardening induced during the initial forming and then finish forming the blanks on a second machine.

After forming, nut blanks have their thread cut on tapping machines.

Hot Forging of Bolts

Figure 5. shows two alternative operation sequences for the production of hot forged bolts together with outlines of the necessary tooling. Bolts are forged from hot rolled round bar of a diameter equal to that of the finished bolt shanks.

In the first process in Figure 5, a blank, or pin, of sufficient length to form one bolt is cut off. Sawing is rarely used for this operation since it takes longer than cropping. Equipment used for cropping ranges from manually operated shears intended for cutting reinforcing bar on building sites to fully automatic high speed cropping machines. Manually controlled purpose made semi automatic cropping machines are available but simple reciprocating mechanical presses can be equipped with cropping tools to do the job in the same way. In such machines the bar stock is supported on the lower shear knife and the head carrying the upper knife reciprocates continuously while an operator pushes the bar in by hand against a stop during the interval between strokes. Sometimes two pins can be cut per stroke by loading bars in parallel. There is usually provision for stopping the head in the raised position between strokes to allow time for the manipulation of heavy bars. Automatic cropping machines are fed from stocks of bars held in magazines, which can be replenished without interrupting production.

Most hot forged bolts are thread cut because steel in the hot rolled state tends to have an uneven and scaly finish, which is unsuitable for extrusion and thread rolling. Slight chamfers are usually cut on the ends of the shanks these serve to remove metal distorted during cropping which might prevent the shank entering the forging die, provide lead ins for thread cutting tools and also help start threads when bolts and nuts are assembled. This pointing operation is similar to that carried out on some cold formed bolts. A variety of purpose built pointing machines are available ranging from magazine fed automatics to simple manually loaded machines. Sometimes old lathes can be modified to do the job.

Before forging, the end of the pin, which is to form the bolt head, is heated. Simple pin heaters consist of open hearths burning solid fuel with ledges round the top edges on which pins rest. The tips of the pins are introduced through holes in the refectory bricks. More sophisticated furnaces using oil, gas or electric induction heating are available which automatically deliver heated pins at a predetermined rate. Induction heating equipment is expensive to purchase but results in less surface scale and allows precise control over temperature. Three unsupported diameters of bar can be hot upset in a single blow if the end of the bar is square to its longitudinal axis. However, because the ends of most cropped pins are not flat and may be deflected sideways it is usual to employ two blows even for heads requiring less than three diameters of material. The two blow hot heading method shown in the left hand column of Figure 5 is similar to two blow cold heading in that a cone and cheese are upset using two punches and a closed die which supports the shank of the blank. On most two blow headers the die is mounted on a saddle so that it can be moved clear of the punches for the insertion of long pins. The operator can push the saddle back and forward but more often this is done automatically. The operator uses tongs to load the heated pins into the die. After heading, the ejector pin pushes the blank out so that its shank can be grasped by tongs for complete removal. Due to the uneven surface of hot rolled bar more clearance is provided between the bores of hot heading dies and work pieces than in cold heading dies. Because of this clearance and because the ejector pin does not have to push the bolt right out of the die, the length of blank that can be hot headed in a closed die is not restricted as in cold forming and this is a major advantage of hot over cold solid die heading. Water is usually used to cool the hot heading tools.

After hot heading a separate machine is used to hot trim or strip the cheese to form a hexagonal head. The layout consists of an oil fired pin heater, a hot heading machine and a hot stripping machine. This layout enables a furnace man and one operator on each machine to head and strip bolts in one heat. The rate of output of such teams of three men is usually governed by the work pace of the heading machine operator. The sequence of operations on the right hand side of Figure 5 can be used to forge bolt heads without trimming waste. This process is called hot upsetting and is carried out on forging machines. Forging machines squeeze rather than hammer the work into the required shape. Because scale and surface defects are set cut away from round the head by stripping operation, this method is usually employed for heading large bolts with wider absolute tolerances than those on small bolts. The length of bar required to form the head is measured by the operator pushing the heated end of the pin against the first outside die. The gripper dies are closed to hold the shank before the heading stroke of the outside die commences. If the finish of the head is unsatisfactory, the bar can be rotated one sixth of a turn and the operation repeated. The head is finish formed at the second station.

Forging machines can be equipped so that the work piece is manipulated mechanically, but on the smaller machines required for most sizes of bolt, the operator usually inserts and removes the work with tongs. Since the shanks of bolts protrude from the forging machine during upsetting the process does not restrict the length of bolt that can be headed.

Screw cutting which is the final operation required to finish hot forged bolts is usually carried out on special purpose machines using rotating tangential cutting dies arranged as shown at the bottom of Figure 5. One advantage of this particular type of thread cutting is that the dies can be resharpened many times. The dies cut the thread in one pass and spring open before the return stroke.

Hot Forging of Nuts

The material stock for hot forged steel nuts is normally hot rolled bar. Figure 6 shows alternative ways of hot forging nut blanks. In the sequence on the left of the figure the rectangular bar is progressively fed into the semi automatic nut press by an operator. Once the bar has cooled below the forging temperature it is returned by the operator to the furnace. Forging is accomplished by first forging vees into the top and bottom faces of the bar to produce two sides of the hexagon of the first nut and two sides of the second nut and then shearing the blank of the first nut off from the parent bar. During shearing the cut off tool pushes the blank horizontally into an enclosed die where the hole is then pierced before the finished blank is ejected. Since forging in a hot nut press takes place to an enclosed die an automatic adjustment is provided to compensate for surface scale and variations in bar section. After hot pressing it is common for the end face of a nut to be lightly machined to remove punch burrs. This operation, called frazing, is most simply carried out using an end milling cutter mounted centrally in a vertical rotating spindle above a nut clamping fixture.

The automatic hot nut forging sequence on the right hand side of Figure 6 has more in common with the cold nut forming process in Figure 4 than with the hot nut pressing method. The bar heated can be either fed from an automatic magazine or manually and the heat source can be a coal, oil or gas fired furnace or an electric induction coil. From the heater bars pass straight into the hot nut forging machine. Due to the ductility of the hot steel only three forming stations are required.

A third method of upsetting a hexagon from round bar in a forging machine is not shown in Figure 6 since it is similar to that used for hot upsetting bolt heads shown on the right hand side of Figure 5. After upsetting a hexagonal nut blank on the end of a round bar, a hole is pierced through the upset hexagon, by pushing the bar back, this leaves the forged nut in the die. The metal pierced out of the nut remains attached to the end of the bar and is incorporated into the next nut. Several nuts can be made from a length of bar in one heat. Although this upsetting process wastes little or no metal, it is relatively slow with the result and it is usually only used for large nuts for which there is a relatively small demand.

Machining of Bolts and Nuts from Hexagon Bar

The bar stock for turned bolts and nuts is usually cold drawn to a hexagonal section and machining is usually on automatic lathes or operator controlled capstan or turret lathes. Both capstan and turret lathes grip one end of the work piece in a chuck or collet leaving the space around the other end of the work piece unrestricted so that a series of tools can be positioned there in an indexible turret. This arrangement is convenient for drilling and boring through the centre of a part and for facing its unsupported end. Turret and capstan lathes can have additional tools mounted on cross slides between the chuck and the turret.

Figure 7 shows sequences of operations for turning bolts and nut blanks from hexagonal bar. The chuck which rotates the bar is opened when it is necessary to feed a new length of bar. The bar stock is fed against a job stop mounted in the first turret station. The second turret station holds a roller steady tool holder for turning the shank of the bolt. Roller steady tool holders are designed so that the cutting thrust, which tends to deflect the work piece away from the tool is balanced by rollers located on the opposite side of the work piece. During the roller supported cutting operation the turret is driven along the bed. The tool in the third turret station is a screw cutting die head, which springs open automatically at the end of the screw cutting run prior to a rapid return stroke. The back of the cross slide carries a parting off tool which is also used for cutting an annular groove prior to the head chamfering operation. A form cutter for chamfering is amounted on the front of the cross slide. This illustration is based on the use of three turret stations, but the turrets could be double kitted by loading an identical set of tools into the remaining stations to halve the turret indexing time per piece.

Nuts are turned using a similar tool set up to that just described for bolts. The place of the roller box tool holder is taken by a drill and a tool to chamfer the lip of the hole as the drill completes its cut.

On manually operated lathes, the operator starts and stops the spindle, changes gear to alter the spindle speeds and tool feed rates between cuts, indexes the turret and feeds the bar stock. It may therefore not be possible to take two cuts simultaneously by, for example, cutting the chamfer on the corners of a nut while the hole is being drilled. But some automatic lathes can take more than one cut at a time, which can result in considerable savings in the time required to manufacture each piece. Another advantage of the automatic lathe is its reduced dependence on operator skills this in turn reduces waste and inspection requirements. Multi spindle automatics are available which can work on several parts simultaneously by passing each part to a succession of tools. The tool motions and feed rates on most automatics are controlled by rotating cams but increasingly electrical sequence controlled single spindle automatics are used which can be set up more quickly than can automatics and require less attention from operators than turret lathes.

The internal threads on standard nuts are usually not cut before the nut is parted from the material stock because of the need to reverse the direction of spindle rotation to remove the thread cutting tap from the blind hole.

The threads on most nuts are cut by specialized bent tap machines. Blanks are gravity fed down a channel from a magazine onto the nose of a continuously rotating tap. The cutting flutes of the tap are positioned in the middle of a stationary hollow hexagonal guide way, which prevents the nuts from rotating as they move along the tap. The shank of the tap beyond the threaded portion is bent so that it can be driven and the nuts are thrown off radially. Another type of nut tapper has a number of vertical spindles carrying straight taps. Nuts are placed by hand in a trough of lubricant under each spindle and foot pedals lower the spinning taps into the nuts. Threaded nuts collect on the taps and are periodically removed by hand.

Casting of Steel for Flat Products

Type of Cast Products

Cast products utilized for flat rolling can be produced in the following forms

1. **Ingots** These are castings of simple shape. Slab ingots range in weight from 9 to 36 metric tons (10 to 40 net tons). In order to roll strip from the ingots, the latter are usually first rolled down to the size of a slab with thickness range from 150 to 350 mm (6 to 14 in.). Then they are further reduced in thickness at the roughing stands of hot strip mill down to 25 65 mm (1.0 2.5 in.) with subsequent reduction to the desired hot rolled thickness at the finishing mill. Final reduction in thickness may be done by rolling at the cold mill.
2. **Thick cast slabs** These castings are usually from 150 to 350 mm (6 to 14 in.) in thickness. Utilization of the thick cast slabs allows one to eliminate reduction at the slabbing mill.
3. **Thin cast slabs** These castings may be from 25 to 64 mm (1 to 2.5 in.) thick. Utilization of the thin slabs allows the elimination of both the slabbing mill and the roughing mill.
4. **Cast strip** The thickness of the cast strip can be as thin as 1.3 mm (0.05 in.). It allows one to eliminate entirely the hot rolling process.

Casting of Ingot

After the steel making operation is completed, the liquid steel is poured into a steel ladle. Additional alloying materials and deoxidizers may be added during the tapping of heat. The steel is then poured or teemed into a series of molds of the designed dimensions.

The ingot molds are tall box like containers made of cast iron with the internal cavity that is usually tapered from the top to the bottom of the mold. There are two principal types of molds

Big end down molds.
Big end up molds.

The inner wells of the molds may be plain sided, cambered, corrugated, or fluted. The last two shapes of the wall promote faster cooling and therefore minimize surface cracking during solidification.

