Ryerson Handbook
— on —
Alloy Steels

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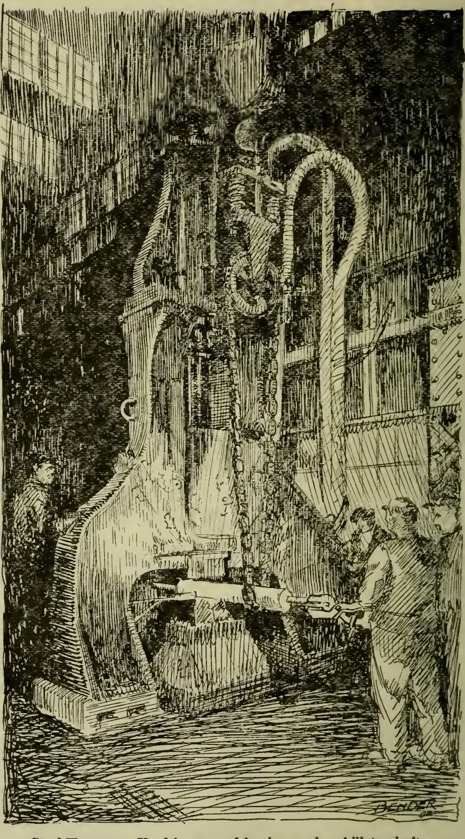

Steel Hammer. Used for general forging, such as billets, shafts, special shapes, etc.

SHOP HANDBOOK
ON
ALLOY STEELS

A technical subject
treated in a
non-technical way

BY

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INTRODUCTION

THE alloy steel industry has shown remarkable growth and development during the last five or six years.

The World War and the automobile industry have been the principal factors in this development.

The advent of the automobile made it necessary to produce steels having great strength and also a ductility or toughness far beyond that of the better known carbon steels. Alloy steel research work has therefore been carried on by certain steel manufacturers and also by the members of the automobile industry, and as a consequence remarkable results have been obtained in a short time.

To the steel using fraternity in general the highly successful nature of the results of this experimental work in alloy steels has been fairly well known, but coupled with this knowledge has too often come the belief that the use of alloy steel involved the handling of various mysterious and secret processes which were summed up under the general heading of "heat treatment."

As a result, while many people recognized the decided advantages of alloy steels, they hesitated to use them, believing that satisfactory results could only be obtained by the maintenance of large, expensive laboratories coupled with the services of highly trained technical men.

While more general use of alloy steels had been making itself apparent prior to the great war, progress has been extremely slow. Coupled with the entrance of our country into the conflict came the heavy demand for automobile trucks, ordnance, armor plate, steel helmets, and the many other army and navy requirements which could only be manufactured successfully by the use of the highest types and best grades of alloy steels, and then only when these steels were subjected to careful and accurate heat treatment.

Our government arsenals, of course, have long been familiar with the use of alloy steels in the manufacture of guns, armor piercing shells, rifle barrels, and other naval and military equipment, but their productive capacity was naturally too small to turn out the large quantity of material necessary to meet the emergency. To supplement the manufacturing facilities of the few highly specialized shops, it was necessary for the manufacturers of the country in general to take up the production of government material, and thus it followed that many shops that had never before used alloy steels found themselves buying, machining, and heat treating these special steels, and found also that they could obtain entirely satisfactory results.

The present situation is such that alloy steel parts are in demand by all industries and that these steels are coming into more general use every day.

Representative steel-service plants of the country are carrying alloy steel bars in stock the same as any other standard steel product.

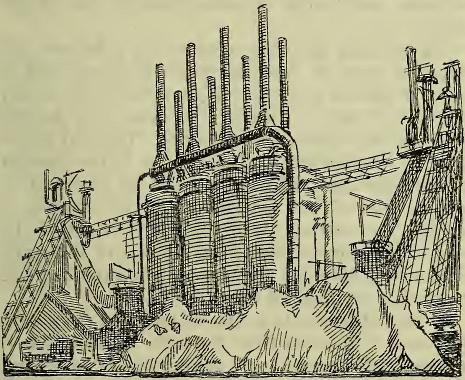
Alloy steels have come to stay, and every day finds some heavy part which had previously been made of carbon steel replaced with a lighter, tougher, and better part made from one of the various commercial grades of 3½ per cent nickel, chrome nickel, or other special steels.

It is the purpose of this book to avoid all technicalities and to condense in a small space sufficient information to enable the average shop superintendent to take hold of a special job, select and buy the steel for it, and finally to give it such heat treatment as will produce the desired result.

Free and generous exchange of views and ideas by members of the trade are always of value and interest.

The various heat treaters organizations about the country have done much along this line, and will undoubtedly do much more to spread practical information in the future.

During our association with many of the leaders in the manufacture and use of alloy steel, and membership in various societies and associations, we have built up a fund of information, data and experience which of necessity can not all be included in this small book, but which is available for all who seek it.



CHAPTER I

QUALITY

(Analysis not the only factor)

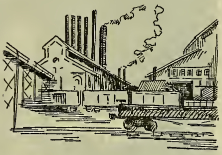
IT seems appropriate at the start to call the attention of the reader to the matter of quality of the alloy steel which he may contemplate buying and using.

Practically all users of alloy steels have been in the past, or are at present, users of tool steels, and they will therefore understand that chemical analysis is far from being the only factor governing the ultimate result to be obtained from the use of any steel.

All tool and die makers know the difference between a piece of common grade tool steel and a piece of special grade tool steel, even if the carbon content of each is exactly the same and general analysis very close in both grades. The real difference in the two steels mentioned is in the method of manufacture. This is governed by such factors as the kind of raw material used, the method of melting and casting, the amount of steel cut off the end of the original ingot, the amount of rolling or hammering done and the care used in annealing and inspecting the finished bars.

A mild steel bar is in the majority of cases used just as it is received from the mill. If, therefore, it satisfactorily passes mill inspection for size and freedom from surface defects it will generally be satisfactory to the ultimate consumer. Tool steel, on the other hand, as received from the mill has only started its journey, and it may be said that its manufacture is not completed until it has passed through its final process, which consists of heat treatment or hardening.

Inasmuch as practically all of the alloy steel purchased is subject to heat treatment before use, it would therefore seem that alloy steels, like tool steels, cannot be judged entirely by their analysis. It is well known to alloy steel manufacturers that the ability of these steels to withstand the severe



stresses put upon them by heat treatment depends not only on their analysis or composition, but also on the various processes through which they have passed during the period of manufacture at the mill.

For these reasons it should be clearly remembered that in purchasing alloy steels the reliability and reputation of the manufacturer should be given full consideration. The element of original cost must not be overlooked in order to secure economical production; but it is equally important to remember that each finished part represents just so much money spent for machine work and heat treating, and in most cases a cent or a fraction of a cent per pound in the initial cost is a very small factor when compared with the money expended on machine work, heat treating, freight, and other elements of the total cost.

Casting. Molten steel being poured from ladle into molds.

CHAPTER II

METHOD OF MANUFACTURE

ALLOY steels are being manufactured by the following processes:

Crucible Process.
Open Hearth Process.
Electric Furnace Process.

The crucible process, owing to extreme cost, is not used for heavy tonnage production, and need not be considered by the average manufacturer, it being impossible to produce a strictly crucible melted alloy steel at a price sufficiently low to enable the user to compete with others who are using steel made by one of the other methods.

A discussion of the relative merits of the open hearth process and electric furnace process would cover far more space than is permitted in this book and would also of necessity be extremely technical.

Steel of the very best quality can be made by either the electric furnace or the open hearth process, and it is perhaps safe to assume that the ultimate quality depends more on the selection of raw material, care used in manufacturing, and knowledge and experience of the maker rather than the particular method which he follows in making the steel.

After all, the best solution of this problem for the average shop is to buy material from an entirely reliable source of supply, specifying the purpose for which the material is to be used and leaving it to the sellers to furnish steel in which they have confidence and on which they are willing to stake their reputation.

CHAPTER III

ELEMENTS, AND THE PART THEY PLAY

IN this chapter we will endeavor briefly to outline the various properties imparted to steel by the addition of the most commonly used metals, such as nickel, chromium and vanadium, also the effect of the presence of carbon, manganese, silicon, phosphorus, and sulphur.

Carbon

One of the most important elements in any steel is carbon. The effect not only makes itself apparent in the steel itself and the results obtained from its use, but is also of primary importance in the determination of the correct heat treatment.

In straight carbon steels, that is, steels composed of iron, carbon, and small percentages of such elements as manganese, silicon, phosphorus, and sulphur, the varying amounts of carbon produce steels which may be roughly listed as follows:

- Dead soft steel, carbon not over 0.10 per cent.
- Mild steel, carbon not over 0.25 per cent.
- Machinery steel, carbon 0.25 to 0.40 per cent.
- Crucible machinery steel (not necessarily a crucible product), carbon 0.40 to 0.60 per cent.
- Low carbon tool steel, carbon 0.60 to 0.75 per cent.

Carbon over 0.75 per cent is used in various grades of tool steel, sometimes running as high as 2 per cent. The most common range of carbon in tool steel is 0.75 per cent to 1.20 per cent.

From these figures it will be readily understood that the greater the amount of carbon used in steel the harder the steel becomes. This is true for steel either in the annealed condition, the natural or untreated condition, or the heat treated or tempered condition.

Straight carbon steel which is cooled rapidly from above its critical point No. 1 (this term is explained on page 43) begins to show an increased hardness when the carbon content is over 0.25 per cent. The amount of hardening, while increasing with greater carbon content, does not tend to produce any great degree of brittleness until the carbon content has reached about 0.50 per cent.

When steel containing more than about 0.50 per cent carbon is suddenly cooled from above its critical temperature, it becomes intensely hard and also develops extreme brittleness. Therefore, for the great majority of purposes, alloy steels do not contain much more than about 0.45 per cent carbon. The reason for this is that alloy steels are principally used where great strength, toughness, and freedom from brittleness are required.

Phosphorus

In practically all steels the presence of phosphorus may be considered a detrimental impurity. The great danger of high phosphorus content is that it renders a steel liable to fracture when subjected to intense vibration or sudden shock. High phosphorus does not seem to give any particular trouble during the course of manufacture, and high phosphorus steel can be successfully worked as long as it is at a relatively high temperature.

From this explanation it is obvious that alloy steels must not contain excessive phosphorus. The generally accepted maximum limit is in the neighborhood of 0.04 per cent for commercial alloy steels.

In good tool steel 0.025 per cent is about the permissible maximum.

Sulphur

Sulphur may be considered an undesirable impurity in all steels, but its effect is more or less the opposite of that produced by phosphorus, inasmuch as steel containing excessive sulphur develops cracks, flaws and weaknesses when worked hot. The detrimental effect is nevertheless present in cold steel, and for this reason it is not usual to permit a percentage of sulphur exceeding .045 per cent.

Manganese

Manganese is present in all steels, and, when added in relatively large proportions, produces a special steel with properties entirely different from those of any other known analysis. This steel is known as manganese steel and may contain as much as 14 per cent to 15 per cent of manganese.

Manganese steels are not in the class of material to which this book particularly refers, and no further mention will, therefore, be made of them.

When present in small quantities such as 0.25 per cent to 0.80 per cent, manganese serves as a cleanser or purifier of the steel. This action is brought about by the manganese forming a chemical union with the dissolved oxygen which is present in the steel, thus forming an oxide of manganese which is carried off in the slag. It has also been found that in steels where the phosphorus and sulphur might tend to produce a rather coarse grain the presence of manganese tends to reduce this grain to a more normal and desirable size.

Silicon

When present in small quantities silicon has very much the same effect as similar percentages of manganese. When present in larger quantities silicon, like manganese, produces steels of unique characteristics, the principal among these being the effect on the magnetic properties of the steel.

Chromium

This is, perhaps, one of the most important elements to be considered from the standpoint of alloy steels, and it is used in the production of many classes of material, among which may be mentioned high speed steels, certain grades of water hardening tool steels, hot working die steels, ball and roller bearing steels, chrome nickel steels, chrome vanadium steels, etc.

Chromium has in general the effect of producing hardness in properly treated steels, and when added in the correct proportions and in suitable relation to the balance of the analysis, takes the place of a certain portion of the carbon in producing a hardening and strengthening effect.