There are two methods of teeming the ingots

Top pouring method,
Bottom pouring method.

The use of the bottom pouring method is found especially beneficial for high quality steels.

Types of Ingots

Molten steel solidifies first at the regions close to the mold walls, so the gases, chiefly oxygen, evolved from still liquid portions may be trapped to produce blowholes.

Depending on the amount of gases released during solidification, the following types of ingots are known

1. **Fully killed ingot** It is fully deoxidized and therefore it evolves no gas, its top is slightly concave, and below the top there is a shrinkage cavity that is commonly called pipe.
2. **Semi killed ingot** This ingot is deoxidized less than fully killed. As a result, a small amount of carbon

monoxide evolves producing a domed top. The blowhole formation in the lower half of the ingot is prevented due to ferrostatic pressure.

3. **Capped ingot** It is produced by pouring steel into big end down bottle top molds in which the constructed top or mouth of the mold facilitates the capping operation. The rimming action is allowed to begin normally but is then terminated at the end by sealing the mold with a cast iron cap. In capped ingot, the gas bubbles in upper half are swept away due to the strong rimming action. An ingot of this type does not have the interiors of its blowholes exposed to oxidation during heating and soaking.

4. **Rimmed ingot** This type of ingots is usually tapped without addition of deoxidizers to the steel in the furnace, and with only small additions to the molten steel in the ladle. The evolution of gas produces a boiling action that is commonly known as rimming action. Ingot No. 7 in Fig. 3 is a typical rimmed ingot in which gas evolution was so strong that the formation of blowholes was confined to only lower part of the ingot.

There are two types of design for the ingots.

Hot topped ingots

Non hot topped ingots.

The big end up; hot topped killed steel ingots are used in order to provide a complete freedom from pipe.

Methods of Continuous Casting of Thick Slabs

A number of methods have been proposed for continuous casting of steel. Below are some of the methods that have been practically implemented.

Vertical or stick casting In this method, a straight mold, a vertical cooling chamber and a flame cut off are used. A tilting receiving mechanism transfers the continuously cast slabs onto horizontal run out table.

Vertical plus bending casting In this method the casting direction is smoothly changed from vertical to horizontal as soon as the cast steel emerges from vertical cooling chamber.

Semi horizontal or curved mold casting This method allows one to simplify design and to substantially reduce dimensions of the continuous casting machines.

Horizontal continuous casting Schematic representation of a typical horizontal casting machine is shown in Fig. 6. Some horizontal casting machines provide continuous movement of strand with oscillation of either both tundish and mold or mold only. However, the most reliable operation was achieved by providing an intermittent strand movement as shown Figs. 6c 6e.

Continuous Casting of Thick Slabs

The most common method for continuous casting of thick slabs is vertical plus bending casting. Below is a brief description of the casting process that utilizes this method.

In order to start the casting process, the dummy bar is inserted in the mold so that its top closes the bottom of the mold. The insertion of the dummy bar is made either from the top of the machine or through entire machine in the bottom of the mold. Liquid steel is then poured at a controlled rate from ladle into the tundish and then the metal flows through nozzles in the bottom of tundish and fills the mold.

There are two methods of pouring the steel from ladle to tundish and from tundish to mold

Open stream casting

Close stream or shrouded casting.

In an open stream casting the liquid metal flows through the air and therefore it picks up oxygen and some nitrogen from the air. It results in formation of undesired inclusion in the liquid steel. Shrouded casting allows to avoid this problem. In this method, steel is protected from contact with the air either by refractory tubes or by gas shrouding as shown in Fig. 9.

After the mold is filled, withdrawal of the dummy bar is initiated. The gradually solidifying metal would follow the dummy bar head. At certain position, the dummy bar head is mechanically disassociated from solidified metal being cast and then the dummy bar is removed.

Liquid steel starts to solidify in the water cooled mold and the solidification of steel continues progressively along its path. The rate of solidification is controlled by secondary cooling water sprays. The distance from the meniscus level in the mold to the point of complete solidification is called metallurgical length. The point of complete solidification is usually ahead of straightener. Electromagnetic stirring of liquid steel during solidification may be implemented in order to improve steel quality and increase casting rate.

The mold is oscillated in a vertical direction in order to prevent sticking of the solidified shell to the mold. Also, lubricants such as oils or fluxes are used to reduce friction. Support rolls are installed to guide the metal and to prevent bulging of the solidifying shell from internal ferrostatic pressure. Cutting of the cast section is done after straightening either by shears or by torches.

Table 1 shows main characteristics of one of the continuous casting machines installed at the Indiana Harbor Works for casting of thick slabs.

Slab Width Control

Desired slab width is usually achieved by using one of the following three methods.

1. **Slab slitting** This method allows one to cast a small number of master slab sizes with the slab product being slit longitudinally in a separate operation using either oxy natural gas torches or rolling machines.
2. **Adjustable mold width** This method allows one to minimize the time required to replace a mold. Various design for changing the mold widths is utilized. In the continuous casting machines of earlier designs, the mold width adjustment can be made while the previously cast slab is being removed from the machine. In the latest designs, the mold taper can be changed during the actual casting operation.
3. **Divided molds** According to this method a divider installed in the mold permits the casting of two narrow slabs simultaneously in a single strand machine.

The Rolling of Rails, Wheels and Rings

Introduction

By definition, the standard rail is a section symmetrical about its vertical axis, which consists of three areas head, web and base. The term tee is used to designate the general class of rail designs which resemble an inverted letter T, and to distinguish those rails, which are generally used in open track construction, from girder and girder guard rails which are usually embedded in pavements. Crane rails differ from standard rails in that they feature shorter, thicker webs, larger heads and thicker bases to withstand heavy, concentrated loads. For railroad applications rails are rolled to sections up to 155 pounds per yard although most rails made today are 140 pounds per yard or less and are of the standard length of 39 feet.

Normally, the rail section is formed from rectangular blooms by a series of 10 passes. Roll passes must be carefully designed and the rolling operation properly supervised in order to meet the stringent dimensional and quality specifications. After rolling, the rails, with their complete identification hot stamped or rolled into them, are hot sawn so that they cool to within 3/8 inch of the desired cold length. They are then cambered (with the head on the convex side) so that they will be essentially straight at ambient temperature.

Many rails are controlled cooled, being cooled normally on hot beds until their temperature falls to within the range 725 to 1000ºF. The rails are then charged into large insulated metal containers for a minimum of 10 hours.

After cooling, rails are subjected to various finishing operations (straightening and drilling for joint bolts), inspected, the rail head chamfered in a grinding operations and the ends of the rail hardened.

Many rails are now heat treated by a full oil quench and temper, which hardens the entire rail section, or subjected to an induction heating operation, which provides a surface hardening of the wearing surface of the head. However, with the use of chromium and molybdenum as alloying elements, rails are being conventionally produced with yield strength of 200,000 psi and with a wear resistance equivalent to that of heat treated rails.

This chapter reviews the early types of rails and their production, examines the evolution of rail mills, describes some modern rail making facilities and discusses rail joints and their manufacture. In addition, the production of railroad wheels and the hot rolling of rings are also reviewed.

Early Types of Rails and Their Production

The earliest type of metal rail used in the eighteenth century consisted of a wooden base with flat strips of cast metal about 4 inches wide, 1¼ inches thick and 5 feet long nailed to wooden stringers, as illustrated in Figure 1 A. The cast metal straps were replaced by rolled iron straps about 1820 but this simple design soon proved to be inadequate. As a consequence, many improvements were soon developed, one of which is shown in Figure 1 B. This particular type of rail was rolled for the Amboy Division of the Pennsylvania Railroad as late as 1831.

John Birkenshaw of the Bedligton Iron Works in England produced in 1820 rails consisting of a head and a web but no base. Rails such as these, laid on the ties in cast chairs, were used on the Stocketon Darlington Railway in 1825. They were produced with rolls contoured as illustrated in Figure 1 D. A more advanced design, shown in Figure 1 E, was used on the Boston and Lowell Railroad in 1830 as well as in England. Although the preference in England was for the bullhead rail shown in Figure 1 F, in the U.S.A., the tee rail soon became popular. R. L. Stevens of the Camden and Amboy Railroad designed the first tee rail in 1830, which was rolled in Great Britain in 1831.

Another popular type of rail was the U rail shown in Figure 1 H, rolled by the Mount Savage Rolling Mill Company of Allegheny County, Maryland, in 1844 and said to be the first shaped rail produced in the U.S.A. Roll passes used for a similar type of rail made in England about 1855 are shown in Figure 2.

Of the many different rails produced during the last two hundred years, one interesting type was the hollow iron or closed U rail rolled at the Camkbria Iron Works. However, the demand for more metal in the head of the rail for better wear resistance forced a final return in the period 1858 to 1868 to the tee shape with wide thin flanges.

With respect to the early rolling of rails, it is probable that existing mills designed to roll bars were utilized with such alterations as were necessary. Credit for rolling the first steel rail in 1857 is given to the Dowlais Plant in Wales while credit for the first steel rail in the U.S.A. goes to Captain Wards North Chicago Rolling Mills, where the first 50 pound Bessemer steel rails were rolled experimentally in 1865 from blooms made of hammered ingots at Wyandotte, Michigan.

Rail production was initiated on two high mills with the bar pulled back over the top roll. To eliminate idle passes, various mills of unique design were tried. These included mills with oscillatory rolls, which provided rails of limited length, and the Double Duo mill featuring two pairs of work rolls in the same mill stand, such as was used at the Dowlais Plant. Another mill, credited to Cabrols Colamineur, was developed about 1850. It consisted of two trains of rolls set almost side by side with each set rolling in opposite directions. After a bar had emerged from one pair of rolls, it was transferred laterally by a hand buggy for entry into the other pair.

In 1866, a two high mill utilizing, for the first time, a reversing steam engine was developed by the Ransbottom Crewe Works of the London and Northwestern Railway. About the same period, nonreversing engines were used with gearing and clutches being employed to reverse the mills.

The Evolution for the Rail Mill

The successful development of the three high mill in 1857 by John Fritz of the Cambria Iron Company of Johnstown, Pennsylvania, led to its general use in rail mills. In fact, by 1866, many of the two high mills used for rolling rails had been converted to three high units, commonly called Fritz mills.

The three high mill produced rails from blooms or piles of bars in 7 passes with the stand using hanging guides on the top roll. Such guides were necessary for the back pass and their construction is illustrated in the top drawing of Figure 3. However, in 1857, an English 3 high rail mill was designed to roll rails in 5 passes and used resting guides throughout, as shown in the bottom drawing of Figure 3. To avoid the use of hanging guides and alternate live and dead holes in the mill, it was necessary to turn the bar over between passes.

Because of the considerable demand for rails, a large number of mills were built in the U.S.A. primarily for rolling such products. Sixty nine mills were reported to have been rolling rails of various weights in 1874, one being as far west as Laramie, Wyoming. Of these mills, one rolled Bessemer rails exclusively, seven rolled iron and Bessemer, two rolled steel headed rails only, two rolled steel headed and iron rails and one produced cast steel and also rolled iron rails. Of the sixty nine mills, thirty five made heavy (65 to 140 IL/yd) and thirty four made light rails (60 1b/yd and lighter).

The layout of a rail mill built in 1881 at South Chicago is illustrated in Figure 4. Considered an excellent mill for its time, it consisted of a 40 inch three high blooming mill rolling 14½ inch square ingots and a 26 inch two high reversing finishing mill with a table equipped with beveled collars on the table rollers for turning the bars when needed. The ingots were heated in four flat hearth furnaces, each holding 12 ingots. The ingots were charged and discharged from the furnaces by a hydraulic machine but were delivered to the blooming train by a hand operated buggy. The bloomer had 15 passes (eleven box and four roughing passes).

After blooming and roughing, the workpiece was conveyed on driven spools to the finishing rolls 120 feet ahead of the end of the lifting table. Sixty feet ahead of the finishing mill was a shear where the workpiece was cropped after one pass in the finishing mill. After cropping, the piece was returned to the finishing mill where the rolling was completed using a total of two roughing and five finishing passes.

The finished rail was then conveyed to a single hot saw equipped with movable gages. After sawing, the rail passed through a cambering machine and then to the cooling beds, with the straightening of the rails being accomplished by gag presses.

In 1902, the mill was completely rebuilt on a more elaborate basis as shown in Figure 5. In 1927, the three high blooming mill was replaced with a two high reversing mill. The finishing mill, as it was reconstructed, consisted for four three high stands. The roughing and finishing stands were driven by one engine and the second roughing and dummy were driven by another. The blooming mill produced a bloom approximately 8 inches square and the finishing mill converted the bloom to a rail in 9 passes direct from the ingot (three in the roughing, one in the second roughing, one in the dummy stand and four in the finishing stand). Using the three high blooming mill and this pass arrangement, a record tonnage of 1730 gross tons of 90 1b rails was rolled in a 12 hour turn with approximately one hour delay.

Prior to 1865, the stock used for rolling the larger rails in the U.S.A. consisted of wrought iron piles or hammered or rolled blooms of puddled iron. In rolling tee rails from piles, considerable difficulty was experienced in the flange passes because of unsatisfactory welding between the layers of the piles. As mentioned in the preceding section, a few small Bessemer steel ingots were experimentally rolled into light rails at the works of the North Chicago Rolling Mill Company in 1865. Two years later, the first Bessemer steel rails made to order for a railroad were produced on the 21 inch three high mill of the Cambria Iron Company of Johnstown, Pennsylvania. Although iron rails were not completely superseded until much later, steel rails were in great demand and several new mills were built to roll them. Yet, as the demand for rails subsequently slackened, many of the rail mills went out of existence or were converted to roll other products.

Modern Rail Mills

By the mid 1900s, only eleven mills on the North American continent were rolling large tee rails and, of these, only eight were classified strictly as rail mills. Some of these had been built much earlier and had been modified in the intervening years. Only three mills in the U.S.A. rolled rails directly from the ingot without any reheating operation.

In the 1950s the largest rail mill in the U.S.A. was that of the U.S. Steel Corporation in Gary, Indiana, the layout and roll pass design for which are shown in Figure 6. This mill began operation in February, 1909 and rolled more than 880,000 tons of rails and other products during 1951. This mill includes for 40 inch two high stands in tandem (one 2000 hp, 214 rpm, 6600 v a c motor driving stands 1 and 2 through gear drives and a comparable motor driving stands 3 and 4) in which 24 inch square fluted ingots of lengths ranging from 74½ inches to 89 inches are given one pass per stand and are turned after each pass. The first four blooming passes are of the diamond, diamond square and box pass design. The bloom then enters a three high 40 inch blooming mill stand with five box passes, the final pass being slightly tapered. Following this stand is the 10 inch by 10 inch electrically driven bloom shear and the cross country arrangement of seven stands in two groups of three stands and one separate stand. These seven 28 inch stands are as follows a three high rougher (with three passes) equipped with vertical lifting tables, a two high former stand, a dummy stand, a first edger stand, a second edger stand, a leader stand (containing a head wheel when rolling rails) and a finishing stand (using a base wheel for rail rolling). The rougher, second edger and leader stands are in a train powered by a 6000 hp, 83.3 rpm, 6600 v a c motor through pinion gears. The former stand is a 28 inch single, two high unit powered by one 2000 hp, 58 rpm motor. The dummy, first edger and finisher stands constitute the finishing train which is driven by a 6000 hp, 88 rpm, 6600 v a c motor. Transfer beds are located after the dummy stand for conveyance of the workpieces to the second mill line and after the second edger stand for their transfer to the third mill line.

Data pertaining to the various passes used in rolling rail section 11525 are presented in Table 1 and sketches illustrating the passes of the leader and finisher stands are shown in Figure 7.

At the end of 1969, only five mills in the U.S.A. were producing railroad rails. These mills were far from standardized in layout. Some had a large number of stands others only a few. Some used two high stands throughout while others used three high units.

Rails are formed by two general methods know as the tongue and groove (or flat or slab and edging) and the diagonal (or angular) methods. Some rail mills combine these two methods. The tongue and groove method is illustrated by a roughing stand shown in Figure 8 and it is to be noted that the axis of symmetry of the rail coincides with the pitch line and is parallel to the train line of the rolls. The diagonal or angular method of rolling is exemplified by the roughing stand shown in Figure 9. It differs from the slabbing method in that the shaping of the rail is begun in the first pass in the roughers and, instead of first compressing the bloom to a smaller size and then forming the section partly through compression and partly by spreading, the process is one of compression from beginning to end.

One of the more recently installed large section mills that is used for the rolling of heavy rails has been described by Gino and Gocho. A layout of this mill is shown in Figure 10. The facility uses 13 ton ingots (that have been bloomed, hot scarfed, sheared, cooled, spot scarfed and reheated) to roll rails as long as 50 meters. The pass sequence utilized for the rolling of rails is shown in Figure 11 and it is seen that four stands are used, these being a breakdown mill, two roughers and a finisher.

To produce rails of the desired quality, the mill stands feature high moduli (22 ton/mm), mill motors of adequate power and excellent control characteristics, a high pressure descaling system and roll pass lubrication (consumption about 2 litres/ton). Grain rolls are used in the second rougher and finishing stands to minimize spalling, these being specially manufactured to provide a barrel hardness of 50±3 shore, a barrel strength of 7 to 8 kg/mm2 and a wobbler strength of 20 kg/mm2.

Following the rolling operation, ordinary rails are identified on the web by the use of a marking wheel (carrying type on its periphery), end finished and shipped. Rails to be head hardened are transferred by crane on to the quenching furnace approach table without pretreatment, such as prebending. Charging into the furnace is continuous at 360 mm/min, with the aid of pinch rolls. The 2390 mm long quenching furnace has a temperature of 1150ºC which heats the rails to about 820ºC. The rails are then water quenched and tempered in a 3460º mm long furnace held at 820ºC which reheats the rails to about 570ºC.

The sizes of the sections rolled on the above mill and the corresponding production rates are presented in Table 2.

Another Japanese rail mill, built at the Yawata Works of Nippon Steel Corporation was commissioned in 1970. It utilizes reversing break down and universal mill stands.

The U.S.S.R. claims to be the world leader in rail production rolling some 3.2 million tonnes in 1975. Open train structural mills built in post World War II years roll heavy rails (up to 75 kg/m) from 6 tonne blooms at speeds up to 2.5 m/sec.

The latest rail mill planned for the U.S.A. is that to be built by U.S. Steel Corporation at Chicago. This facility will be fed by a continuous caster.

Mill automation for the rolling of flat products

Automation of flying shear operation in a continuous hot rolling mill

Upon leaving the last stand, the strip speed is usually 2 to 5 per cent higher than the peripheral speed of the rolls due to forward slip which is a function of many variable values (temperature, coefficient of friction, strip thickness, etc.) that change during the rolling of even a single strip.

To obtain higher accuracy in cutting the strip into measured lengths, the speed of the flying shear must coincide with the actual travelling speed of the strip on the table and not with the peripheral speed of the rolls. For this purpose, a special measuring roller is held against the strip from which it is rotated without slipping. A tachogenerator TGR is mounted on the roller shaft (Fig. 1.). Before rolling begins, the speed of the shear drums conforms to the stand roll speed by mean of tachogenerator TGS whose voltage is compared to the voltage of the shear generator G. As the strip runs out of the rolls, the excitation of this generator is switched over to the tachogenerator TGR of the measuring roller. After this, the speed of the shear will exactly coincide with that of strip travel (by comparison of the voltages of TGR and TGS which excite the rotary amplifier RA in the circuit of the exciter GE of generator G).

Still higher accuracy may be achieved with an electronic counting circuit (Fig. 2). Here, the speed of the driven measuring rollers MR corresponds to that of the driven feed rolls FR. A photoelectric relay PR is mounted before the feed rolls at a definite distance from the shear. This relay switches on shear SH upon the approach of a strip. The strip speed and the distance from the photoelectric relay to the shear determine the length of strip cut. The speed of the measuring rollers equals the strip speed the pulse generator PG on the roller shaft (a wheel with teeth and a coil) transmit pulses to the electronic counting circuit ECC. Rotation of the roller pulse generator through one division (one tooth) corresponds to a strip travel 50 mm. Provision is made for obtaining 200 pulses when strip is cut into the maximum lengths of 10 m. The pulses are counted by the counting circuit after a definite number of pulses, the counting circuit sends a command to operate the shear. This number of pulses after which a cut is made is set up beforehand by the operator.

Automation of coiler operation for hot strip

When the strip leaves the last stand of a continuous strip mill it is traveling at a speed from 6 to 10 m per sec along table I driven pinch rolls 2 and guide rolls 3 direct the strip to coiler drum 4. The strip is held against the drum by wrapping rollers 5. After 3 or 4 turns of the strip on the drum, the wrapping rollers are withdrawn. The tightness of the first turns is due to the fact that the peripheral speed of the drum is slightly higher than that of the pinch rolls. Speeds are made to correspond in the following manner.

The reference winding RW is connected to the armature of tachogenerator TG on the last stand of the mill while the voltage winding VW is connected to the armature of generator GPR which supplies the pinch roll drive motor MPR. The characteristics of the drive windings are adjusted so that upon idle rotation of the coiler drum its speed exceeds that of the pinch rolls. Therefore, the strip is tensioned when it begins to wind on the coiler to obtain several tight turns of the strip on the drum. This loads the pinch roll motor MPR. Strip tension is regulated by the current winding CW and also in the circuit of the coiling drums motor MCD.

Automation of strip measuring gauges for hot rolling

Measuring the strip width. It is desirable that the slab width correspond to the given strip width at a definite thickness. This reduces the amount of scrap trimmed from the side edges of the strip. If the strip obtained from the slab is wider than required for subsequent trimming to the finished sheet, it will be necessary to roll a narrower slab in the broadside stand.

A photoelectric width gauge is mounted beyond the finishing stand of the mill, above the roll table, to continuously check the strip width.

The edges of the hot strip are projected through optical lenses to the photoelectric heads PH. Upon changes in strip width, the intensity of the light illuminating the photoelectric heads is changed correspondingly. As a result, the indicating or registering instrument on the control desk will show the variation (in mm) of strip width.

Measuring strip thickness. One system of continuous measurement of the thickness of moving hot rolled strip is based on the principle of X ray absorption by the strip.