The amounts of chromium used in different classes of steel vary widely, although the following list will give an approximate idea of the more generally accepted percentages:

Kind of Steel	Percentage of Chromium.
Chrome Nickel Steels	0.35 to 1.25
Ball and Roller Bearing Steels	0.80 to 1.25
Hot Working Die Steels	3.00 to 4.50
Chrome Vanadium Steels	0.75 to 1.25
Certain Water Hardening Tool Steels	0.20 to 0.50
High Speed Steel	3.00 to 5.00

The presence of chromium having, as before mentioned, a somewhat similar effect to carbon in producing hardness under heat treatment, it is very essential that the percentage of chromium be known and given full consideration when any heat treatment formula is being developed.

Chromium increases the susceptibility of steel to heat treatment, and it also has the property of carrying the hardness produced by quenching to a greater depth so that steels of a fairly high chromium content after quenching will, in medium sized sections, be found to have hardened all the way through to the center. When present in rather large proportions, such as are found in hot working steels, chromium enables the steel to retain its hardness at relatively high temperatures, and it is this property that makes these steels particularly suitable for gripper dies and other work where the steel will be used at high temperatures and must still retain a reasonable degree of hardness.

Nickel

Nickel is the best known of all the elements used in the manufacture of alloy steels. Nickel steel was one of the first alloy steels generally used and still continues to be extremely popular.

Various percentages of nickel have been tried, and it has been found that for general all round work about 3½ per cent nickel seems to give the best results, both in the way of producing a high tensile strength and elastic limit and at the same time leaving the steel ductile and tough.

The presence of nickel may be said to increase the toughness and strength of the steel and also to increase its resistance to sudden shock and excessive vibration. Steels containing nickel respond very readily to heat treatment, so much so that a bar of 3½ per cent nickel steel containing 0.40 carbon will have an elastic limit of about 60,000 pounds per square inch in the annealed condition and about 200,000 pounds per square inch in the maximum heat treated condition.

CHAPTER IV

HOW TO BUY AND SELECT ALLOY STEELS

PERHAPS one of the most difficult problems that must be solved by the user of alloy steels is the selection of a suitable grade to use for a certain piece of work.

A study of the table on page 22 (Table A) will show that somewhat similar physical characteristics may be obtained from the use of any one of the several commercial grades of alloy steel mentioned, and the user will, therefore, perhaps, be at a loss to decide which class of steel to select. For this reason we call attention to the following.

There are many elements which must be taken into consideration besides the actual physical properties which may be obtained from any one grade of steel. Among these may be mentioned availability, cost, machine qualities, equipment necessary for heat treatment, and past experience of the user in handling the steel selected.

The largest warehouse tonnages of alloy steel are confined to the chrome nickel steels, containing about 1 to 1.5 per cent nickel and .40 to .75 per cent chromium, and the 3½ per cent nickel steels (carbon contents varying in both).

These two alloy steels are suitable when properly heat treated for the manufacture of such parts as axles, jack shafts, oil hardened and case hardened gears, high duty bolts and nuts, cams, crank shafts, connecting rods, and the thousand and one different parts entering into the manufacture of automobiles, trucks, tractors, and other special machines.

Table A

Comparative Properties of Alloy Steels

The following are the approximate physical properties which may be obtained from some of the alloy steels under ideal conditions of heat treatment.

GRADE OF STEEL	Elastic Limit Lbs. per sq. inch	Reduction of Area Per cent of Original area	Elongation Per cent in 2 inch
Chrome Nickel S. A. E. 3120			
Natural Condition.	40,000	65	30
Heat Treated......	100,000	50	20
Chrome Nickel S. A. E. 3135			
Natural Condition.	55,000	50	20
Heat Treated......	120,000	39	18
3½ Percent Nickel S. A. E. 2320			
Natural Condition.	45,000	55	30
Heat Treated......	130,000	50	15
3½ Percent Nickel S. A. E. 2340			
Natural Condition.	60,000	50	18
Heat Treated......	170,000	45	15

The analysis ranges most commonly used in chrome nickel and 3½ per cent nickel steels are as follows:

Low Carbon Chrome Nickel Steel
(S. A. E. Specification 3120)

Carbon	0.15 to 0.25
Nickel	1.00 to 1.50
Chromium	0.40 to 0.75
Manganese	0.50 to 0.80
Phosphorus maximum	0.04
Sulphur maximum	0.045

High Carbon Chrome Nickel Steel
(S. A. E. Specification 3135)

Carbon	0.30 to 0.40
Nickel	1.00 to 1.50
Chromium	0.40 to 0.75
Manganese	0.50 to 0.80
Phosphorus maximum	0.04
Sulphur maximum	0.045

Low Carbon 3½ Per Cent Nickel Steel
(S. A. E. Specification 2320)

Carbon	0.15 to 0.25
Manganese	0.50 to 0.80
Phosphorus not over	0.04
Sulphur not over	0.045
Nickel	3.25 to 3.75

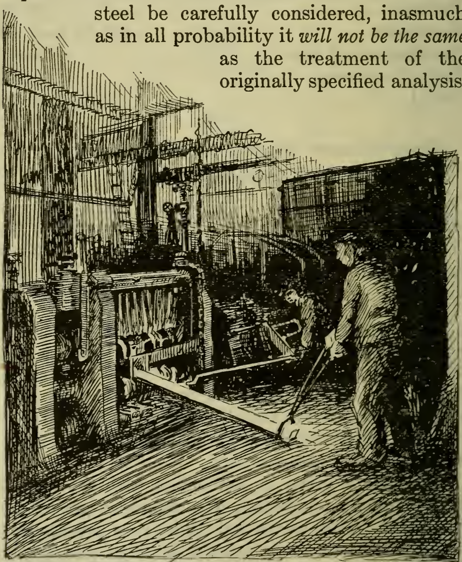
High Carbon 3½ Per Cent Nickel Steel
(S. A. E. Specification 2340)

Carbon	0.35 to 0.45
Manganese	0.50 to 0.80
Phosphorus not over	0.04
Sulphur not over	0.045
Nickel	3.25 to 3.75

These steels are available from stock in practically all sizes from ⅜ inch to 6 inches round with a hot rolled finish, and can also be secured in many sizes with a cold drawn finish. The S. A. E. 2320 and 3120 analyses steels are also carried in cold drawn hexagons for the manufacture of high duty hexagon head bolts and hexagon nuts.

This data is given in connection with the use of the previously mentioned four standard grades of alloy steel, owing to the fact that these can readily be secured from stock sources in large and small quantities.

It is not always possible to obtain the size or quantity of steel needed in the particular analysis desired, and we therefore attach a possible substitution list. A study of this list will show that where a certain analysis is specified one or more of the other alloy steels can probably be used in its place with satisfactory results. It must not, of course, be taken for granted that this will hold true in each and every case, and where a doubt exists the matter should be referred to some authority on the subject. In using the substitution list it is of the utmost importance that the heat treatment of the substitute steel be carefully considered, inasmuch as in all probability it *will not be the same* as the treatment of the originally specified analysis.



Bar Mill.

Substitution List

Steel Specified S. A. E. No.	Possible Substitution S. A. E. No.		
3120	2320	....	6120
3130	2320 2330 2335	3120 3135 3140	6120 6125 6130
3135	2330 2335 2340	3130 3140	6125 6130 6135
3140	2330 2335 2340	3135	6130 6135 ....
2320	....	3120	6120
2330	2320 2335 2340	3130 3140	6125 6130 6135
2335	2330 2340	3135 3140	6125 6130 6135
2340	2330 2335	3135 3140	6130 6135
6120	2320	3120	....
6125	2330 2335	3130 3140	6120 6130
6130	2330 2335 2340	3130 3135 3140	6125 6135 ....
6135	2335 2340	3135 3140	6130 ....

It must be clearly remembered that in selecting an alloy steel for any special purpose the physical properties of the steel in its heat treated condition must determine its use. Alloy steels in the untreated or natural condition undoubtedly have advantages over the non-alloy steels, but the advantages are not sufficient to warrant the increased cost. Another factor in this matter is that no reliance can be placed on the physical properties of untreated alloy steels.

These physical properties will vary widely in bars of different sizes and also in different bars of the same size. This condition depends upon the amount of work which has been done on the steel at the mill and also largely on the final temperature of rolling.

The most readily procured alloy steels may be roughly divided into two classes, the first being of low carbon content and the second of relatively high carbon content. These two classes are naturally used for widely divergent purposes. In order to assist the prospective user we will endeavor to give a brief outline of the general application of the two classes of material.

Low Carbon Alloy Steels

The low carbon alloy steels, such as chrome nickel (S. A. E. 3120) and 3½ per cent nickel (S. A. E. 2320) with a carbon range of from .15 to .25 per cent, are used primarily for parts which are to be case hardened. They are also used for certain structural purposes such as spring clips, bolts, and other parts which will be subjected to frequently alternating stresses and intense vibration. When properly heat treated these low carbon steels, though not developing a very high tensile and elastic limit, show a very fine fibrous structure and one having consequently great resistance to fatigue, or what is commonly but erroneously known as crystallization.

Owing to the ability of these low carbon steels to stand relatively high temperatures without deterioration, they are particularly suitable for drop forging.

High Carbon Alloy Steels

The most popular and generally used high carbon alloy steels have a carbon range of from .30 to .45 per cent carbon, and can readily be obtained in either chrome nickel (S. A. E. 3135) or 3½ per cent nickel (S. A. E. 2340) grades.

These higher carbon steels are used in the most part for structural purposes where relatively high elastic limits coupled with a reasonable degree of toughness are required.

The physical properties obtainable by heat treatment of high carbon alloys render them suitable for the manufacture of such parts as crank shafts, connecting rods, counter shafts, rocker arms, gears, keys, and in fact all parts where high physical properties are necessary.

It has been found very advantageous to use some of these alloy steels in the manufacture of certain parts of machine tools such as lathe spindles, milling machine spindles, and other parts where the least amount of bending under severe stress would render the tool entirely useless. By the use of these high grade steels the weight of many machines can be materially lowered without in any way impairing their efficiency or reducing their load capacity.

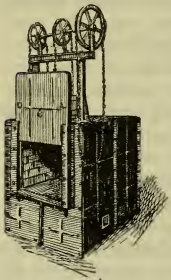
The higher carbon alloys can be successfully drop forged, although they cannot with safety be raised to as high a temperature as the lower carbon series.

From the preceding remarks in this chapter the reader will have noted that the selection of the correct grade of alloy steels presents several more or less technical problems, and these problems are supplementary to the very important question of availability. In view of these conditions we believe that the most satisfactory method of handling this problem will be to take the matter up in detail with some reliable source of supply. The sellers of special alloy steels naturally have available the services of men thoroughly familiar with the various problems of alloy steel procurement and use, and, therefore, although they do not know all that is to be known, they are in a position frequently to give advice which will save both time and money for the user.

CHAPTER V

SHOP EQUIPMENT

ONE of the most important elements to be considered when undertaking any heat treating operation is the matter of shop equipment. Primarily heat treatment consists of subjecting the parts to definite temperature increases over and above the normal atmospheric temperatures during certain periods of time, and also subjecting parts to decreases in temperature from various definite points to the normal atmospheric temperature, also during certain time intervals.


Single Chamber Heating Furnace.

It will be readily understood that in order to adequately handle this work there are three essentials to be considered:

First, some device whereby the temperature of the part may be increased to a certain point and maintained for any desired length of time at that temperature.

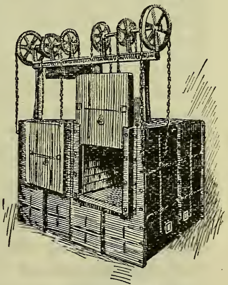
Second, some device whereby the temperature of a piece may be reduced from one point to another at any desired rate.

Third, some means for definitely measuring the various high and low temperatures which are used in this work.

CHAPTER VI

FURNACES

THE device referred to as the first essential may be one of the numerous gas, oil, or coal fired furnaces which are on the market, or may consist of a molten lead, molten salt, or oil bath. The question of furnace design is too large a subject to be handled in this book, so it will suffice to say that money spent in procuring a first class furnace is well invested. The selection of such a furnace should be undertaken in conjunction with the service departments of one of the reputable furnace manufacturers. The question of the design is, of course, dependent upon such factors as the fuel most readily obtainable, the size of work to be handled, temperatures required, and other shop factors. The same remarks will also apply in the matter of the selection of apparatus using molten salt, molten lead, or hot oil for heating.