The X ray tube XT emits two perpendicular beams, one upwards through wedge WI on the strip and the other, to the right on the master wedge W2. The tube is supplied with alternating current and, therefore, its beams pulsate, Head H2 is arranged behind wedge W2 and has a fluorescent screen. The head contains a gas discharge tube which also pulsates and serves as a standard. If the brightness of the fluorescent screen upon pulsation of the right hand beam from the X ray tube is equal to the standard brightness of the gas discharge tube, then the luminous flux incident to a photoelectric element in head H2 does not have variable component and the potential at amplifier EA2 equals zero. If there is a difference in luminescence, then the voltage of amplifier EA2 acts upon the sensitive electronic regulating device RD which reduces the voltage on the high voltage transformer TIIV as much as required to equalize the brightness of the screen and of the tube. Since the tube serves as a standard, the regulating device RD maintains constant emission capacity of the X ray tube XT. Head HI is similar to H2 if the strip thickness equals the thickness of wedge W1, the potential at the electronic amplifier EA1 equals zero. If potential appears at EAI, the reversible motor RM is switched on. This motor will advance wedge W1 and thus equalize the brightness of the luminescence on the screen and tube in head HI. The total thickness of the strip and wedge WI will be equal to this thickness of wedge W2.

Thus, the strip thickness equals the difference in thicknesses of W2 and W1. The position of wedge W1 is transmitted by synchro transmitter ST to synchrorepeater, SR which has a scale graduated into units indicating the deviation of the strip thickness from the specified value. The same type of transmission is provided in the actuating mechanism of wedge W2 on the scale STI, the operator sets the graduation beforehand corresponding to the nominal thickness of the strip. If the hand on the other scale OI points to zero then the strip thickness equals the specified value.

Deviation of hand OI from its zero position corresponds to deviation of strip thickness from the present value. A recording device can be connected to the synchrorepeater. SR for registering deviations in strip thickness during the rolling process. The readings of the instruments are stabilized by supplying the whole installation from a constant voltage regulator CVR. The X ray tube is mounted above the roll table in a rigid water cooled hood.

Automation of continuous pickle line operation

Strip is pickled in a continuous line at a speed of 2 3 m per sec. To provide continuous operation, the tail end of each strip is welded to the leading end to the next strip. This operation is done in a welder where the ends of the strip are set by hand under the clamps of the machine to obtain an even weld. The strips are welded without stopping the movement of the strip through the baths. Looping pits are provided in the line to maintain continuous strip travel. Several loops of the strip with a total length of 50 to 200 m are made available beforehand in the pit. During welding of the strips the line is supplied from the slack in the pit. After making the weld, the entry speed of the strip into the looping pit increases and the required slack is restored.

In new mills, the size of the loops in looping pits 2 is checked automatically by means of photocells and light sources. When the number of loops of strip is reduced in the pit, the photocells are excited one after another by the lamps. Pulses transmitted by the photocells reduce the strip speed through pickling tanks I and increase the strip uncoiling speed.

The strip speed through the tanks is controlled by a dancer roll the lever of this roll is linked to the slide of a rheostat which varies the exciting current of motor M1 powering the pinch rolls PR.

Automation of strip thickness gauges for cold reduction

The strip thickness is measured in cold reduction in a continuous (or reversing) mill with the same type of X ray gauge used for hot rolling (this gauge was first applied to cold reduction and only later-to hot rolling). Essential disadvantages of X ray gauges are their high cost and the necessity for having a complete outfit to generate the rays.

Radiation thickness measuring gauges that have come into use in the last years, since they are more economical, employ gamma rays (for thick strip) or beta rays (for thin strip), i.e., they employ radioactive isotopes that emit these rays.

Beta ray gauges are substantially cheaper than X ray types while their accuracy is sufficient for this purpose (1 percent for strip up to 0.5 mm thick).

The principle of the radiation gauges is similar to that of the X ray gauge. An artificial radioactive emitter E of beta rays is located under the strip S. Part of the rays passing through the strip enter the ionizing chamber IC, arranged above the strip and produce an ionizing current. This current is very small, however, and cannot be directly measured by the instrument. Therefore, a high ohmic measuring resistance MR is connected into the current circuit. The voltage drop over this resistance is proportional to the chamber current and, therefore, to the strip thickness. This voltage drop is not directly measured but is compared to a preset value, i.e., the determined value is the difference in voltages appearing when the strip thickness deviates from that specified. The recording instrument RI is connected in parallel with the indicating device ID, as well as the signaling device SD. The latter is operated when the strip thickness variation exceeds the permissible value and it signals the operator. If the isotope thallium 204 is employed, steel strip up to 0.15 mm thick can be measured while strontium 90 is suitable for strip up to 0.9 mm thick. The half - life of this second isotope is such that it can be used for up to 40 years and, therefore, does not practically require replacement.

In passing through the strip, the beam of beta rays is weakened not only by the metal but by oil and water as well. Therefore, in rolling it is necessary to see that the strip surfaces are clean at the place of measurement (by wiping, etc.).

General Steelmaking Processes

Welding Material for Super Low Temperature Steels

U.S. Patent 3,966,424 June 29, 1976 assigned to Kobe Steel Ltd., Japan describe a nickel base alloy welding material which can give excellent strength and impact value characteristics to the weld zone in welding of super low temperature steels. These and other objects as will hereinafter become more readily apparent, have been attained by this welding material comprising not more than 0.2% carbon, 5 to 12% manganese, not more than 30% chromium, 4 to 8% niobium, not more than 22% iron and not more than 1.5% silicon, the balance being substantially nickel. The welding material is formed by integrally combining a metal forming material having the above composition with a flux of the lime or lime titania type.

The welding material can be used with any known welding method, such as manual welding, TIG welding or submerged arc welding. The term Welding material formed by integrally combining a metal forming material with a flux includes a coated electrode for arc welding, composed of a core wire covered with a flux. A composite wire composed of a metal casing packed with alloy powder optionally together with a flux or the like.

The flux comprises, on the weight basis, 10 to 50% calcium carbonate, 16 to 50% fluorspar, 2 to 20% magnesia clinker and up to 10% rutile. An especially preferable flux is one containing magnesia clinker and having a ratio of fluorspar to calcium carbonate of 1 to 1.5. Not more than 60% of ingredients of such flux may be substituted by a deoxidizing agent, an alloy constituting element or the like.

The process of preparing a welding material is described briefly by reference to a welding rod. The components of the lime or lime titania coating material and the above alloy components are blended together with water glass (an aqueous solution of a mixture of sodium silicate and potassium silicate)-10 to 2% based on the total weight of the welding rod. The assembly is dried at 200º to 250ºC. Thus, the process is not different from the conventional process of preparing welding rods.

Example Welding Material composition (1)-The chemical composition of the core wire (%) is
C, 0.05 Mn, 10.2 Si, 0.42 P, 0.005 S, 0.006 Cr, 18.5 Nb, 6.0 Fe, 11.5 and Ni, the balance.

The blending ratios of the ingredients of the coating material are calcium carbonate, 40% fluorspar, 53% rutile, 5% and ferrosilicon, 2% (silicon content equals 50%). The binder is an aqueous solution of the mixture of sodium silicate and potassium silicate of SG 1.40. The covering ratio of the coating material is 25% based on the total weight of the welding rod.

Welding Material Composition (2)-The chemical composition of the core wire (%) is
C, 0.06 Mn, 1.2 Si, 0.55 P, 0.4 S, 0.006 Cr, 14.0 Nb, 1.5 Fe, 7.3 and Ni, the balance.

The blending ratios of the ingredients of the coating material are calcium carbonate, 28% fluorspar, 31% rutile, 2% magnesia clinker, 4% metallic mangahjese, 15% and ferroniobium, 20% (niobium content equals 70%). The binder is an aqueous solution of the mixture of sodium silicate and potassium silicate of SG 1.40. The covering ratio of the coating material is 40% based on the total weight of the welding rod.

Welding Material Composition (3)-The filler rod composition (%) is
C, 0,10 Mn, 7.0 Si, 0.7 P, 0.05 S, 0.04 Cr, 14.0 Nb, 6.0 Fe, 10 and Ni, the balance.

The above three welding materials [welding materials of the compositions (1) and (2) are for arc welding using a coated electrode, and the welding material of the filler rod composition (3) is for MIG welding], and a commercially available nickel base alloy welding rod were subjected to tensile test, impact test and chemical analysis with respect to the as welded deposited metal. Further the tensile test and impact test were conducted on the weld metal in the weld zone of 9% nickel steel.

The welding was conducted and tensile test specimens and impact test specimens were taken. The tensile test was conducted at room temperature and the impact test at -196ºC. As is apparent from the test results on welding rods shown in the following table, the deposited metal exhibited a tensile strength and ductility comparable to those of 9% nickel steel base, together with a sufficient low temperature toughness.

9% Ni steel was subjected to groove welding, and mechanical properties of the weld metal diluted with the base metal were examined. Two sheets of 20 mm (thickness) × 250 mm (length) × 200 mm (width) were welded in a butt joint to form a test specimen. The groove conditions were as follows a groove angle of 60º, a root face of 0.5 mm, and a root gap of 1 mm. The surface side was metal welded, and then the back chipping was effected, followed by one layer welding on the back.

Tensile test specimens were taken in a direction parallel to the welding direction. Impact test specimens were taken. The tensile test was conducted at room temperature and the impact test was effected at -196ºC. As is apparent from the test results shown in the table below, in welding rods the weld metal exhibited a tensile strength comparable to that of the base metal and a sufficient low temperature toughness.

Refining Steel by Blowing Oxygen Beneath the Surface

U.S. Patent 3.960,547 June 1, 1976 assigned to Youngstown Sheet and Tube Company describe a process for melting iron bearing material adding the melt to another molten composition to modify the carbon content of the composition and further refining the resultant mix with oxygen.

The method includes oxy fuel melting a charge of solid material, bearing iron, which melting produces a relatively low carbon containing composition. The low carbon composition is added to another molten composition of relatively higher carbon content, such as that produced by conventional blast furnace practice, to provide a molten mix. Unmolten iron bearing material is added to the molten mix in a refining vessel having means for introducing essentially pure oxygen beneath the surface of the melt of the refining vessel.

Suitably, the high carbon melt may be blast furnace iron at 2400º to 2500ºF comprising, by weight 0.5 to 2.0% silicon, at least 2% carbon, 0.40 to 1.5% manganese, and the balance being essentially iron. Preferably, the high carbon molten composition comprises 1% silicon, 4% carbon, 0.5 to 1.0% manganese, and the balance essentially iron. Also preferably, a composite molten mix is provided which is comprised of 40 to 75% low carbon composition and 60 to 25% of the high carbon composition. The mix will usually result in a composition being at a temperature of 2600ºF and comprising 0.5 to 0.6% silicon, 1.8 to 2.0% carbon, 0.3 to 0.4% manganese, and the balance essentially iron.

In a typical and preferred process, sufficient molten mix metal is provided to the vessel, where refining is to take place without the addition of more heat, to constitute 85 to 95% of the total anticipated work charge. The remaining 5 to 15% of the charge may be advantageously comprised of cold unmolten scarp, and/or iron ore pellets, and/or other iron bearing materials in solid form. After the charge is completed, refining is conducted by introducing substantially pure oxygen beneath the surface and blowing through the molten charge. Of course, if additional heat is provided, such as by burners in the refining vessel, then the amount of unmolten scrap may be increased.

It will be noted that the total hot metal (relatively high carbon content composition) input to the refining vessel is 22 to 54%, i.e., 25 to 60% total charge to mixing vessel × 90% total charge to refining vessel. In contrast, conventional open hearth and BOF practices utilize 55 to 60% and 70% hot metal, respectively. It is also anticipated that higher yields of usable steel are attainable through the use of the refining medium below the surface of the molten bath, as opposed to blowing unto the surface. One of the contributing factors is better utilization of the refining medium attained by virtue of the more intimate contact with the bath. Another factor is that there is less iron oxide emission loss than that encountered with the use of oxygen lances and the resultant fuming.

Cold Reduced Aluminum Stabilized Steel having High Drawability

U.S. Patent 3.959,020 May 25, 1976 assigned to Nippon Kokan KK, Japan described a steel which is suitable for severe cold forming. Al stabilized steel is subjected, after a first cold working step, to decarburizing annealing as an intermediate heat treatment. The steel is then successively passed through a second cold reducing step and then a final softening annealing step. The resulting steel is capable of withstanding any press forming operation.

Al stabilized steel which may be used consists of 0.03 to 0.15% C, 0.02 to 0.07% SolAl, and other elements, e.g., Fe, Mn, P, S, N, present in ordinary quantities as in other Al stabilized steels. When continuous hot rolling is used, the finishing temperature should be more than the Ar3 point, and the coiling should be carried out at less than 600ºC, so that precipitation of AlN does not occur. In this case, thickness of more than 3.2 mm will be desired as the finishing thickness of a hot rolled strip, because the next two stages of cold reducing may be more readily carried out depending upon the thickness.

The first cold reducing is carried out at a reduction rate of more than 30% and successively the steel is subjected to an intermediate decarburizing annealing wherein the C content in the steel is reduced to less than 0.01%, preferably to 0.002%. The reduction rate of the second cold reducing stage is more than 30%, and preferably more than 50%. A final annealing process is carried out to produce a steel having an r value (Lankford value) or 2.2 to 2.3. Such a Lankford value shows that the steel is capable of sustaining any severe press forming.

Sulfide Modification of Steel

U.S. Patent 3,955,967 May 11, 1976 assigned to The Algoma Steel Corporation, Limited, Canada describes sulfide modification of molten steel in the ladle suitably during transportation of the molten steel from the steel making furnace for casting. This treatment is effected by the addition of agents, which usually have a high affinity for oxygen, particularly rare earth metal silicides.

The process comprises enclosing the addition agent in a metal container, and fixedly suspending the container in the ladle to submerge at least that portion of the container containing the addition agent so as to melt the container and release the addition agent beneath the surface of the molten steel in the ladle. The container has walls of selected thickness to provide the required time delay in releasing the addition agent into the molten steel to allow for the desired amount of deoxidation of the steel to have taken place. While rare earth metal silicides are particularly preferred to completely deoxidize molten steel for sulfide modification, other additives particularly boron compounds, calcium metal, and alloys, e.g., calcium alloys and deoxidizers may be used.

The process also provides a device for use in the treatment of molten steel in a ladle during transportation of the molten steel from a steelmaking furnace for casting by the addition of agents which are normally strong deoxidizing agents. The device comprises a yoke adapted to extend across the open top of the ladle and at least one hollow tube closed at one end for containing the addition agent.

The tube is fixedly mounted in the yoke such that when the yoke is in position on the ladle each tube is suspended vertically in the ladle with at least that portion of the tube adjacent the closed end containing the addition agent submerged in molten steel contained in the ladle. Each tube is of preselected wall thickness to provide a selected time delay in releasing the addition agents into the molten steel in the ladle after initial contact of each tube with molten metal to allow for the desired amount of deoxidation to take place.

It is a critical feature that the container containing the additive be fixedly suspended in the ladle with that portion containing the additive disposed beneath the surface of the steel bath. This ensures that the additive is released beneath the surface of the bath and not on the surface of the bath and further that the distribution pattern of the additive in the molten steel can be selected to best advantage.

A heat was produced in a basic oxygen furnace of nominal 100 ton capacity. It was desired to produce plate to meet a minimum yield strength of 65,000 psi and notch toughness of minimum Charpy impact energy (heat average based on 2/3 size transverse specimen at 0ºF) of 30 ft lb. To attain these minimum requirements it is necessary to desulfurize the steel to a level of 0.012% sulfur and to modify the sulfide inclusion morphology by treatment with rare earth elements. Prior to tapping the furnace into the ladle, a yoke was assembled suspending two 10 foot long, 11 inch diameter steel pipes each having a wall thickness of one half inch. Before assembling, each pipe had been filled with 65 lb of rare earth silicide which contained 30% of contained rare earth elements. The space in the pipes above the top level of the rare earth silicide was filled with lime. The wall thickness of the pipes had been so designed that the steel pipes at their lower extremity will melt whereby the rare earth silicides are released well below the level of molten steel in the ladle during the pour from the furnace. Furthermore, the upper regions of the pipes do not melt until a discrete time interval after completion of the tap from the furnace and after the artificial slag cover has been formed.

At the time of tapping the furnace into the ladle, the following ladle additions were made 340 lb aluminum, 3,800 lb ferromanganese, 330 lb ferrocolumbium, and 250 lb lime. In addition, 700 lb of fly ash was added to the ladle at the end of the tap to provide the artificial slag cover. The temperature of the steel after all additions were made was 2855ºF. Prior to teeming the melt into ingot molds, the steel in the ladle was stirred with an argon gas injector for 7 minutes to achieve a uniform distribution of the additions made and to equalize the temperature for teeming at 2840ºF.

From the analysis and properties attained it would be obvious that good sulfide modification was effected and full value obtained from the rare earth silicide addition. In an alternative process, the steel is tipped into the ladle from the steel making furnace together with the deoxidizing agent and the device is subsequently lowered into the ladle so as to submerge the tubes. The melting of the walls of the tubes releases the rare earth metal silicides into the steel beneath the surface of the slag and provides for a distribution of the rare earth metal silicides in the steel. Good distribution of the rare earth metal silicides and other additives having a strong affinity for oxygen is assisted by argon stirring the ladle immediately prior to teeming the steel into the ingot molds.

Steel Sheets having Excellent Enamelability

U.S. Patent 3,950,191 April 13, 1976 assigned to Kawasaki Steel Corporation, Japan describe a method for producing cold rolled steel sheets having an excellent enamelability. The process comprises adding to a molten steel containing not more than 0.020% of carbon, not more than 0.03% of silicon, not more than 0.50% of manganese, not more than 0.01% of aluminum, not more than 0.050% of oxygen, and having a nitrogen content of less than 0.01%, boron with a range of 0.005 to 0.020% in such amounts that B(%) x O(%) is more than 1 × 10-5, hot rolling the resulting steel, cold rolling, and recrystallization annealing under a decarburization atmosphere.

Example The steels having the components as shown in Table 1 were melted and slabbed and then hot rolled into a sheet having a thickness of 2.8 mm at a finishing temperature of 860ºC and a coiling temperature of 550ºC. The hot rolled sheet was pickled and then cold rolled by a tandem roll into a sheet having a thickness of 0.8 mm, after which the resulting sheet was annealed in a bell type annealing furnace at a uniform temperature of 760ºC or subjected to decarburization annealing in an open annealing furnace at a uniform temperature of 700ºC and then to a tempering rolling of 1%. The resulting steel sheets are subjected to the enameling treatment to obtain the results as shown in Table 2.

As the conditions for the enameling treatment, such pretreatment steps that fish scales and the other defects are liable to be caused were selected and the immersion in Ni bath which is practically inevitable was omitted and the frit for the high temperature firing was used.

In Table 2, the adherence PEI (%) was determined by means of Porcelain Enamel Institute adherence tester as follows. The sample was subjected to a compression deformation and the glaze was forcedly exfoliated to measure electrically the exposed area of the base metal and calculate the area applied with the glaze on the deformed portion and the total area of the deformed portion to read as PEI (%) no exfoliation is expressed by 100% and the entirely exfoliated area is expressed by 0%. The method for measuring this index is described in ASTM C 313. From the results of this test, it can be seen that even if the steel is enameled under the conditions which are apt to cause the defects, very stable results can be obtained.

Liquid Sintering with Titanium Alloys

Sintering ferrous materials have found wide application as structural components in machines. The failure to use sintered materials as main structural components stems from the porous character of such components, which are inferior in mechanical properties to casting, or forged materials having the same composition. To promote the use of sintered materials in such components, various efforts have been made to increase the density of the sintered material up to a value close to the theoretical density.

Accordingly, U.S. Patent 3.950,165 April 13, 1976 assigned to Mitsubishi Jukogyo KK, Japan describe a method of sintering ferrous materials which comprises mixing an iron powder with an alloy of iron titanium and forming a liquid phase during the sintering. The alloy is prepared by mixing selected amounts of iron and titanium powders to form an iron titanium alloy powder consisting of 14 to 46% by weight of tatanium and the balance iron, and preferably 14 to 30% by weight of titanium. The sintering step is carried out as a temperature at which the powdered mixture is always in the liquid phase during sintering. Under these conditions oxidation of titanium is suppressed during melting and the alloy is not too soft nor too difficult to pulverize and use for manufacturing machine components such as piston rings, which have surprisingly good properties.

Liquid Solid Alloys for Casting

U.S. Patent 3.948,650 Apr. 6, 1976 assigned to Massachusetts Institute of Technology describe a metal composition characterized by degenerate dendritic or nodular primary discrete solid particles suspended in a secondary phase having a lower melting point than the primary particles and which secondary phase can be solid or liquid. This composition may be prepared by raising the temperature of a metal alloy to a value at which the alloy is largely or completely in the molten state.

The melt then is subjected to vigorous agitation and the temperature is reduced to increase the portion of the mixture in solid degenerate dendrite or nodular form up to 65%, but usually up to 50%, while continuing the agitation. At this juncture the temperature of the liquid solid composition can be stored and later it can be brought again to the liquid solid mixture state and then recast.

The compositions can be formed form any metal alloy system or pure metal regardless of its chemical composition. Even though pure metals and eutectics melt at a single temperature, they can be employed to form the composition since they can exist in liquid solid equilibrium at the melting point by controlling the net heat input or output to the melt so that, at the melting point, the pure metal of eutectic contains sufficient heat to fuse only a portion of the metal or eutectic liquid. This occurs since complete removal of heat of fusion in a slurry employed in the casting process cannot be obtained instantaneously due to the size of the casting normally used and the desired composition is obtained by equating the thermal energy supplied, for example by vigorous agitation and that removed by a cooler surrounding environment.

Varnishing and Printing of Packaging Steels

Introduction

The success of metal packaging in tinplate or chromium plated steel is due to a large extent to the varnishing and decorative printing operations which complete the corrosion protection already provided by the electrolytic coatings. For this reason, varnishing is always used on chromium plated sheet and is also employed in the majority of tinplate applications. In the sheet by sheet varnishing process, most frequently used for packaging materials, one coat of varnish or ink is applied at a time, followed by baking in a convectively heated horizontal oven. It is a discontinuous operation, in which the sheets are unstacked at the start of the line and restacked at the end, as many times as there are coats of varnish on one or other of the two faces. Continuous coil varnishing processes also exist, capable of high speed coating of either one or both faces.

General Aspects of Organic Coatings Used for Varnishing and Printing

The organic coatings (varnishes, pigmented coatings or inks) are used for the internal protection and external decoration of the packaging whenever justified by the technical or commercial requirements of the intended application. In fact, these coatings serve three purposes

They protect the metal against chemical corrosion by the contents of the packaging and against various external aggressions, such as atmospheric corrosion, scratching, shock, forming, etc.

They decorate the outside of the packaging

They facilitate forming, for example by acting as a lubricant during drawing.

Definition

Varnishes are liquid preparations which, when applied as a thin film on a substrate, are transformed by evaporation of their volatile constituents and reaction of their binder resins to a solid sheet or film which adheres to the metal surface.