Double Chamber Heating Furnace.

In general the following items should be considered in furnace selection: The size will, of course, depend entirely on the class of work to be done, and, while the furnace must be of sufficient proportions to accommodate the largest pieces which are to be heat treated, it must be remembered that small pieces can not be heated economically in a large furnace. It is also well to note that the greatest economy in furnace operation is obtained when it is run at a more or less uniform temperature. Every time the furnace is heated through a certain temperature range the furnace itself absorbs a large amount of heat, and consequently when the furnace is again cooled this heat is lost and will have done no useful work in the heat treatment process. In many cases this alternate raising and lowering of the furnace temperature is unavoidable, but the matter is worthy of consideration inasmuch as frequently the loss occasioned by this condition may be eliminated by the use of two or more furnaces which are maintained at different but uniform temperatures.

Molten Lead, Salt, and Oil Baths

MOLTEN LEAD BATHS

For certain work the molten lead or molten salt bath is a very desirable method of raising temperatures. The steel is protected from contact with furnace gases which, if not properly balanced or proportioned, may cause excessive oxidization. A strong point in its favor is that it will hold a very accurate temperature. Owing to the high specific gravity of molten lead, steel will float in it and must, therefore, be held down.

It is very important that the lead used be free from impurities, this applying particularly to sulphur which, if present in the bath, may be absorbed to a certain extent by the steel. The lead bath when dirty can be cleaned by throwing in perfectly dry sodium chloride (common salt) and stirring, inasmuch as this will bring all dirt to the surface where it may readily be removed.

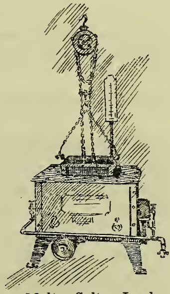
Where it is found that the lead adheres to the surface of the pieces of steel, the difficulty can be overcome by dipping the pieces in a saturated water solution of potassium cyanide prior to heat treatment. The pieces must be dipped cold, and the solution allowed to dry on the surface before they are placed in the lead bath.

Heating in lead has no influence on the quenching temperature of quenching medium, and steel after it is removed from the lead bath is handled exactly the same as if it has been heated in a furnace or by some other method.

Molten lead baths may be used conveniently for temperatures from about 700° Fahr. to 1600° Fahr.

MOLTEN SALT BATHS

In some particular instances molten salts, such as barium chloride, cyanide of potassium, mixtures of calcium chloride and sodium chloride, and various other mixtures seem to give very satisfactory results. The molten salts, however, frequently give considerable trouble by having a chemical effect upon the surface of the steel. It is well known that cyanide of potassium, for instance, will raise the carbon content of the surface of the steel to a very high point, and, although this penetration is not deep this method is frequently used as a quick and easy means of case hardening. Other salts cause erosion and pitting under some conditions; and, therefore, owing to the many problems that arise in connection with molten salt baths, we do not particularly recommend their use.


Molten Salt or Lead Furnace.

OIL BATHS

Oil is one of the most useful mediums for the heat treater. It is employed both as a heating and cooling medium. At present we will consider oil only from the standpoint of heating, wherein it may be used for temperatures up to and including about 600° Fahr. This temperature, of course, does not have any material effect on untreated or annealed steel, but is used to relieve the internal strains brought on by quenching from higher temperatures and to change the physical properties of heat treated steel. For this purpose an oil bath is extremely desirable owing to the fact that a steady uniform temperature can be maintained for any desired length of time. This is an extremely difficult operation to carry out in a furnace when using such low heats.

CHAPTER VII

QUENCHING EQUIPMENT

WE will now consider the matter of temperature reduction, which is listed in Chapter V under the heading of essential No. 2.

In heat treatment temperature reduction is the second operation and follows the initial heating of the parts which are going through the process.

Various mediums are available for this heat reduction or quenching, such as oil, water, brine, ashes, slack lime, air, etc. Note that, in addition to the large number of different quenching mediums used, these various mediums are used at different temperatures, all this depending upon the degree of cooling desired and also the time element or rate of cooling necessary to give the desired result.

The physical properties of heat treated steel depend primarily on five factors:

First, the analysis of the steel.

Second, the size of the piece under consideration.

Third, the temperature at the time when the temperature reduction starts.

Fourth, the rate at which the temperature reduction takes place.

Fifth, the temperature of the final heating or drawing.

Oil and water are probably the most generally used mediums for temperature reduction or quenching, and in the great majority of cases these two mediums are used as nearly as possible at normal atmospheric temperature. In order to secure uniform results it is necessary that the temperature of the quenching bath be kept as nearly constant as possible. Because repeated quenchings will raise the temperature of the quenching medium, these baths, except where used for very intermittent service, are provided with cooling coils through which cold water is circulated. Sometimes this cooling system is modified, and the oil is pumped from the tank through an exterior coil which is surrounded by cold, circulating water.

Addition of salt to water increases the specific heat of the solution, and therefore produces a more rapid cooling of the parts which are quenched in it. However, care must be used to always maintain about the same proportion of salt in the bath or a non-uniform quenching will result.

With certain steels, and where certain physical properties are required, the atmosphere will form a desirable quenching medium, in which case pieces are merely removed from the heating furnace and allowed to cool in the air. This is naturally a slow medium of cooling, and physical properties thus obtained are consequently lower than those given by the same steel when quenched from the same temperature in such mediums as oil or water.

The whole problem of quenching mediums, designs of quenching tanks, and other shop details are of too broad a scope to be taken up in detail in this book, and should be included in a general scheme of shop equipment at the time the furnace installation is determined. The following general remarks may, however, be useful.

Be sure that you provide means of keeping your quenching bath at constant temperature. This factor is governed by:

First, the weight of steel being quenched in a given time.

Second, the temperature of steel at time of quenching.

Third, the quantity of quenching medium provided.

Fourth, the efficiency of system used to cool the quenching medium.

It will be well to emphasize the need of a very quick transfer of the hot steel from the furnace to the oil quenching tank. As soon as the steel is taken from the furnace it starts to lose heat, and even if the temperature of the steel while in the furnace is correct it will have dropped too low if much time is lost in making the transfer to the quenching tank. For this reason the quenching tanks should be as near the furnaces as possible.

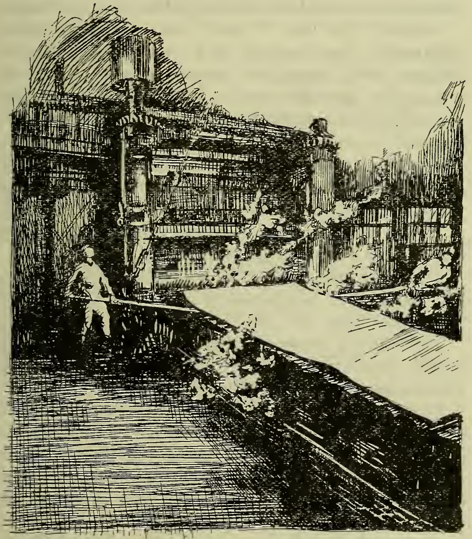


Plate mill, consisting of top and bottom rolls. Plates rolled on these mills are irregular on the edges and must be sheared on all four sides.

CHAPTER VIII

HEAT MEASUREMENT

THE matter of heat measurement has already been given as the third essential in shop equipment for heat treating, and, while this matter has been taken up as the third element, it must not be considered as being third in importance.

Granted the use of good steel and high class equipment for heating and quenching, neither accurate nor dependable results can be obtained unless the operator has a means of determining accurately the temperatures of the various furnaces, lead baths, oil baths, etc.

Temperatures up to 600° Fahr. can be accurately measured by the use of high temperature mercurial thermometers, but where the temperatures used are in excess of this figure it becomes necessary to use some other means of determination.

There are two methods in common use of measuring the higher temperatures: (1) by the optical pyrometer, and (2), the thermoelectric couple.

The optical pyrometer has its application and is useful in many cases, but for numerous reasons the thermoelectric apparatus is generally used.

Very briefly, the principle of the thermoelectric couple is as follows: When two pieces of metal of different composition are joined together at both ends so as to form a complete electric circuit, a flow of current is produced when the two junctions or joints are at different temperatures.

Provided that the wires are of exactly uniform composition throughout, the difference in electromotive force, or voltage, is directly proportional to the increase in temperature, and therefore, if a very delicate voltmeter or galvanometer be placed in the circuit, a reading can be obtained which will indicate the difference in temperature of the two junctions.

Selection of pyrometer equipment must be governed by such factors as the permissible original cost and also shop conditions and kind of work which will be undertaken. These several matters having been determined, the pyrometer equipment installation should be turned over to one of the recognized and dependable pyrometer manufacturers, all details being left to their experience and co-operation.

In connection with this matter, it may be well to emphasize the desirability of recording pyrometers. These instruments are provided with a moving chart, on which a line is automatically drawn representing the furnace temperature at all times. Such a recorder can be kept in a locked box, thereby providing evidence as to just how accurately the furnace operator has followed his instructions in reference to temperature and time.

Whatever system is installed, it must be remembered that the pyrometer is essentially a delicate instrument, and the voltages and currents handled are necessarily extremely small. For these reasons it is essential that the couples be properly protected from furnace gas action and that they be handled with care. All *contacts* must be kept *scrupulously* clean and the indicating and recording instruments so placed that they are free from excessive vibration and jar, such as may be produced by steam hammers or other heavy machines. Pyrometers must be accurately checked at fairly frequent intervals, this being best handled by the service departments of the various pyrometer manufacturers. (See page 73.)

If the pyrometer equipment is given adequate care and attention, readings of remarkable accuracy can be obtained, but, on the other hand, if not properly cared for, inaccuracies are bound to develop and trouble with heat treatment will surely follow.

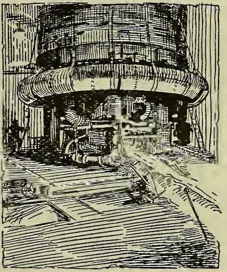
Heat treated alloy steels are used for the most vital parts of automobiles, trucks, aeroplanes, and other fast moving mechanisms, and the safety of human lives depends on their withstanding the severe stresses that are imposed upon them. Their success in fulfilling their function depends more largely on their heat treatment than any other factor, and it is, therefore, a duty of all those doing heat treatment work to see that this work is properly done and that no chances are taken, either with the use of inferior material or equipment.

In using the thermoelectric pyrometer to determine the heat of a piece of steel, it is well to place the thermo couple near the steel, and by observation of the heat color it may be readily seen whether the thermo couple and the steel are at the same temperature. This matter is of importance inasmuch as no furnace will be the same temperature at all points, and, where the thermo couple is distant from the steel, the temperature which it registers may not be the actual temperature of the steel being heated.

CHAPTER IX

HEATING

IN another section of this book there are tables giving the correct quenching temperatures for various alloy steels, together with the drawing temperatures and the approximate physical properties resulting therefrom. In order that these tables may prove of the greatest possible value, it will be in order to outline briefly the general principles to be observed in following the heat treatment formula given in these tables, and we will therefore first consider the matter of heating.



Tapping Blast Furnace.

All steels when heated are subject to expansion, the amount of expansion being more or less directly proportional to the increase in temperature. If a bar of steel is allowed to remain in a furnace which is at a certain temperature, the center of the bar, or that part of the metal farthest from the surface, will ultimately reach approximately the same temperature as the furnace. It will be obvious from consideration of this matter, however, that the heat must pass by conduction from one particle of the steel to another, starting at the outside and penetrating inward. A certain amount of time is therefore required for the steel to assume the same temperature throughout, consequently if the bar is placed in an extremely hot furnace, the outside will for a while be very much hotter than the inside portion.

The difference in expansion of the outside and center of a piece of steel, owing to the difference in temperature, is dangerous, and to this cause may be frequently attributed the development of cracks or checks. This condition is more highly developed with some steels than with others on account of the difference of density and heat conductivity. High speed steels and certain high percentage chromium steels are particularly dense, and in such extreme cases very rapid heating is almost sure to produce disastrous results. On the other hand, low carbon steels which contain no alloys, such as mild steel, are more free from danger in this respect.

As a general rule it may be stated that the higher the carbon and the greater the percentage of alloys in a steel the more care must be used in raising the temperature. There are exceptions, of course, to this rule, but by taking it as applying to all cases no harm will be done and many undesirable results may be avoided.