Types of Organic Coating

Varnishes are clear transparent substances, which may sometimes be colored. Apart from a few special cases, such as colored finishing varnishes (blue, green, etc.), the color of varnishes is due solely to their base resin. For example, the golden tint of epoxy phenolic varnishes is due to the color of the phenolic resin. When varnishes are colored by white titanium oxide, they are called white pigmented lacquers. This is the case most frequently encountered in food packaging, but other colors, such as yellow, black, etc., are often used for decorative purposes on the outside. The organic coatings are classified according to their applications

Printing inks are used only for printing the outside of the packages.

Primer coats are applied directly to the metal (usually tinplate) and serve as a bond layer for the inks, films or varnish topcoats. They are used in small quantities (3 6 g/m2).

Finish coats or topcoats are applied in similar thicknesses (4 6 g/m2).

Internal varnishes are specifically designed to resist mechanical forming (drawing) and chemical attack. The thickness applied (5 8 g/m2) depends on the degree of protection required.

White, or more rarely, colored coatings are generally applied to the outside, but are occasionally used on the inside. Their thicknesses vary from 15 to 20 g/m2 on average, depending on the degree of protection desired on the inside or the opacity required on the outside.

Organic Coating Constituents

The formulation of varnishes includes resins, pigments, solvents and additives, such as surfactants, lubricants, catalysts and filler materials.

The resins or binders

The binders are composed of a non crystalline solid (natural or synthetic resin), which, after drying and hardening, forms the essential component of the film. The resins belong to a limited number of chemical families (the phenolic, epoxy, vinyl, polyester, acrylic and amino resins), but can be modified to a greater or lesser extent with other resins, depending on the properties required. These different families and their principal characteristic properties are described in Table 1.

The pigments

The pigments are present in the form of very fine crushed solid particles, of the order of a micron in size, dispersed in part of the binder, in which they are insoluble. They are usually inorganic substances, such as titanium and iron oxides or aluminum. The printing inks use other pigments, which may be either inorganic or organic, in order to cover a much wider range of colors.

The solvents

The solvents are volatile liquids, which transform the binder to a solution sufficiently fluid to facilitate application. Since the resin must be soluble, the solvents employed vary with the type of binder, the most common ones being alcohols, esters, ketones, aliphatic and aromatic hydrocarbons and water. In fact, mixtures of two or more solvents are often employed, since more than one resin must generally be dissolved. After application, the solvents are allowed to evaporate from the varnish layer, leading to uniform spreading and better wetting of the metal, and avoiding the formation of a porous coating. The solvents also serve to adjust the viscosity of the varnishes or lacquers, in order to compensate for evaporation during recycling of the unused product.

The additives

Although the additives represent minor constituents of varnishes and films, they are by no means of secondary importance. In particular, the surfactants lower the surface tension of the paint, enhancing wetting and facilitating spreading.

The lubricants

The lubricants are added to facilitate handling and forming of the varnished sheets, particularly drawing operations.

The catalysts

The catalysts enhance chemical reactions between the different constituents of the varnish and accelerate cross linking. They are usually acids, amines or metal salts.

Application and curing of organic Coatings

Application with Roller Varnishing Machines

The liquid mixture mentioned above, consisting of macro molecules and solvents, is generally applied on a flat surface. This can be done on separate sheets or coiled strip with the aid of a roller varnishing machine. The latter has a number of rollers, which transfer an appropriate quantity of varnish from a tray and apply it in a uniform controlled thickness onto the surface of the metal as it passes through the machine. The varnish is pumped from a container E into the tray in which the feed roller A rotates, taking up a small amount of varnish, which is distributed over the transfer roller B. The varnish is then passed from the transfer roller to the application roller C which coats the surface of the metal sheet. The pressures between the different rollers and their relative velocities can be adjusted to deposit a precise quantity of varnish on the metal. The application roller is made of steel and is coated either with hardened gelatine or polyurethane elastomer. The varnish can either be applied to the whole surface or uncoated edges can be left, as is necessary, for example for welded cans. The application roller then has an appropriate profile so as to leave part of the sheet unvarnished.

In coil coating operations, both faces can be coated simultaneously, by means of a second application roller, which replaces the counter roller D, additional rollers being added to drive the strip. In sheet by sheet varnishing, the tangential speed of the application roll is generally equal to the sheet displacement velocity, whereas in coil coating, the application rollers can move in the opposite direction to the strip, leading to improved coating quality.

Curing

After application, the organic coatings are baked to obtain a dry film. The solvents are evaporated and the constituents react to produce cross linking of the polymer chains, forming a solid film firmly attached to the metal. Baking or curing is generally performed in a conveyor chain tunnel oven. Conveyor ovens consist of a series of individual metal frames or wickets mounted on a chain which is drawn slowly through the heating chamber. The chain speed being synchronized with the varnishing machine, so that each wickets receives a sheet after passing through the machine. The furnaces are generally gas fired, with either direct or indirect heating. The baking cycle (temperature and time) depends on the type of varnish, and specifications are usually given by the manufacturers. Higher temperatures allow the use of shorter baking times, so that various combinations are possible. Certain varnishes can be cured in extremely short times, of the order of a few seconds (flash curing).

Another curing technique is based on induction heating, the heat being generated directly within the metal substrate. Such treatments can be extremely rapid (a few seconds) and are well suited to high varnishing speeds (>100 m/mn), such as those prevailing in coil coating. In such cases, flash curing is essential to maintain reasonable oven lengths.

Other Application Techniques

Varnishes can also be applied with spray guns, for applications such as

Local side stripe lacquering of weld zones to protect the regions left uncoated before the welding operation

For the internal protection of DWI (drawn and wall ironed) beverage cans and certain aerosol containers, where varnishing cannot be performed before forming

For repair varnishing of the inside of DRD (draw and redraw) cans after drawing.

Other application techniques include electrostatic powder deposition, which is used for side stripe lacquering and is being introduced in other areas, due to process improvements. Several heating methods are employed for baking side stripe lacquers, including hot air, induction, direct flame impingement, and infrared radiation. Curing times vary from 2 to 30 seconds.

Inspection Methods

The protective action of the varnish is related to three essential factors, namely adherence to the metal substrate, chemical inertia and the absence of porosity. The film/substrate interface is severely loaded during forming of the varnished tinplate to can components, and the varnish must be able to follow the metal without delamination or flaking. Good adhesion is obtained when surface bonding of the two mating components is complete, but there are sometimes incompatibilities between the two materials. Chemical inertia is generally assured if the varnish has been adequately cured, since complete cross linking eliminates the active groups capable of reacting with ions from the can contents. The presence of porosity can considerably impair the protective quality of the film, and must be carefully controlled. Increasing film thickness decreases the tendency for porosity.

Phase Transformation in Steel

Phase Diagram

A phase diagram is a graphical representation of the temperature, pressure and composition limits of phase fields in an alloy system as they exist under conditions of complete equilibrium. It is also known as equilibrium or constitutional diagram.

In a phase diagram, temperature is plotted vertically and composition is plotted horizontally. Any point on the diagram represents a definite composition of a constituent and its temperature, each value being found by projecting to the proper reference axes. For illustration, let us consider the changes that take place during cooling of an alloy containing 50 percent element A and 50 percent element B. The alloy remains homogeneous liquid solution until temperature drops to a value indicated by the intersection of the liquidus line at c0. The crystals which form from 50 50 liquid consist of a solid solution, the composition of which is found on the solidus line at c1, 80 percent element B and 20 percent element A.

As the mass cools, the composition of the growing crystals changes along the solidus line from c1 to c5, while the remaining liquid alloy varies in composition along the liquidus line from c0 to c4.

Figure 2 illustrates the iron cementite phase diagram, which is also known as iron carbon phase diagram.

Constituents in Steels

Plain carbon steels are generally defined as the alloys of iron and carbon which contain up to 2.0% carbon.

For the present, we will neglect the effects of such elements as manganese which may be present in most ordinary steels and regard steels as being simple iron carbon alloys.

Constituents in steels exist mainly as phases. They include molten alloy, delta ferrite, austenite (gamma phase), ferrite (alpha phase), cementite and graphite. Another constituent in steels is pearlite. It is not a phase but an aggregate.

Austenite

In iron carbon alloys austenite is the solid solution formed when carbon dissolves in face centered cubic (gamma) iron in amounts up to 2%. Its microstructure is usually large grained.

Austenite is a difficult structure to retain at room temperature unless a steel contains a large percentage of alloy, such as manganese or nickel. Austenitic steel is characterized by high tensile strength and unusually great ductility. The tensile strength is often around 125,000 pounds per square inch with elongation in two inches of 35 to 40 percent.

Ferrite

In iron carbon alloys ferrite is a very dilute solid solution of carbon in a body centered cubic (alpha) iron and containing at the most only 0.02% carbon. Its microstructure appears as polyhedral grains.

Ferrite is very ductile and soft and has a low tensile strength but high elongation. Its tensile strength is about 40,000 pounds per square inch and an elongation in 2 inches of about 40%.

Graphite

Graphite, or graphitic carbon, is a free carbon in steel or cast iron. The carbon is amorphous, having no particular form.

The metallographic appearance of graphite in a low carbon steel which has been subjected to a prolonged heating at a temperature below that at which austenite is formed.

Cementite

Cementite, or iron carbide, is an interstitial compound of iron and carbon containing 6.69% carbon. Its approximate chemical formula is $Fe3C$. When it occurs as a phase in steel, the chemical composition will be altered by the presence of manganese and other carbide forming elements.

In case of a slow cooled, relatively high carbon steel, microstructure of cementite appears as a brilliant white network around the pearlite colonies or as some needles interspersed with the peralite. The metallographic appearance of spheroidized cementite in a steel, which has been heated to a temperature just below that at which austenite first forms.

Cementite is a very hard compound. Its tensile strength is about 5,000 pounds per square inch and an elongation in 2 inches is equal to zero. Cementite is an unstable phase. Given sufficient time, cementite decomposes into two complete equilibrium constituents, iron and graphite.

Eutectoid

The term eutectoid is usually defined as

An isothermal reversible reaction in which a solid solution is converted into two or more intimately mixed solids on cooling, the number of solids formed being the same as the number of components in the system.

An alloy having the composition indicated by the eutectoid point on an equilibrium reaction.

An alloy structure of intermixed solid constituents formed by a eutectoid.

Pearlite

Pearlite is a lamellar aggregate of ferrite and cementite. It is a result of the eutectoid reaction which takes place when a plain carbon steel of approximately 0.08% carbon is cooled slowly from the temperature range at which austenite is stable.

Pearlite has lamellar micrographic structure known as the eutectoid structure. It exerts maximum hardening power of any constituent. It has a tensile strength of around 125,000 pounds per square inch and an elongation in 2 inches of 10 percent.

Eutectic

The term eutectic is usually defined as

An isothermal reversible reaction in which a liquid solution is converted into two or more intimately mixed solids on cooling, the number of solids formed being the same as the number of components in the system.

An alloy having the composition indicated by the eutectic point on an equilibrium diagram.

An alloy structure of intermixed solid constituents formed by an eutectic reaction.

Ledeburite

Ledeburite is a eutectic of the iron carbon system, the constituents being an austenite and a cementite. The eutectic contains 4.3% carbon. This eutectic is a constituent of iron carbon alloys containing more than 2.% carbon and for this reason the dividing line between steels and cast iron is set at 2.0% carbon.

Phases in Hypoeutectoid Steel

Hypoeutectoid steels are those containing less than the eutectoid percentage of carbon, which is about 0.80% in plain carbon steel.