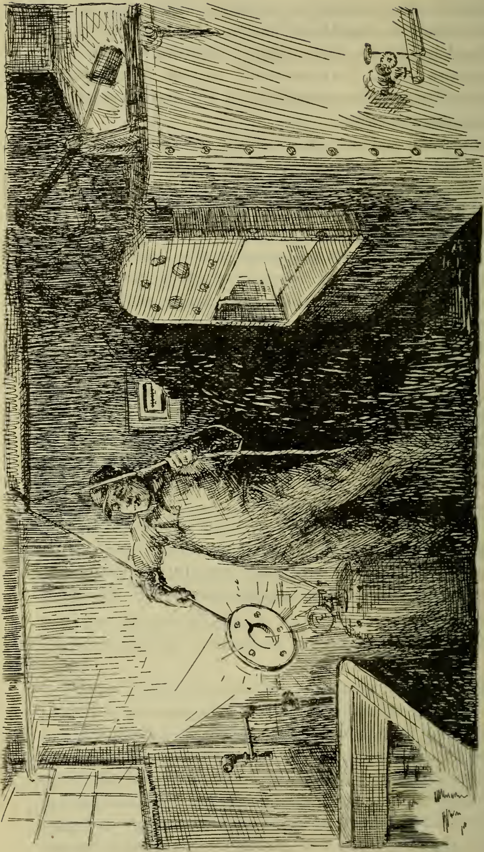
Heating, therefore, should be done as slowly as is commercially possible, and in all cases the steel must be allowed to remain in the furnace for a *sufficient length of time to insure absolutely uniform heat penetration throughout all parts of the bars or pieces.*

Where a long run of heat treatment is contemplated it is sometimes advantageous to use two or more furnaces; furnace number one may be maintained at a comparatively low temperature and used solely for the purpose of pre-heating the steel. After having reached the temperature of the pre-heating furnace, the pieces can then be transferred to the higher temperature furnace and brought up to the ultimate heat which is required. This system will give quicker results and avoid the heat loss occasioned by alternately raising and lowering the temperature of the furnace itself, as well as insuring a gradual rise in temperature of the parts which are being heat treated.

Furnace atmosphere is of the utmost importance, and great care should be used in properly proportioning the relative amounts of fuel and air.

Air is composed of oxygen and nitrogen, and where an excess of air is mixed with the fuel a surplus of free oxygen will exist in the furnace atmosphere. Free oxygen, when brought in contact with heated steel, will combine chemically with the iron contained in the steel, forming iron oxide or scale. Oxygen will also combine readily with the carbon in steel and will thus change the carbon percentage in the outside surface of the bar. Scaling and decarbonizing are, of course, both undesirable and can be practically eliminated by properly proportioning the mixture of fuel and air so that there will be sufficient fuel to use up all the oxygen which is being fed into the furnace.

The necessity of using a slight excess of fuel has already been indicated, but this action must not be carried too far. Where large amounts of excess fuel are used no advantage is gained and waste will occur.



Quenching Tool Steel Shear Blades. Note that the quenching tank and furnace are very close to one another. The rope tackle enables the operator to swing the blade from the furnace to the tank with a minimum loss of time and temperature.
See page 35.

CHAPTER X

COOLING OR QUENCHING

HAVING in the previous chapter considered the matter of raising the temperature of steel for heat treatment, we will now touch on the matter of temperature reduction, more commonly called quenching. The matter of heat reduction for the purpose of annealing will be considered in another chapter.

When steels are heated to a certain temperature, which will be different in every grade and analysis of steel, certain changes take place in the metal. These changes are of physical and chemical nature, and the point at which the change occurs is known as the "critical temperature" or "critical range" of the particular steel in question. The nature of these changes is known and very ably discussed by many authors of technical books on the subject of metallurgy. It is not within the scope of this book to go into these technicalities, and we will therefore content ourselves with accepting the fact that such a point of change actually does exist.

When steel is heated above the critical temperature, the changes so caused are such that, if they can be retained in the steel after cooling, the physical properties of the steel will be entirely different from those of the same steel prior to the change having taken place. When the temperature of a piece of steel is raised to a point slightly above the critical temperature, the changes do not occur *instantaneously*, a certain amount of *time* being necessary for this action. On cooling a piece of steel from a temperature above the critical point (we will call this critical point No. 1), providing that the cooling is done slowly, the changes which have occurred will reverse themselves and the steel will return to its original condition. The temperature at which the return to original condition starts is lower than the No. 1 critical point and this point may be, for convenience, called critical temperature No. 2.

In considering a decreasing temperature and the change which the steel undergoes during such decreases, the *time element is of the utmost importance*, inasmuch as the changes occur not instantaneously but over a certain period of time.

The whole operation of heat treating, therefore, depends upon the following facts:

First, that steel undergoes a change when heated above a certain point.

Second, that such change will be reversed on sufficiently slow cooling, thus returning the steel to its original condition.

Third, that the changes can not occur instantaneously.

Fourth, that the physical properties of the steel will be different provided the changes which took place on heating can be retained in the steel when in a cold or normal temperature condition.

Owing to the fact that time is required for the changes to occur on a falling temperature, we can, by heating steel above the critical point No. 1 and cooling it quickly by quenching in water, oil, or some other medium, to a certain extent prevent the return of the steel to its previous condition.

It is not possible to entirely prevent the return of the steel to its previous or natural condition. From a practical standpoint the more we do to prevent the return of the steel to the natural condition the harder and stronger it will be; therefore, it will be obvious that the final physical properties of the steel will depend on the *rate of cooling*.

Different rates of cooling may be obtained by using different cooling mediums, and also by holding these various cooling mediums at different temperatures. The above remarks make it clear that it is very necessary to maintain the quenching bath at a uniform temperature if uniform results are to be obtained.

It will now be obvious to the reader why the matter of size of the pieces being heat treated has such an important bearing on the final result. It is, of course, physically impossible to cool a 6 inch round bar as rapidly as can be done in the case of a 1 inch round bar. The great difference in the final physical properties produced by the different rate of cooling is clearly shown in Table B.

TABLE B

EFFECT OF SIZE ON RESULTS OF HEAT TREATMENT

SIZE	TENSILE STRENGTH Lbs. per sq. Inch	ELASTIC LIMIT Lbs. per sq. Inch	EXTENSION Per cent in 2 Inch	CONTRACTING AREA Per cent of original area
1-in. Rd.	138,500	106,000	18.80	60
2-in. Rd.	125,000	95,000	19.00	58
3-in. Rd.	112,000	84,000	19.50	56
4-in. Rd.	107,000	70,000	19.00	54
5-in. Rd.	105,000	69,000	18.90	54
6-in. Rd.	98,000	68,500	19.00	49

These tests were made on steel of exactly the same composition and the heat treatment given was identical in regard to quenching and drawing temperatures, the difference being in the time required to cool the pieces through a certain temperature range. This illustrates very clearly the fact that the result of heat treatment depends on the *Rate of Cooling*, all other factors such as analysis, quenching temperature, and final temperature being equal.

It is not very practical to work out a definite chart indicating the probable effect of size in heat treating, and this matter must, therefore, be determined by experience and by actual test.

Cleanliness is of importance in heat treating as well as all other manufacturing operations, and is particularly important in reference to quenching baths and tanks. *Where oil is used, it should be clean,* and it must be remembered that it will not last indefinitely. The effect of the high temperatures on quenching oils will in time change their specific heat or cooling ability; and this matter must, therefore, be watched with care.

Arrangements must be made to keep the cooling solutions agitated, as otherwise the parts being treated will raise the temperature of the cooling medium in their immediate neighborhood to a high degree, thus cutting down the cooling effect.

Oils may be agitated by pump circulation which carries the oil from the tank out through cooling colis and then back to the tank, or the piece may be kept in motion until it has lost most of its heat.

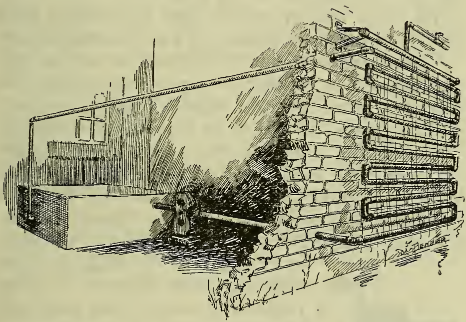
When water is used as a cooling medium, the agitation problem is not quite so hard to handle inasmuch as fresh water can be constantly added to the bath, and owing to the low cost the loss thus occasioned will not be serious.

The quenching tanks should be placed close to the furnaces, inasmuch as after being removed from the furnace the hot steel must reach the quenching medium with the least possible delay.

Where the pieces are light the quickest and most efficient cooling can be accomplished by having a heavy wire screen placed well down in the cooling medium on which the pieces can rest. The screen will allow the quenching medium to circulate freely and the pieces will be cooled much more rapidly than if they were resting on the bottom of the tank.

With heavy parts such as long bars, some mechanical arrangement for suspension in the liquid quenching medium should be made, so that either the bars or the bath can be kept moving constantly.

In quenching do not allow the pieces to rest on the bottom of the tank, because when this is done the upper part of the piece will be cooled much more rapidly than the lower part and uneven results and possible warping will occur.



Oil Quenching Tank with cooling unit located outside of building. Note this system is equipped with water spray pipe for use when necessary to increase the cooling effect.

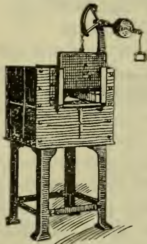
CHAPTER XI

DRAWING

DRAWING is a term used to designate a reheating of steel that has been heated and quenched. When steel is quenched from above the critical temperature No. 1, it is usually too hard and does not possess the necessary toughness for most purposes. For this reason the drawing or reheating process is necessary.

We have already shown that by heating steel above critical temperature No. 1 and cooling rapidly by quenching we retain in the steel certain properties induced by heating, owing to the fact that we have not given the steel sufficient time during the cooling process to return to its original condition.

Considering a piece of steel as it is removed from the quenching bath, we will now understand that its physical condition is fixed owing to the fact that no change can occur while the steel remains below a certain temperature. The tendency of the steel is to return to its original condition, and each increase of temperature above a certain point will allow the steel to approach more closely to its condition prior to the heating and quenching operations.


Small Heating Furnace.

The temperature at which the return to normal condition starts will vary with different steels; however, in most cases this temperature will be somewhere between 270° and 300° Fahr. The amount of change occurring will depend entirely on the temperature and the time at which the steel is held at this temperature. The change increases until the temperature has reached the critical point No. 1, when the change will be complete and the steel will have returned to exactly the same condition as it was prior to the initial heating and quenching. The drawing should not be carried beyond the critical temperature, as if this is done all the work of quenching and drawing will be wasted and the steel will again be in the same condition as it was prior to the first quenching. The ability to partially return the steel to the normal condition is naturally very valuable, inasmuch as it will enable us to produce any desired degree of strength, toughness, or hardness within the range of the particular steel which we may be using. The practical application of this operation is shown in the tables in another part of this book.

Like all other heating operations, drawing must be handled with care and above all with extreme accuracy. The hot oil bath gives the most accurate method of drawing where the temperatures do not exceed 600° Fahr. Molten lead may be successfully used for higher temperatures, and in some cases, where the furnace control is good and the proper care is exercised in their use, furnaces will give accurate and dependable drawing.

CHAPTER XII

ANNEALING

IT will sometimes be desirable to anneal alloy steel which may be either in the form of rolled or hammered bars or forgings. Such annealing may be for the purpose of rendering the steel softer so that it may be machined more readily, or it may be with the idea of refinement of the granular structure where this has been coarsened by the forging or rolling operation having been finished at too high a temperature. Internal stresses resulting from forging or rolling can also be relieved by proper annealing, and sometimes this operation is very desirable.

The equipment necessary for annealing will be similar to that used for other heat treatment work, and will consist primarily of a furnace for raising temperatures together with some means of lowering temperatures slowly.

In heating steel during the annealing process it is important that the furnace gases be so proportioned that they *do not contain an excess of oxygen.* Steel during the annealing process is maintained at relatively high temperatures for a considerable length of time, and if, therefore, the furnace atmosphere is of an oxidizing nature, considerable decarbonization will occur and a heavy scale will be formed as well as loss of carbon in the surface.

We have already pointed out that no change in the physical structure of the steel will take place unless the steel is heated slightly beyond the critical temperature No. 1, and therefore, where grain refinement is desired the annealing temperature will be above this point.

We have already shown that the slower the cooling from above this critical temperature the greater is the opportunity given the structural changes to reverse themselves, thus bringing the steel back to its normal condition. It will, therefore, be seen that annealing consists of raising the temperature of the steel to a point above the critical No. 1 and then allowing it to cool very slowly.

From the preceding explanation the reader understands that the degree of annealing will depend upon the selection of the right heating temperature and the rate of cooling. This annealing temperature will, of course, vary for different steels. On page 52 of this book will be found a table showing the approximate figures to be used.

As in all other heat treating, time is a factor as well as temperature, and after the steel has been brought to the proper annealing heat it must be held at this temperature for sufficient length of time for the necessary changes to take place. The time during which steel should be held at the annealing heat will depend primarily on the size of the pieces. No very definite rule can be made, and the actual time will vary from a few minutes in some cases to several days in others.

For small forgings, such as automobile engine connecting rods and similar parts, about 20 to 30 minutes at the annealing temperature will be sufficient to insure heat penetration and completion of the structural changes. For a bar 6 inches in diameter about two or three hours at the full annealing heat should insure penetration, although these are matters which must be worked out by experiment in each particular case.

Where it is necessary that a part be produced having a clean, smooth surface after annealing, it is usual to pack the parts in some non-active material, such as pulverized ashes or dry slaked lime. Other operators prefer to use charcoal or powdered anthracite coal; either of these substances will give satisfactory results, the pieces, of course, being packed in boxes having tight fitting lids or covers which will exclude all air.

The whole object of packing parts prior to annealing is to exclude air and thus prevent oxidization and decarbonization.

Where the steel is packed in boxes and surrounded by one of the previously mentioned substances, it must be borne in mind that the steel will not attain the full furnace temperature owing to the fact that it is surrounded by poor conductors of heat, and this matter must be considered in regulating the temperature of the furnace.

One of the best methods of reducing the temperature slowly is to leave the pieces in the furnace; shut off the fire and, having closed the doors, close up all openings or cracks with clay. When closed up tight the furnace will cool very slowly, and if the annealing temperature has been correct the annealing result will in all probability be entirely satisfactory.

ANNEALING TEMPERATURES

Straight Carbon Steels

.15 to .25 Carbon	1570° Fahr.
.25 to .35 Carbon	1550° Fahr.
.35 to .45 Carbon	1525° Fahr.
.45 to .55 Carbon	1500° Fahr.
.85 to 1.10 Carbon (Tool Steel)	1425° Fahr.

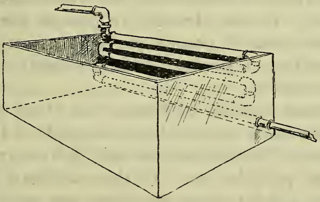
3½ Per Cent Nickel Steel

.15 to .25 Carbon	1530° Fahr.
.25 to .35 Carbon	1500° Fahr.
.35 to .45 Carbon	1450° Fahr.

Chrome Nickel Steel
(S. A. E. Specification 3120 to 3140)

.15 to .25 Carbon	1600° Fahr.
.25 to .35 Carbon	1550° Fahr.
.35 to .45 Carbon	1500° Fahr.

Where alloy steels have been severely overheated and a very coarse structure has thereby been produced, the condition can be frequently rectified by a double annealing process. This process consists of raising the temperature to about 180° Fahr. over the normal annealing temperature, cooling quickly and following this by the regular annealing, using the temperatures given for annealing in the above table. The temperatures given for annealing are of necessity only approximate and must be considered as such.



Quenching Tank with coil for cold water circulation.

CHAPTER XIII

TESTING HEAT TREATED STEEL

AFTER we have completed the heat treatment of steel, provided the work has been done properly, we should have a very close idea of just what results we have obtained. In order to check our work, however, it is desirable to submit the heat treated parts to certain tests for physical properties. Such tests will not only tell us whether or not the steel is suitable for the purposes for which it is to be used, but it will also serve to indicate as to whether or not our equipment, such as furnaces, quenching baths, pyrometers, etc., have been functioning properly.

The usual tests to which steels are submitted are for the purpose of determining the following physical properties: Tensile strength in pounds per square inch, elastic limit in pounds per square inch, elongation (usually as a percentage in 2 inches), and contraction of area.

The usual method of testing for these physical characteristics is to turn down a sample of the steel to a known diameter and submit it to a gradually increasing pull in one of the standard testing machines. The testing machines are so designed that the actual stress on the specimen can be read at all times, and this stress is increased until the specimen is fractured, thus giving the desired information.

Testing machines are large, heavy, and expensive, and the services of a thoroughly trained man are necessary in order to successfully operate them. Where considerable testing is to be done a machine is, of course, a necessary investment, but otherwise it is more economical to send sample pieces to one of the fully equipped commercial testing laboratories that handle this work and furnish accurate reports of the results obtained.

It has long been known that a relation exists in steel between hardness and tensile strength; and the method of determining the approximate tensile strength by first determining the hardness may, therefore, be used.

Hardness may be ascertained by one of several methods. The most widely used methods are those employing the Brinell testing machine and the Shore scleroscope.

The Brinell system consists of exerting a definite and known pressure on a hard steel ball of certain diameter which rests on the surface of the material to be tested. The area of the indentation made by the steel ball on the surface of the specimen is carefully measured and is used as a basis for figuring the so called Brinell hardness of the specimen. The Brinell machine is rather expensive, and where accurate results are to be obtained it must be used with great care. The results are, however, entirely reliable within certain hardness ranges. The Brinell method does not work very satisfactorily on extremely hard steels, owing to the fact that the impression will be too small to be measured with accuracy, and that the ball instead of penetrating the sample will flatten out to a certain extent.

The Shore scleroscope consists of a glass tube and a small piece of extremely hard steel which is free to travel up and down the center of the tube. The machine is so arranged that the glass tube is placed vertically and at right angles to the surface of the material to be tested, and the small piece of steel is allowed to fall through the tube from a certain height. The harder the sample to be tested the higher will the small piece of steel rebound, and the amount of this rebound is taken as a measure of the hardness of the sample. The scleroscope is perhaps the cheapest of all the standard hardness testers, and if used with care fairly reliable results may be obtained. The scleroscope is particularly useful in working on hard material, and it is, therefore, used for testing the hardness of tempered tool steel dies, the teeth of hardened gears, roller bearing and ball bearing surfaces, and other kindred work.

In the following tables will be found the Brinell and scleroscope hardness numbers and the approximate corresponding tensile strength in pounds per square inch on carbon, chrome nickel, and 3½ per cent nickel steels. These tables are as nearly accurate as possible, but must not be taken as being exact.

Carbon Steel

Scleroscope Reading	Brinell Reading	Tensile Strength in lbs. per sq. inch
20	130	63,000
30	195	108,000
40	260	150,000
50	325	200,000
60	390	250,000
70	455	290,000
80	520	335,000
90	585	390,000
100	650	425,000

Chrome Nickel Steels

Scleroscope Reading	Brinell Reading	Tensile Strength in lbs. per sq. inch
20	141	74,000
30	195	111,000
40	249	147,000
50	303	183,000
60	357	215,000
70	411	258,000
80	465	292,000
90	519	331,000
100	573	366,000

3½ Per Cent Nickel Steels

Scleroscope Reading	Brinell Reading	Tensile Strength in lbs. per sq. inch
20	158	70,000
30	213	100,000
40	268	145,000
50	323	180,000
60	378	225,000
70	433	260,000
80	488	280,000
90	543	320,000
100	598	350,000

CHAPTER XIV

CASE HARDENING OR CARBONIZING

IT is sometimes desirable to produce a piece of steel having an intensely hard exterior or surface, intended to resist wear, coupled with a tough and strong core or center having considerable resistance to shock.

This result is obtained by what is commonly known as case hardening or carbonizing. This process consists of taking a comparatively low carbon steel, and, after having formed it to the desired shape, raising the carbon content on the surface to a sufficiently high point so that when quenched it will become extremely hard. While under certain conditions steel can be made to absorb carbon, such absorption or penetration will not extend very far beneath the surface; and, therefore, when this material is quenched the interior, being of low carbon content, will merely be toughened, thus giving an extremely hard surface with a tough and strong supporting core or center.

Various materials under certain heat conditions will give up some of their carbon to steel, and among those commonly used may be mentioned charred leather, crushed and charred bone, charcoal, and certain gases which contain a large percentage of carbon such as carbon monoxide.

In commercial case hardening the pieces to be treated are packed in an iron box or container and are surrounded with the carbonizing material, which may consist of one of the foregoing substances or, better, of the numerous prepared carbonizing mixtures that are sold for this purpose. The box is now raised to a certain temperature in the furnace and held at this temperature for a definite length of time. When sufficient carbon penetration has taken place the parts are subjected to various heat treatments which will be described later.

The rate of case hardening and the depth of penetration are controlled by the following factors:

First, the class of steel.

Second, the class of carbonizing mixture.

Third, the shape of and the material from which the box or container is made.

Fourth, the temperature at which the carbonizing is done and the length of time during which this temperature is maintained.

Roughly speaking, the higher the temperature, the more rapidly will the carbonizing mixture give up its carbon to the steel, but this heat factor is governed by the degree of heat which the steel can stand without detrimental effect; and, therefore, a deep penetration can only be obtained safely by using the normal case hardening temperature and holding this for a length of time dependent on the depth of case required.

Attention is called to the following points in connection with this work.

Carbonizing Mixtures

There are many good carbonizing mixtures available, all having their good points. However, the following features should be considered when buying:

First—Should have a good heat conductivity.

Second—Should be uniform in granular size.

Third—Must carbonize at a uniform rate.

Fourth—Must be capable of being used time after time in order to be economical.

Fifth—Should not contain phosphorus or sulphur, inasmuch as these may be absorbed by the steel.

Sixth—Must be of uniform composition throughout so that it will give uniform results on all parts of the steel being carbonized.

A very good carbonizing medium can be made by mixing the following:

Barium Carbonate, 2 Parts.

Wood Charcoal, 3 Parts.

Both the barium carbonate and charcoal must be finely granulated and thoroughly mixed. This mixture has an advantage in that if spread out and exposed to the air, it will "revive," owing to the fact that the barium oxide produced during the carbonizing process will take up carbon dioxide from the air and in this way again become barium carbonate; the charcoal must of course be replenished after it has become depleted by use.

Case Hardening Boxes

The boxes used for hardening should be sufficiently heavy to withstand the high temperature used for a considerable length of time without warping, and should be made of material which is a good heat conductor. It is important that the boxes be so designed that after the pieces are packed in them they can be closed so as to exclude all air. Iron pipe is satisfactory for small pieces, although cast iron boxes are more generally used. Where long runs are contemplated it is sometimes economical to use boxes made from certain cast alloys. These special boxes are advertised in the trade journals and can be readily procured.

Carbonizing Furnaces

Furnaces for carbonizing should be such that the temperature can be accurately controlled over any desired period of time, and in this respect they, of course, do not differ from furnaces used for other heat treating operations.

Temperature for Case Hardening

There are so many factors, such as the character of the steel, kind of case hardening mixture used, the size of the case hardening boxes, depth of penetration desired, etc., that govern case hardening temperature that it is almost impossible to give any accurate data on this subject. The following list will probably be useful as a general guide on this subject, although it must be modified to meet special conditions.

Carbon Steel S. A. E. 1020

.10 to .25 carbon, 1625° to 1725° Fahr.

3½ Per Cent Nickel Steel S. A. E. 2320

.15 to .25 carbon, 1600° to 1650° Fahr.

Chrome Nickel Steel S. A. E. 3120

.15 to .25 carbon, 1625° to 1700° Fahr.

Depth of Penetration

The depth of penetration depends on numerous factors which have already been mentioned, and, owing to there being so many things that have a bearing on this matter, it is hardly practical to make any definite statement in regard to depth of penetration which may be expected for a given time and temperature. As a general guide to what may be expected, when working with a straight carbon steel using the previously mentioned barium carbonate mixture, the accompanying table can be referred to, although this is only approximate.