At some temperature above Ae3, steel containing 0.40% carbon is completely austenitic. On slow cooling below Ae3 the austenite first rejects ferrite, which concentrates at grain boundaries. As the temperature falls down to Ae1, the crystals of austenite shrink and their carbon content increases to 0.80%. On cooling below Ae1, the austenite changes to pearlite so that the final constituents in steels below Ae1 are ferrite and pearlite as illustrated in Fig. 3.

Phases in Eutectoid Steel

Eutectoid steel is a steel containing the eutectoid percentage of carbon which is about 0.80% in plain carbon steels.

The eutectoid steel will not begin to transform from austenite on cooling until the critical temperature Ae1 3 is reached. Then the transformation will begin and end at the same temperature (723ºC or 1333ºF). The final structure will be entirely pearlite as shown in Fig. 4.

Phases in Hypereutectoid Steel

Hypereutectoid steels are those containing more than the eutectoid percentage of carbon, which is about 0.80% in plain carbon steels.

At some temperature above Aecm, a steel containing 1.2% carbon is completely austenitic. On slow cooling below Aecm the carbon will precipitate as needle shaped crystals of cementite around the austenite grain boundaries. As a result the carbon content in an austenite will be gradually reduced down to 0.80% at the temperature Ae1 3. Below this point the remaining austenite will then transform to pearlite as shown in Fig. 5.

Phase Transformation Hysteresis

The phase transformations do not occur at the same temperature in heating as in cooling. The metal is rather reluctant to change its physical state so that on heating, the Ac temperatures are somewhat higher than equilibrium temperature Ae. Likewise, the Ar temperatures on cooling are lower than equilibrium temperatures Ae. The difference in temperature between the Ac and the Ar varies. In some cases it is as great as 24ºC, or 75ºF.

Supercooling or Austenite

As it has been shown in this chapter that austenite transforms to pearlite when it is cooled slowly below the Ar critical temperature. When more rapidly cooled, however, this transformation is retarded. The faster the cooling rate, the lower the temperature at which transformation occurs resulting in a formation of the micro constituents shown in Table 1.

Martensite

Martensite is a metastable phase of steel formed by a transformation of austenite below Ms temperature. It is an interstitial supersaturated solid solution of carbon in iron having a body centered tetragonal lattice. Transformation to martensite occurs almost instantly during cooling and the percentage of transformation is dependent only on the temperature to which it is cooled. It is the hardest of the transformation products of austenite. The microstructure of martensite is acicular, or needlelike.

This structure is formed when martensite is reheated to a subcritical temperature after quenching.

Optimization and Modernization of Hot Strip Mills

Main Strategy in Optimization of Rolling Process

In the process of rolling a uniformly preheated slab in hot strip mill, its temperature changes due to the various types of the heat transfer have been described earlier. The following three temperature profiles are usually used for evaluating the temperature rundown of the workpiece as well as a degree of uniformity of the temperature along its length and width

Temperature rundown of a selected portion (for example, a head end, tail end, or a middle portion of the workpiece expressed) in relation to each rolling pass.

Temperature variation along the workpiece length after the same rolling pass.

Temperature variation across the workpiece width.

The temperature rundown in hot strip mill is shown in general form in Fig. 1. The main parameters of the temperature rundown include.

The temperature variation across the workpiece length can be defined as a difference between the temperatures measured at the middle and near the edge of the workpiece DTW.

The strategy of controlling the workpiece temperature during hot rolling is twofold. Firstly, it is necessary to maintain the optimum temperature of the rolled piece, which allows one to obtain the desired properties of the rolled product with minimum energy consumption, required production rate, and maximum yield. Secondly, it is desirable to achieve a uniform workpiece temperature in both longitudinal and transverse direction during each rolling pass which helps to improve quality of the rolled product.

Metallurgical Requirements

The boundary conditions for material temperature during the rolling deformation process are defined by metallurgical requirements.

To ensure the homogeneity of the rolled product, all deformations in conventional hot rolling process are usually made in the austenitic phase. For low carbon steel, this implies that the last deformation must occur at a strip temperature TE above the phase transformation point between austenite and ferrite for low carbon steel the optimum range for TE is 1550 to 1650ºF.

The second important metallurgical requirement is that the slab temperature T0 be high enough to ensure dissolution of intermetallic phases or compounds resulting from the addition of alloying elements. From this point of view, the minimum value of T0 for low carbon steel is approximately 2000ºF.

The maximum value of T0 is usually limited because of another metallurgical phenomenon related to excessive grain coarsening, which can have a detrimental effect on the final product. The maximum value of T0 for low carbon steel is approximately 2400ºF.

More detailed description of the metallurgical requirements for rolling of different types of steels is given in the following chapters.

Energy Consumption Requirements

Energy consumption directly related to the hot rolling process can be divided into three components

Energy required for heating the slab in the reheat furnace.
Energy required for maintaining heat during transfer of the workpiece between rolling mill stands.
Energy required for hot rolling of the workpiece.

Product Quality Requirements

Temperature variation of the rolled material in both the longitudinal and the transverse direction is a major obstacle in maintaining the required strip gage, profile and shape tolerance.

The most drastic variation in the longitudinal direction occurs when the transfer bar enters the first finishing stand. Because the head end of the bar is usually transferred from the last roughing stand to the first finishing stand in less time than the tail end of the bar, the tail end is subjected to heat radiation loss for a longer time than the head end. The resulting temperature rundown increases with increasing slab weight. As will be shown later, if no preventive measures are taken to reduce this rundown, the temperature differential between head and tail end of the bar at the entry of the finishing train DTF can be as much as 300ºF for a 1000 PIW coil.

The adverse effect of this temperature differential on strip shape is inversely proportional to the rolled material thickness.

Rolled material temperature variation in the transverse direction is mainly due to excessive radiation near the edges where the surface to volume ratio increases substantially. If no measures are taken to reduce edge cooling, the transverse temperature variation DTF can be as much as 180ºF.

Analysis of Temperature Conditions in Hot Strip Mill

Review of the foregoing requirements shows that there is no universal definition of optimum temperature conditions for hot strip mills. For example, a possible reduction in reheat furnace temperature due to heat conservation on the transfer table might not be fully utilized because of power limitations of the roughing train or, in another case, because of poor surface quality of the slabs loaded into the furnace, which requires maintaining the higher reheat furnace temperature needed to enhance the scaling process that helps to improve the slab surface.

These facts suggest that the optimum temperature conditions must be found for each hot strip mill on an individual basis. However, the following common criteria can be applied for objective evaluation of different solutions

Reduction in mean temperature differential, MTD
Reduction in primary scale, m
Savings in fuel energy, Ef
Savings in electrical energy consumption, Ee
Total annual cost savings due to reheating and rolling optimization, St
Total additional capital cost, Ct
Payback time, PBT.

Low Carbon Constructional Alloy Steels

Low Temperature High Strength Tough Steel

U.S. Patent 3,960,612 June 1, 1976 assigned to Nippon Steel Corporation, Japan describe the preparation of steel for use as a pressure container to be used at temperature below the ice point, or as a structural material such as a pipeline in a cold environment capable of standing high pressure and low temperature.

The method comprises (1) providing a steel material as hot rolled comprising 0.03 to 0.15% C, 0.05 to 0.40% Si, 0.2 to 2.0% Mn, 1.0 to 4.5% Ni, 0.1 to 0.5% Mo, 0.005 to 0.050% Nb, not more than 0.02% N, 0.005 to 0.070% Al, and if necessary, one or more than one member of the group consisting of V, Ti, Cr, Ca and Ce, the rest being iron and unavoidable impurities (2) quenching the material after heating at 660º to 750ºC and then (3) tempering after heating at 650ºC or less.

The steel material in the form of plates, rods, etc. having the above composition can be manufactured as follows. The molten steel obtained by the use of a converter, electric furnace or other smelting furnaces, and if necessary, a vacuum degassing apparatus is formed into a slab through the steps of ingoting, blooming or continuous casting, and then hot rolled to the steel material. The steel material as hot rolled can be any type, but it is preferable that the crystal grain is larger than the crystal grain size No. 5 of JIS and that the space factor is below 80%, and the smaller, the better. In order to make the structure of the steel finer as hot rolled, the steel material used may be that which has been heated at 840º to 930ºC and quenched.

The steel material which can thus be manufactured by hot rolling with or without the subsequent heat treatment is subjected to the quench treatment of heating at 660º to 750ºC), followed by rapid cooling, whereby extremely fine structure can be obtained, which results in the enhancement of the low temperature toughness. This steel material is further subjected to a temper treatment at 650ºC or less (preferably at least 400ºC, whereby the strength and the toughness are enhanced and the cold workability and the brittleness due to strain aging can be improved.

In the heat treatment normalizing the steel material after it has been hot rolled but before temper treatment may be considered. The quenching treatment of this process, however, produces a material of much finer structure and is thus of advantage.

Alloy Steel for Arctic Service

The development of oil and gas fields in the Arctic had encouraged a search for structural steels having good low temperature properties for such applications as line pipe, line pipe fittings and critical bridge members. The low cost carbon and high strength, low alloy steels currently used for these applications in warmer environments do not have the desired toughness at low temperatures in section thicknesses of about 1 to 2 inches. For such Arctic applications, it will be necessary that the structural steel have a minimum yield strength of at least 60 ksi, and good impact toughness down to temperatures as low as -80ºF.

U.S. Patent 3,955,971 May 11, 1976 assigned to United States Steel Corporation describes a low alloy steel ideally suited for Arctic applications. This weldable, low alloy steel is characterized in the quenched condition by a ferritic pearlitic bainitic microstructure which in the tempered condition has a minimum yield strength of 65 ksi in plate thicknesses to at least 2 inches, and a Charpy V notch 50% shear transition temperature below -80ºF and a Charpy V notch energy absorption of at least 50 ft/lb in both the longitudinal and transverse directions.

Iron and conventional impurities   Balance

In the quenched and tempered condition, at least in thicker sections (i.e., 5/8 inch and greater) the above composition will render a ferritic pearlitic bainitic micro structure. Unlike the quenched and tempered low carbon constructional alloy steels, the above steel is not characterized by high hardenability and is not martensitic in the quenched condition. Indeed, lower yield strengths are achieved but low temperature toughness is improved. The quenched and tempered low carbon ultra service steels can be similarly distinguished in addition to containing considerably more carbon and total alloy content.

Example An 80 ton commercial heat was produced in an electric furnace, aiming for a content of 1% each of nickel and chromium and 0.30% molybdenum. The product composition was 0.09% C, 0.58% Mn, 0.007% P, 0.010% S, 0.31% Si, 1.05% Ni, 0.98% Cr, 0.30% Mo and 0.03% Al. Ingots from this heat were processed to 5/8 , 1 and 2 inch thick plates and to 24 inch OD by 0.969 inch wall seamless pipe (610 by 24.6 mm). The table 1 gives the test results. It is significant to note that all products exceed a 65 ksi yield strength and a transverse Charpy V notch energy absorption of 50 ft/lb and 50% shear fracture appearance at -80ºF.

High Strength Cold Rolled Steel with High Press Formability

Demands have been increasingly made for development of a cold rolled steel sheet having still higher strength without substantially lowering press formability as compared with the conventional cold rolled steel sheet for use in inside sheets and outside skins of a safety automobile. Particularly, for parts such as member sides which are subjected to severe stretching and bending and whose increased strength has a large effect on the safety, demands are increasingly made for a cold rolled steel sheet which has high tensile strength such as 45 to 90 kg/mm2, 35 to 75 kg/mm2 yield strength as well as excellent ductility such as stretchability and yet shows a high F value of drawability in certain applications.