Approximate Carbon Penetration at 1650°F.		Approximate Carbon Penetration at 1775°F.	
Hours	Depth in Inches	Hours	Depth in Inches
1	0.030	1	0.040
2	0.045	2	0.050
3	0.050	3	0.075
4	0.060	4	0.085
5	0.065	5	0.098
6	0.070	6	0.110
7	0.080		

In case hardening it must be remembered that the temperature of the furnace is not the same as the temperature of the piece being case hardened. The heat has to first penetrate through the walls of the box and then through the case hardening mixture, and consequently the piece being carbonized will be at a lower temperature than the furnace itself.

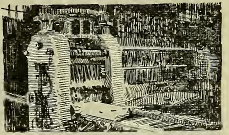
Where accurate results are required it is a good plan to make a few experiments by placing a thermo couple in contact with or near the pieces being treated, and also another thermo couple in the furnace so the difference in temperature between the furnace and the piece can be observed.

Heat Treatment after Carbonizing

When carbonization has been completed the hardening process is next undertaken, and it is of the greatest importance that this be carried out accurately and scientifically if uniform and dependable results are to be obtained.

It must be remembered that the carbonized pieces have been held at a temperature considerably above the critical range during a long period of time; and it, therefore, follows that the grain of the steel has been coarsened.

After hardening, the surface or case of a carbonized part will be intensely hard and brittle, and will in consequence not have any great degree of toughness. For these reasons it is necessary that we depend on the center or core of the piece to support the hard outside surface; and we must, therefore, bend our efforts toward putting the core in the best possible condition in regard to granular structure, strength, and elasticity.



Sheet Mill.

Speaking generally, the best method of obtaining this result is by first cooling the parts slowly, this being accomplished by allowing them to remain in the case hardening boxes until comparatively cold, then removing and proceeding with a refining treatment.

On page 92 will be found formulæ which may be used as a general guide for carbonizing operations. The important fact to remember is that no set rule can be given to cover all cases. Where a new job is undertaken time and money will be saved if the heat treater will take samples of the steel he intends working with, and submit them to the process he contemplates using for the work in hand. Should the treatment contemplated not be correct, the samples will show it and steps can be taken to avoid the loss of material and time that would result had tests not been made. It must be realized that experience and patience are necessary when good dependable results are to be obtained. Your first batch may turn out well. If it does you are very fortunate, but if it does not, don't be discouraged. If you fail there is a reason. Study it out and correct it next time.

Packing

Inasmuch as the heat in case hardening must penetrate first through the containing boxes and then through the case hardening mixture before reaching the surface of the steel, it is obvious that a uniform temperature on all parts of the piece being case hardened can not be obtained unless the piece is surrounded on all sides by equal thickness of case hardening mixture. As the rate and depth of penetration depend upon the temperature, it is obvious that to obtain uniform results we must surround the pieces being case hardened as nearly as possible with a uniform amount of case hardening mixture.

Packing is an important operation in case hardening and care should be used to see that the pieces being treated are placed as nearly as possible in the center of the case hardening box.

It is not wise to use very large case hardening boxes or to endeavor to place too many parts in the one box. When this is done the parts nearest the wall of the box will naturally attain a very much higher temperature than those near the center, and a nonuniform result will be secured.

Superficial Case Hardening. Where an extremely thin surface of hardened steel is required, and in cases where such hardening must be obtained quickly, the following method may be employed, although the results are not uniform nor, as a rule, particularly good:

Melt sufficient potassium cyanide in a pot so as to form a bath in which the parts to be case hardened may be immersed.

Raise the temperature of the molten potassium cyanide to about 1550° Fahr., and allow the parts to remain in this bath for about fifteen minutes. The length of time that the parts remain in the cyanide bath will depend on their size, but in any event it will be necessary that they remain for a sufficient length of time to insure uniform heat penetration all the way through to the center.

Ten minutes immersion will give a penetration of about 0.005 inch and twenty minutes a penetration of about 0.01 inch when using a straight carbon steel such as S. A. E. 1020.

The pieces should be removed from the cyanide bath and plunged directly into cold water, after which the surface will be found to be hard and the interior core in a fairly good condition.

Great care must be used in employing a molten cyanide bath, inasmuch as this material will give off highly poisonous fumes which should be carried off by suitable apparatus.

In case hardening it must be borne in mind that there are two objectives: The first, which is well known and commonly recognized, consists in obtaining a hard exterior surface, intended, of course, to resist wear and abrasion. The other, which is frequently overlooked although of equal importance, is the building up of a core of adequate strength and toughness so that it may give the proper support to the exterior or wearing surface.

In case hardening we believe it very necessary to examine the finished pieces in a more comprehensive manner than merely testing the exterior for hardness. The core examination referred to can be carried out by either cutting through one of the pieces, polishing the section and subjecting it to microscopic examination, or, in the event of the lack of the necessary equipment for such examination, a very good idea can be obtained by partially cutting through the piece and then fracturing. This will give an opportunity to examine the granular structure of the steel, and the thickness of the case.

CHAPTER XV

GENERAL REMARKS

HAVING read the previous chapters the reader will now understand the reasons underlying the following general remarks on the subject of the use of alloy steels.

If you are sure of what particular steel to use for a certain purpose, well and good; but if doubt exists in your mind, put the matter up to some reliable seller of this material. The sales department of the mills and the large warehouses are handling thousands of tons of alloy steel every day, and their wide experience will undoubtedly have covered the point on which you are not sure.

Do not buy too much on a price basis. Original cost must naturally be taken into account; but in view of the large amount of work that is done on alloy steel in the way of machining and heat treating and the vital importance of the parts manufactured being up to standard, it is absolutely essential that first class material be obtained. Remember that analysis is not the only point to be considered in the selection of alloy steels. Freedom from pipes, seams and other defects, accuracy in the matter of size, straightness of the bars, finish of the surface, and many other points are of great importance. Steel may conform to your specification in analysis and yet be made in such a way that it will develop cracks, checks, or other defects when it is subjected to the violent action of a quenching process.

In heating alloy steels, do not place a cold bar in an extremely hot furnace. This will apply more in the case of larger bars, and the reason will be obvious if the notes on this subject as given in another part of this book are read. Do not expect to get the same physical properties from a 10 inch round forging as you will from a 1 inch round bar just because the analysis may be the same and because you give it the same heat treatment. Where high physical properties are required from large forgings or large rolled bars, the desired result can to a certain extent be obtained by using a quenching temperature higher than that which would be used with a smaller section. However, irrespective of the size of the bar, the quenching temperature must not be raised to a point which will be detrimental to the steel. As a safe rule, do not exceed the quenching temperatures given in this book by more than 150° Fahr. Where large sections are being heat treated, higher physical properties will be obtained by raising the temperature, as already mentioned, and by using a quicker quenching medium; thus cold water may be substituted for oil in certain cases.

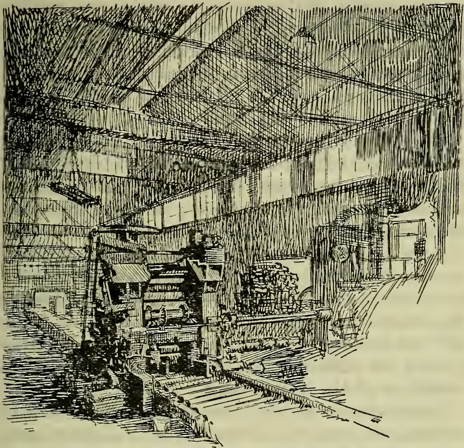
Do not place a heavy flat bar directly on the brick bottom of a furnace and then expect the lower part of the bar to have the same temperature as the top. Keep the pieces which you are heating slightly raised from the bottom of the furnace so that the hot gases can circulate around them, but in doing so place your supports sufficiently close together so that the hot bars will not sag down between the supports and thus become bent and crooked. A bar can be heated uniformly by placing it on the bottom of the furnace provided that it is turned over at frequent intervals. This method is satisfactory only in cases where a few pieces are being heated at once and where the operator can give the time necessary to constantly watch the heating operation. So arrange your shop that the distance between your furnace and the quenching bath is as short as possible. As soon as a steel has reached its proper quenching temperature all the way through to the center, it should be immediately quenched, and it should be quenched on a rising or stationary heat and not on a falling heat. If the distance between the furnace and the quenching bath is great, or if the method of handling the steel is clumsy and inefficient, considerable time will elapse between removing the bars from the furnace and the actual quenching. When this condition exists it will be necessary to overheat the bars in the first instance, which will tend to give a poor result.

If time is lost between the removal of steel from the furnace and the quench, and should the bars be heated to the correct quenching temperature, then by the time they reach the bath they will have dropped below this point, and, in consequence, the heat treatment will not be effective.

When you have finished your work and submitted it to physical tests, you may find that your physical properties are either higher or lower than you intended them to be. The remedy will, of course, lie in a change of the heat treatment formula that you originally used; and it is, therefore, obvious that accurate records of all operations should be kept.

It is a good plan, where considerable work is being done, to use a regular heat treatment form. A place for the customer's name, order numbers, description of the parts, sizes, weights, etc., should appear at the top. Under this should appear your shop instructions or heat treatment formula, and opposite this space there should be blank spaces for the shop men to fill in the actual temperatures and times which were used in executing the order.

Such a record properly kept will give invaluable information in reference to any particular order that has been handled in the past, and can also be used as a basis for determining rapidly and accurately the most desirable heat treatment formula for other work.



Universal Mill. Rolls plates and bars on all four sides.

Insist on the heat treating shop being kept clean and neat, and do not allow refuse bars and other scrap to accumulate. Such material gets in the way and cuts down the general shop efficiency, and there is always a possibility of bars of different analysis getting mixed up.

In selecting shop equipment for heat treating, do not depend on your own judgment too much unless you have had considerable past experience. Turn your problems over to reliable furnace people, and thus get the benefit of their experience for which they have probably paid a good price.

As we have explained elsewhere, rapid heating tends to expand the outside of a bar more quickly than the inside, thus giving it a tendency to crack. The reverse, of course, is true in quenching, inasmuch as the outside of the bar will shrink more rapidly than the inside, and this also has a tendency to crack the steel. For these reasons, it is obvious that square corners are to be avoided as much as possible, and wherever a radius or fillet can be used it renders the heat treatment much more safe.

Don't try to heat a piece of steel to 700° Fahr. in a furnace that shows a temperature of 1100 or 1200° Fahr. In other words, have your furnace at the maximum temperature which you desire the steel to attain, and then let the steel come up to the full furnace temperature. Where a furnace temperature is used which is in excess of the temperature desired in the steel, the outside part of the piece will reach the desired temperature before the inside, and you will not be able to allow the steel to remain in the furnace for sufficient length of time for the heat to penetrate all the way through.

Remember in drawing that the time element is of importance, and it is better to use a slightly lower temperature for a longer period of time, inasmuch as the changes brought about in the structure of the steel by a certain drawing temperature are more uniform throughout the whole piece when this temperature can be held for a considerable length of time. Bear in mind that a certain drawing temperature held for an hour will produce the same physical properties as a much higher temperature held for ten minutes. The result of the long draw will, however, be more uniform and better.

When case hardening, select a good grade of case hardening mixture made by reliable people; by so doing your work will be more rapidly handled, carbon penetration will be more uniform, and the operation will be more economical inasmuch as you will be able to use the mixture over and over again with less frequent renewal than is necessary with a cheap compound.

When carbonizing any piece use a pot of suitable size. At no point should there be less than 1¼ inches of case hardening mixture between the inside of the pot and any surface of the piece being carbonized, and the more nearly 1½ inches of case hardening mixture can be maintained all the way round the more uniform will be the result.

Always allow your carbonized parts to cool down slowly after the carbonizing process. If possible, allow the pots and their contents to cool down outside of the furnace and then follow the heat treating instructions which are given elsewhere.

Where pieces are to be case hardened, do not be satisfied with your work just because you have obtained a hard surface. A piece of common cold rolled shafting or screw stock or an ordinary mild steel bar can, by case hardening, be made just as hard on the surface as the highest grade of chrome nickel or other alloy steel. This is no indication, however, that a part has been produced which will do the work of a properly case hardened alloy steel part. In some certain instances surface hardness is the only characteristic desired in case hardened work, but as a general thing the case hardened part must have strength as well as hardness, and this can only be obtained to the maximum degree by the use of a high grade alloy steel, properly treated.

This book has made no attempt to cover the technical features of alloy steel problems, and it has been necessary to write in a very general way, only covering a few of the more important points. The use of alloy steel will develop many difficult problems, a solution of which can only be given by experience. Should you, therefore, be uncertain in regard to selection of an alloy steel, its heat treatment, or its application, do not guess at the answer to your question, but put it up to the people from whom you are purchasing your steel.

Watch your furnace atmosphere. An excess of air is bound to give you trouble. The surface of your steel will decarbonize and will, therefore, not harden as it should, and heavy scale will be formed, sometimes ruining parts that are to be machined, or at any rate giving the machine shop a great deal of trouble with cutting tools that are called upon to remove this hard scale.

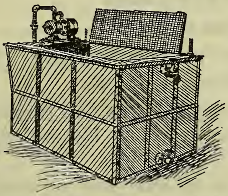
In forging alloy steels remember that steels containing chromium must not be forged at low heats, inasmuch as this will develop defects in the material. The low limit of heat for forging steel containing chromium will, of course, depend upon the percentage of carbon and chromium present, but it is fairly safe to assume that chrome nickel steels should not be forged at a temperature of less than 1550° Fahr.

Chrome nickel steel of a high carbon content (from .55 to .65 carbon), when properly heat treated makes a very fine die block and one which, while sufficiently soft to be machined, is hard enough and tough enough to last for a long period of time. This is a great advantage in making certain drop forge dies, owing to the fact that the danger in quenching a machined die is eliminated. The manufacture of alloy steel die blocks is a specialty which can not be covered in this book, although those interested can obtain full information from the alloy steel producers.

When difficulty is experienced in getting furnace temperature so adjusted that scaling will not occur, the difficulty may be overcome by placing in the furnace some charcoal or a piece of wood. The wood or charcoal will combine readily with any free oxygen that may be present and thus prevent scaling or decarbonization of the steel.

Checking Pyrometers:

This operation is most important and can be taken care of without the use of expensive equipment. Take a clean crucible pot (fire clay or iron) and melt in it some pure common table salt (sodium chloride). Increase the temperature to about 1625° Fahr. and then put the thermo couple (without protecting tube) in the bath. As soon as the indicator shows that the theremo couple has reached the temperature of the salt, remove the pot from the fire and allow it to cool. During the cooling operation readings of the indicator should be taken every ten seconds and the result plotted as a time temperature curve. The kick or flat spot in the curve will show the point at which the salt solidifies or freezes. This point *should* be 1474° Fahr., and if your pyrometer indicates a different point you will know just what correction to make in your reading.



Quenching Tank, with Circulating Pump.

S. A. E. SPECIFICATIONS

A system of numbers has been adopted for the naming of practically all the standard grades of alloy steels. These numbers give a very convenient way of indicating a certain alloy steel and can be used in sending telegrams, letters, or shop drawings and many other places where a full description of the steel would take up a lot of room.

The first figure indicates the class of steel. The second figure indicates the approximate percentage of the principal alloying element. The last two or three figures represent the carbon desired in one hundredths of one per cent or "points."

The key list of first figures is as follows:

1—Carbon Steels.

2—Nickel Steels.

3—Chrome Nickel Steels

5—Chromium Steels.

6—Chrome Vanadium Steels.

9—Silico-Manganese Steels.

From the above SAE 3120 is a chrome nickel steel of about 1 per cent (1 to 1½) nickel, carbon 0.20 (15 to 25).

SAE 2335 is a nickel steel of about 3 per cent (3.25-3.75) nickel, carbon 0.35 (30-40).

SAE 6150 is a chrome vanadium steel of about 1 per cent chrome (0.80 to 1.10), carbon 0.50 (45-55).

SAE 51120 is a chromium steel of about 1 per cent chrome (90-1.10), carbon 1.20 per cent (1.10-1.30).

3½% Nickel Steel — 35-45 Carbon

SAE Specification 2340

Quench in oil at 1425° to 1475° Fahr.

Drawing Temperature	Tensile Strength	Elastic Limit	Red. of Area	Ext. in 2 Inch	Brinell Hardness	Scleroscope Hardness
400	240,000	215,000	32.5%	10.0%	450	70
500	230,000	204,000	34.5%	11.0%	427	65
600	215,000	190,000	37.5%	12.0%	400	61
700	196,000	171,000	42.0%	13.0%	370	56
800	175,000	150,000	47.0%	14.0%	335	51
900	155,000	130,000	51.0%	16.0%	295	46
1,000	135,000	110,000	55.0%	18.0%	260	42
1,100	117,000	92,000	58.0%	20.0%	235	38
1,200	105,000	78,000	60.0%	21.5%	215	36
1,300	96,000	69,000	61.0%	22.0%	205	35
1,400	90,000	60,000	62.5%	22.5%	200	35

3½% Nickel Steel — 25-35 Carbon

SAE Specification 2330

Quench in Oil at 1450° to 1500° Fahr.

Drawing Temperature	Tensile Strength	Elastic Limit	Red. of Area	Ext. in 2 Inch	Brinell Hardness	Scleroscope Hardness
400	220,000	190,000	35%	10%	436	61
500	210,000	182,000	37%	11%	420	59
600	198,000	170,000	40%	12%	400	57
700	180,000	154,000	44%	13%	370	54
800	160,000	135,000	49%	14%	330	50
900	140,000	115,000	54%	16%	290	45
1,000	120,000	95,000	59%	18%	250	41
1,100	104,000	77,000	63%	20%	210	37
1,200	92,000	64,000	66%	22%	180	34
1,300	85,000	55,000	68%	24%	162	32
1,400	80,000	48,000	70%	25%	150	30

3½% Nickel Steel — 15-25 Carbon

SAE Specification 2320

Quench in oil at 1475° to 1525° Fahr.

Drawing Temperature	Tensile Strength	Elastic Limit	Red. of Area	Ext. in 2 Inch	Brinell Hardness	Scleroscope Hardness
400	170,000	140,000	45%	11.0%	375	55
500	168,000	136,000	46%	12.0%	368	54
600	162,000	130,000	48%	13.5%	355	52
700	155,000	123,000	51%	15.5%	340	50
800	145,000	112,000	55%	18.5%	310	46
900	130,000	99,000	60%	21.5%	280	42
1,000	112,000	84,000	65%	25.0%	240	38
1,100	96,000	68,000	69%	27.0%	200	34
1,200	82,000	54,000	72%	29.0%	165	31
1,300	75,000	45,000	74%	30.0%	140	29
1,400	70,000	38,000	75%	31.0%	125	27

210 Brinell considered good for machining properties.

Chrome Nickel Steel — 35-45 Carbon

SAE Specification 3140

Quench in oil at 1475° to 1500° Fahr.

Drawing Temperature	Tensile Strength	Elastic Limit	Red. of Area	Ext. in 2 Inch	Brinell Hardness	Scleroscope Hardness
400	220,000	190,000	27%	7.5%	425	65
500	210,000	185,000	28%	8.0%	410	64
600	205,000	175,000	30%	9.0%	390	62
700	195,000	160,000	34%	10.5%	370	59
800	175,000	140,000	39%	12.5%	345	56
900	150,000	126,000	46%	14.0%	315	52
1,000	130,000	105,000	52%	16.0%	285	47
1,100	115,000	94,000	56%	17.0%	255	42
1,200	100,000	84,000	60%	18.0%	225	38
1,300	93,000	80,000	61%	19.0%	215	36
1,400	90,000	75,000	62%	20%	210	35

Chrome Nickel Steel — 30-40 Carbon

SAE Specification 3135

Quench in oil at 1475° to 1500° Fahr.

Drawing Temperature	Tensile Strength	Elastic Limit	Red. of Area	Ext. in 2 Inch	Brinell Hardness	Scleroscope Hardness
400	210,000	170,000	33%	10.0%	425	58
500	205,000	165,000	36%	10.0%	400	56
600	200,000	160,000	40%	10.5%	375	54
700	190,000	145,000	45%	11.0%	360	52
800	170,000	130,000	49%	12.0%	340	49
900	150,000	115,000	54%	13.5%	310	45
1,000	130,000	100,000	58%	14.5%	280	41
1,100	115,000	90,000	61%	16.0%	250	38
1,200	100,000	80,000	64%	17.5%	225	35
1,300	90,000	75,000	66%	19.0%	215	33
1,400	85,000	72,000	67%	21.0%	210	30

Chrome Nickel Steel — 25-35 Carbon

SAE Specification 3130

Quench in oil at 1500° to 1525° Fahr.

Drawing Temperature	Tensile Strength	Elastic Limit	Red. of Area	Ext. in 2 Inch	Brinell Hardness	Scleroscope Hardness
400	190,000	155,000	37.5%	10%	365	50
500	188,000	150,000	41.0%	11%	360	49
600	180,000	140,000	46.0%	12%	350	48
700	167,000	128,000	52.0%	13%	325	46
800	150,000	115,000	59.0%	15%	315	43
900	134,000	102,000	63.0%	17%	282	40
1,000	120,000	90,000	65.0%	20%	260	38
1,100	104,000	81,000	66.0%	23%	223	35
1,200	92,000	76,000	68.0%	26%	215	32
1,300	86,000	72,000	69.0%	28%	210	31
1,400	80,000	70,000	70.0%	30%	200	30

Chrome Nickel Steel 15-25 Carbon

SAE Specification 3120

Quench in oil at 1575° to 1600° Fahr.

Drawing Tempera- ture	Tensile Strength	Elastic Limit	Red. of Area	Ext. in 2 Inch	Brinell Hardness	Sclero- scope Hardness
400	160,000	120,000	52.5%	15.0%	275	46
500	155,000	116,000	54.0%	15.5%	265	45
600	148,000	110,000	57.0%	16.0%	250	44
700	137,000	102,000	61.0%	16.5%	240	42
800	125,000	95,000	65.0%	18.0%	225	41
900	111,000	84,000	69.0%	21.0%	205	38
1,000	100,000	74,000	71.0%	24.5%	185	35
1,100	91,000	66,000	71.5%	28.5%	175	33
1,200	84,000	60,000	72.0%	31.5%	160	30
1,300	80,000	54,000	72.5%	33.5%	150	29
1,400	75,000	50,000	72.5%	35.0%	150	28

DEFINITIONS

Tensile Strength — Generally expressed in pounds per square inch and as such represents the greatest load a bar, whose sectional area is one square inch (1″ square, ½″ x 2″, 1.13″ round, etc.), can sustain when applied gradually in direction of its length.

Ultimate Strength—From practical standpoint same as Tensile Strength.

Elastic Limit—A term usually expressed in pounds per square inch. If this stress is exceeded the specimen will take a permanent set; for example, a spring stressed beyond its elastic limit will not return to its original shape when load is released.

Yield Point—From practical standpoint may be considered same as Elastic Limit.

Safe Load—The stress that may with safety be applied to any part. This stress must never exceed the elastic limit and is usually considerably less than this figure.

Elongation or Extension—The amount of stretch in a test specimen produced by application of stress sufficient to cause breakage usually expressed as a percentage of a 2″ length, marked off before stress is applied.

Reduction of Area or Contraction of Area—Amount of reduction in cross section of a broken test specimen expressed as a percent of the original area.

Heat Temperatures and Colors for Hardening

Centigrade Degrees	Fahrenheit Degrees	Colors
400	752	Red Heat, visible in the dark
474	884	Red Heat, visible in the twilight
525	977	Red Heat, visible in the daylight
581	1077	Red Heat, visible in the sunlight
700	1292	Dark Red
800	1472	Dull Cherry Red
900	1652	Cherry Red
1000	1832	Bright Cherry Red
1100	2012	Orange Red
1200	2192	Orange Yellow
1300	2372	Yellow White
1400	2552	White Welding Heat

Heats and Temper Colors of Steel Produced by Heat

Centigrade Degrees	Fahrenheit Degrees	Colors
215.6	420	Very Faint Yellow
221.11	430	Very Pale Yellow
226.67	440	Light Yellow
232.23	450	Pale Straw Yellow
237.78	460	Straw Yellow
243.34	470	Deep Straw Yellow
248.9	480	Dark Yellow
254.45	490	Yellow Brown
260	500	Brown Yellow
265.56	510	Red Brown
271.11	520	Brown Purple
276.67	530	Light Purple
282.23	540	Full Purple
287.78	550	Dark Purple
293.34	560	Light Blue
298.9	570	Dark Blue

Flash and Fire Tests of Various Oils

Name	Flash Degrees Fahrenheit	Fire Degrees Fahrenheit
Corn	480	635
Cottonseed	582	644
Prime Lard*	{530 600}	644
No. 2 Lard**	419	468
Boiled Linseed	378	572
Raw Linseed	525	644
Neatsfoot	439	523
Olive	451	541
Light Mineral Oil (25° Beaume)	410	475
75% Light Mineral, 225% Neatsfoot	410	471
75% Light Mineral, 50% Lard	410	489
50% Light Mineral, 50% Lard	423	513
25% Light Mineral, 75% Lard	441	543
Sperm No. 1	428	518
Sperm No. 2	486	574

*Acidity not to exceed 2.0 per cent, determined as Oleic Acid.
**Acidity not to exceed 15.0 per cent, determined as Oleic Acid.