U.S. Patent 3,951,696 April 20, 1976 assigned to Nippon Steel Corporation, Japan describe a method for producing a high strength cold rolled steel sheet having the above strength properties and yet having good press formability, particularly stretchability. The method comprises hot rolling and cold rolling a low Si Mn killed steel, heating the cold rolled steel sheet with an average heating rate not lower than 3ºC per second, annealing the steel sheet for 1 to 15 minutes at a temperature between 650ºC and the A3 transformation point and cooling of the steel sheet at an average cooling rate between 0.5 and 30ºC per second down to 500ºC.

The steel comprises 0.03 to 0.30% C, less than 0.7% Si, 0.6 to 2.5% Mn, 0.01 to 0.20% sol Al, not more than 0.015% O with the balance being Fe and unavoidable impurities.

Example Steel slabs were produced by melting in a converter, by ordinary ingot making and partly by a continuous casting (Steels A2 and B2), and these slabs were subjected to hot rolling, cold rolling, annealing and averaging to obtain cold rolled steel sheets of 1.0 mm thickness. All of the products were subjected to skin pass rolling of 1.0%. The chemical compositions, production conditions, mechanical properties. F values and secondary workability are shown in the table 2 and 3.

As for the secondary workability test, the following impact secondary workability test was conducted. A steel sheet disc of 80 to 160 mm diameter was drawn into a cup like form with an appropriate drawing ratio (primary working drawing ratio), and this cup like test piece was immersed in a vessel containing water and ice to lower the temperature of the test piece fully.

Then a conical punch was inserted into the cup like test piece on the thick steel plate and a steel lump of 20 kg weight was dropped from a height of 3 m to the punch, to see if an embrittlement rupture (longitudinal crack) was caused in the test piece. In this test, the largest primary working drawing ratio (limit drawing ratio), which does not cause the embrittlement crack, represents better impact secondary workability. The secondary workability tends to lower in a steel sheet having higher strength. In case of an ordinary mild rimmed steel the limit drawing ratio is 3.0 to 3.2. As understood from the table, when the steel composition is worked into a cold rolled steel sheet by the production steps including the continuous annealing according to this process, it is possible to produce a high strength cold rolled steel sheet having a high yield ratio of 0.75 and yet excellent secondary workability or drawability.

Meanwhile, if the steel composition is subjected to a box annealing at 700ºC, a high yield point cannot be obtained although satisfactory drawability is obtained so that the utility of this process directed to the inside sheets and outside sheets of safety automobiles is remarkably limited.

In case of a box annealing, the grain growth is suppressed when the annealing is done at a low temperature (600ºC) and it is possible to obtain a somewhat high yield point property, but remarkable results as obtained by the rapid heating and the short time annealing cannot be expected.

Production of High Strength Cold Rolled Steel Sheet

U.S. Patent 3,947,293 March 30, 1976 assigned to Nippon Steel Corporation, Japan describe a method for producing a high strength cold rolled steel or strip. Steel comprising 0.05 to 0.15% of C 0.02 to 0.30% of Si 0.10 to 1.5% of Mn 0.02 to 0.07% of Al and a total of 0.02 to 1.15% of art least one of Nb, V, Ti and Zr with the remainder being iron and unavoidable impurities, is hot rolled whereafter the hot rolled steel sheet or strip is coiled below 750ºC. The coiled sheet or strip is then cold rolled where after the cold rolled steel sheet or strip is subjected to annealing at 670º to 900ºC for 20 seconds to 10 minutes.

The increase of strength by the continuous annealing is considered to be due to the fact that the solid dissolved elements, such as Nb, V, Ti and Zr, which have not completely precipitated during the hot rolling, remain as partial precipitates during the continuous annealing. If the holding time of the continuous annealing is excessively long, the precipitates of the above elements become coarse above the A1 transformation temperature, thus lowering the strength as in case of box annealing and causing economical disadvantage.

Then the cold rolled steel sheet or strip which has been subjected to the short time continuous annealing as above is rapidly cooled so that much carbon in solid solution remains in the steel, particularly when the coiling temperature is relatively low, to wit, not higher than about 550ºC.

Material deterioration, commonly called quench aging, and lowering ductility is thus caused. In order to avoid this problem, it is desirable that an over aging treatment for one or ten minutes, preferably two to five minutes at between 300º to 400ºC, preferably 300º to 350ºC, is conducted during the cooling step after the continuous annealing to accelerate the carbide precipitation, thereby avoiding the hardening effects peculiar to continuously annealed materials.

In this context it should be observed that the carbides and nitrides of Nb, V, Ti, etc. do not precipitate completely with a low temperature coiling at 550ºC or lower so that it is necessary to precipitate them completely by over aging in the continuous annealing step. By contrast, in case of a high temperature coiling between 550º and 750ºC, the carbides and nitrides of Nb, V, Ti, etc. are precipitated completely so that the over aging treatment is not necessary in the continuous annealing step.

The material properties, particularly the balance between yield point and total elongation of the high strength cold rolled steel sheet produced in the above manner are found to be better than those obtained by box annealing. Also it is possible to control very strictly the annealing temperature along the whole length of the coil so that nonuniformity of strength and ductility due to the temperature difference encountered in box annealing can be avoided.

Example A steel heat comprised of 0.12% C, 0.25% Si, 1.33% Mn, 0.0113% P, 0.007% S, 0.05% Nb, 0.03% V, 0.026% Al, and 0.0042% N was tapped and continuously hot rolled. In the hot rolling step, the steel was hot rolled to a thickness of 3.2 mm and coiled at 490ºC. The thus obtained hot rolled steel strip was cold rolled to a thickness of 0.8 mm by an ordinary method, and thereafter subjected to a continuous annealing at 700ºC for one minute and 750ºC for one minute and successively subjected to an over aging treatment at 350ºC for five minutes. The results are shown below in comparison with those of the box annealing.

Full Continuous Annealing Process

U.S. Patent 3,936,324 February, 3, 1976 and K. Uchida, K. Araki, H. Narita, S. Fukunaka and T. Kurihara U.S. Patent 3,904,446 September 9, 1975 both assigned to Nippon Kokan KK, Japan described a method of making a high strength cold reduced steel having the most suitable mechanical properties required as a safe countermeasure for an automobile, and more particularly being easily pressable into a required shape and stepping up the strength by a coating baking treatment after the above presswork.

A steel comprising 0.04 to 0.12% C, 0.50 to 2.00% Si, and 0.10 to 1.60% Mn is passed through ordinary hot and cold rolling processes and is subjected to a full continuous annealing process. The full continuous annealing process is selected from the following processes depending upon the intended use and the required strength level.

High Strength Killed Wire Rods and Bars

U.S. Patent 3,926687 December 16, 1975 assigned to Nippon Steel Corporation, Japan describe a method for producing a high strength steel wire rod having a structure of good workability by controlling the temperature of the rolled steel material and also controlling the cooling rate after the finish rolling. The steel material obtained is useful for high strength bolts, PC wire, metal networks, Umbrella ribs, spring washers and springs.

A wire rod as hot rolled is subjected only to slight skin pass drawing into a required size, and then to heading and threading works, to obtain a bolt having 80 to 100 kg/mm2 of tensile strength without any defect. Heat treatments such as spheroidizing annealing, quenching and tempering can be omitted and thus a high level of economy is assured.

Further, when applied to production of PC wires (prestressed concrete wires) it is sufficient that the wire rod is subjected only to slight skin pass drawing and shape working including indent work for application in prestressed concrete products. Thus the patenting heat treatment which is conventionally done can be omitted. Yet a wire having high tensile strength and very excellent spot weld ability can be obtained.

The wire contains 0.02 to 0.20% C, 0.03 to 0.90% Si and 1.00 to 1.85% Mn together with one or more of not more than 0.05% Nb, not more than 0.08% V, not more than 0.25% Ti, not more than 0.30% Zr, not more than 0.005% B and not more than 0.40% Cr, and contains Al in an amount as contained in an ordinary killed steel with the balance being iron and unavoidable impurities.

The process is carried out by heating a steel having the above composition to at least 1150ºC, conducting intermediate rolling and/or finish rolling at 700º to 1150ºC, controlling the cooling rate from finish of the hot rolling to a coiling to 40º to 350ºC/sec, and controlling the cooling rate from the coiling to gathering to 1º to 15ºC/sec. Hot rolled steel wire rods and bars are obtained having excellent workability and spot weldability and having a tensile strength not lower than 50 kg/mm2 and a reduction of area not lower than 50%.

High Formability High Strength Steel

There is an ever present and increasing demand for high strength steels having good formability properties particularly drawings, biaxial stretching and uniaxial bending properties required, for example, by the automotive industry for auto mobile bumper systems.

U.S. Patent 3,926,686 December 16, 1975 assigned to The Algoma Steel Corporation, Limited, Canada describe a high strength low alloy steel strip having a minimum yield strength of 50,000 psi and good formability properties. The steel consists, by weight, of 0.10% maximum carbon, 0.30 to 0.80% manganese, 0.01% maximum sulfur, 0.02 to 0.06% aluminum, 0.01 to 0.12% columbium, 0.06% maximum cerium, the balance being iron and incidental impurities. Depending upon the composition of the steel, lower yield strengths of 50,000 to 80,000 psi are attained. This composition when hot rolled finished at 1620º to 1700ºF and coiled or collected at 1150º to 1375ºF, exhibits a unique relationship of strength and maximum formability at each of the yield strength levels in the range.

At each strength level, from 50,000 to 80,000 psi, the final structure of the steel is composed principally of ferrite with very limited amounts of pearlite. In conjunction with this and essential to the improved formability properties is the controlled dispersion of the columbium as columbium carbides of columbium carbonitrides. While pearlite is in grain boundaries and as cementite (Fe_3C) in the form of skeletal carbides, the columbium has been found to have a dual form, of row precipitates in excess of 200 Angstrom units from which the initial ferrite grains have formed and secondly, within the ferrite grain itself, as a finely dispersed carbonitride of 30 to 120 Angstrom units.

It may be noted in the steel composition that the level of both C and Mn is considerably lower than in known steels in the same strength range, which provides several major factors contributing to the improved formability properties. The low content of the steel composition, of course, reduces the pearlite content directly. However, more important, the low carbon content and low manganese values act to increase the austenite to ferrite transformation temperature.

It has been found that this increase or higher austenite to ferrite transformation temperature controls the proportion of the columbium that precipitates into coarse and fine dispersion in the composition and distributes the available columbium into its dual form for the purposes of grain refinement and precipitation strengthening. The coarse precipitation of columbium occurs during the hot deformation or actual rolling of the steel up to and including the final deformation, the collecting. This coarse precipitation acts to retard the recrystallization of austenite, immediately after the final deformation, until transformation to ferrite is started. Transformation from the highly deformed austenite guarantees transformation to a fixed and constant ferrite grain size. The ferrite grain size will vary according to the amount of columbium present and the temperature at which the finishing rolling is carried out.

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NIIR PROJECT CONSULTANCY SERVICES
106-E, Kamla Nagar, New Delhi-110007, India.
Tel: 91-11-23843955, 23845654, 23845886, +918800733955
Mobile: +91-9811043595
Email: npcs.ei@gmail.com ,info@entrepreneurindia.co
Website: www.entrepreneurIndia.co