Melting Points of Chemical Elements

Supplied by the United States Bureau of Standards in Washington from latest determinations. These values are the most accurate procurable at the present time. The values originally determined in Centigrade have been converted directly into Fahrenheit, and these Fahrenheit readings should not be taken as correct to a degree at the higher temperatures.

Element	Cent.	Fahr.	Element	Cent.	Fahr.
Aluminum	659	1218	Mercury	—39	—38
Antimony	630	1166	Molybdenum	2500?	4532?
Barium	850	1562	Nickel	1452	2646
Bismuth	271	520	Nitrogen	—210	—346
Boron	2200?	3992?	Oxygen	—218	—360
Calcium	810	1490	Palladium	1549	2820
Carbon	3600?	6510?	Phosphorus	+44	+111
Chlorine	—102	—151	Platinum	1755	3191
Chromium	1520	2768	Potassium	62	144
Cobalt	1480	2696	Silicon	1420	2588
Copper	1083	1981	Silver	960	1761
Gold	1063	1945	Sodium	97	207
Hydrogen	—259	—434	Sulphur S1	113	236
Iodine	113	236	Tantalum	2850?	5160?
Iridium	2350?	4262?	Tin	232	450
Iron	1530	2786	Titanium	1800?	3272?
Lead	327	621	Tungsten	3000?	5430?
Magnesium	651	1204	Vanadium	1720?	3128?
Manganese	1260	2300	Zinc	419	787

TEMPERATURES

Conversion Tables

Degrees Centigrade and Fahrenheit						Degrees Fahrenheit and Centigrade					
C	F	C	F	C	F	F	C	F	C	F	C
0	32	520	968	860	1580	32	0	1040	560	1720	938
100	212	530	986	870	1598	212	100	1060	571	1740	949
200	392	540	1004	880	1616	400	204	1080	582	1760	960
210	410	550	1022	890	1634	420	216	1100	593	1780	971
220	428	560	1040	900	1652	440	227	1120	604	1800	982
230	446	570	1058	910	1670	460	238	1140	615	1820	993
240	464	580	1076	920	1688	480	249	1160	626	1840	1004
250	482	590	1094	930	1706	500	260	1180	637	1860	1015
260	500	600	1112	940	1724	520	271	1200	648	1880	1026
270	518	610	1130	950	1742	540	282	1220	659	1900	1038
280	536	620	1148	960	1760	560	293	1240	670	1920	1049
290	554	630	1166	970	1778	580	305	1260	681	1940	1060
300	572	640	1184	980	1796	600	316	1280	693	1960	1071
310	590	650	1202	990	1814	620	327	1300	705	1980	1082
320	608	660	1220	1000	1832	640	338	1320	716	2000	1093
330	626	670	1238	1010	1850	660	349	1340	727	2020	1105
340	644	680	1256	1020	1868	680	360	1360	738	2040	1116
350	662	690	1274	1030	1886	700	371	1380	749	2060	1127
360	680	700	1292	1040	1904	720	382	1400	760	2080	1138
370	698	710	1310	1050	1922	740	393	1420	771	2100	1149
380	716	720	1328	1060	1940	760	405	1440	782	2120	1160
390	734	730	1346	1070	1958	780	416	1460	793	2140	1171
400	752	740	1364	1080	1976	800	427	1480	804	2160	1182
410	770	750	1382	1090	1994	820	438	1500	816	2180	1193
420	788	760	1400	1100	2012	840	449	1520	827	2200	1204
430	806	770	1418	1110	2030	860	460	1540	838	2220	1216
440	824	780	1436	1120	2048	880	471	1560	849	2240	1227
450	842	790	1454	1130	2066	900	482	1580	860	2260	1238
460	860	800	1472	1140	2084	920	493	1600	871	2280	1249
470	878	810	1490	1150	2102	940	504	1620	882	2300	1260
480	896	820	1508	1160	2120	960	516	1640	893	2320	1271
490	914	830	1526	1170	2138	980	527	1660	904	2340	1283
500	932	840	1544	1180	2156	1000	538	1680	915	2360	1294
510	950	850	1562	1190	2174	1020	549	1700	927	2380	1305

Rules for Conversion

To change Centigrade to Fahrenheit, multiply by 9 and divide by 5, add 32. Result is equivalent Fahrenheit temperature.

To change Fahrenheit to Centigrade, subtract 32, multiply remainder by 5 and divide by 9. Result is equivalent Centigrade temperature.

GALLONS IN CYLINDRICAL TANKS

Depth in Feet	DIAMETERS IN FEET													
	5	6	7	8	9	10	12	14	16	18	20	25	30	35
1	147	212	288	376	476	588	846	1152	1504	1904	2350	3672	5288	7197
5	734	1058	1439	1880	2379	2938	4230	5758	7520	9518	11751	18360	26438	35986
6	881	1269	1727	2256	2855	3525	5076	6909	9025	11422	14101	22032	31726	43183
7	1028	1481	2015	2632	3331	4113	5922	8061	10529	13325	16451	25704	37014	50380
8	1175	1692	2303	3008	3807	4700	6768	9212	12033	15229	18801	29376	42301	57577
9	1322	1904	2591	3384	4283	5288	7614	10364	13537	17132	21151	33048	47589	64774
10	1469	2115	2879	3760	4759	5875	8460	11515	15041	19036	23501	36720	52877	71971
12	1762	2538	3455	4512	5711	7050	10152	13818	18049	22843	28201	44064	63452	86365
14	2056	2961	4030	5264	6662	8225	11844	16121	21033	26650	32901	51408	74027	100759
16	2350	3384	4606	6016	7614	9400	13536	18424	24066	30458	37602	58752	84603	115154
18	2644	3807	5182	6768	8566	10575	15228	20727	27074	34265	42302	66096	95178	129548
20	2938	4230	5758	7520	9518	11750	16921	23030	30082	38072	47002	73440	105753	143942
25	3672	5288	7197	9400	11897	14688	21151	28788	37603	47590	58753	91800	132192	179928
30	4406	6345	8636	11280	14277	17626	25381	34545	45123	57108	70503	110160	158630	215913
35	5141	7403	10076	13160	16656	20563	29611	40303	52643	66626	82254	128520	185068	251899
40	5875	8460	11515	15040	19036	23501	33841	46060	60164	76144	94004	146880	211507	287884
45	6610	9518	12955	16920	21415	26440	38071	51818	67685	85662	105755	165239	237945	323870
50	7344	10576	14394	18800	23794	29376	42301	57575	75205	95180	117505	183600	264383	359855
60	8813	12691	17273	22561	28553	35251	50762	69090	90246	114216	141006	220319	317260	431826
70	10283	14806	20152	26321	33312	41126	59222	80605	105287	133252	164507	257039	370137	503797
80	11750	16921	23031	30081	38071	47002	67682	92120	120328	152288	188008	293759	423013	575768
90	13219	19036	25909	33841	42830	52877	76143	103635	135369	171324	211509	330479	475890	647739
100	14688	21151	28788	37601	47589	58752	84603	115150	150410	190360	235010	367199	528767	719710

$$1 \text{ Gallon} = 231 \text{ cu. in.} = \frac{1 \text{ cu. ft.}}{7.4805} = 0.13368 \text{ cu. ft.}$$

Weight of Round and Square Steel per Lineal Inch

Inch	Size	Round	Square	Inch	Size	Round	Square	Inch	Size	Round	Square
	0	.00	.0000		0	2.01	2.55		0	8.03	10.2
	1-16	.00	.0011		1-16	2.09	2.658		1-16	8.20	10.416
	1-8	.00	.0044		1-8	2.18	2.767		1-8	8.37	10.633
	3-16	.00	.0995		3-16	2.27	2.88		3-16	8.54	10.850
	1-4	.01	.0177		1-4	2.36	2.993		1-4	8.71	11.067
	5-16	.02	.0278		5-16	2.45	3.110		5-16	8.89	11.292
	3-8	.03	.0398		3-8	2.54	3.227		3-8	9.07	11.517
0	7-16	.04	.0542	3	7-16	2.64	3.348	6	7-16	9.25	11.742
	1-2	.06	.0708		1-2	2.73	3.471		1-2	9.43	11.967
	9-16	.07	.0897		9-16	2.83	3.595		9-16	9.61	12.208
	5-8	.09	.1107		5-8	2.93	3.723		5-8	9.79	12.433
	11-16	.11	.1341		11-16	3.03	3.853		11-16	9.98	12.675
	3-4	.13	.1580		3-4	3.14	3.985		3-4	10.16	12.908
	13-16	.15	.1870		13-16	3.24	4.118		13-16	10.35	13.15
	7-8	.17	.2166		7-8	3.35	4.254		7-8	10.54	13.4
	15-16	.20	.2490		15-16	3.46	4.392		15-16	10.74	13.633
	0	.22	.2833		0	3.57	4.533		0	10.93	13.883
	1-16	.25	.3209		1-16	3.68	4.776		1-16	11.13	14.133
	1-8	.28	.3585		1-8	3.80	4.821		1-8	11.33	14.383
	3-16	.31	.3995		3-16	3.91	4.968		3-16	11.52	14.633
	1-4	.35	.4426		1-4	4.03	5.117		1-4	11.73	14.892
	5-16	.38	.4880		5-16	4.14	5.27		5-16	11.93	15.15
	3-8	.42	.5356		3-8	4.27	5.423		3-8	12.13	15.409
1	7-16	.46	.5855	4	7-16	4.39	5.579	7	7-16	12.34	15.675
	1-2	.50	.6375		1-2	4.52	5.737		1-2	12.55	15.947
	9-16	.54	.6917		9-16	4.64	5.898		9-16	12.76	16.208
	5-8	.59	.7481		5-8	4.77	6.061		5-8	12.97	16.475
	11-16	.64	.8068		11-16	4.90	6.225		11-16	13.18	16.743
	3-4	.68	.8675		3-4	5.03	6.392		3-4	13.40	17.017
	13-16	.73	.9308		13-16	5.17	6.562		13-16	13.61	17.300
	7-8	.78	.9958		7-8	5.30	6.734		7-8	13.84	17.567
	15-16	.84	1.063		15-16	5.44	6.908		15-16	14.05	17.85
	0	.89	1.133		0	5.58	7.083		0	14.28	18.133
	1-16	.95	1.2051		1-16	5.72	7.262		1-16	14.50	18.420
	1-8	1.01	1.279		1-8	5.86	7.442		1-8	14.73	18.708
	3-16	1.07	1.355		3-16	6.00	7.624		3-16	14.95	19.
	1-4	1.13	1.435		1-4	6.15	7.81		1-4	15.18	19.283
	5-16	1.19	1.515		5-16	6.30	7.997		5-16	15.41	19.575
	3-8	1.26	1.598		3-8	6.45	8.186		3-8	15.65	19.875
2	7-16	1.33	1.683	5	7-16	6.60	8.375	8	7-16	15.88	20.167
	1-2	1.39	1.770		1-2	6.75	8.567		1-2	16.12	20.467
	9-16	1.46	1.860		9-16	6.90	8.767		9-16	16.36	20.775
	5-8	1.54	1.952		5-8	7.06	8.967		5.8	16.60	21.075
	11-16	1.61	2.046		11-16	7.22	9.167		11-16	16.83	21.383
	3-4	1.69	2.083		3-4	7.38	9.367		3-4	17.08	21.692
	13-16	1.76	2.241		13-16	7.54	9.575		13-16	17.32	22.008
	7-8	1.84	2.341		7-8	7.70	9.783		7-8	17.57	22.325
	15-16	1.92	2.445		15-16	7.86	9.992		15-16	17.82	22.633

Weight of Round and Square Steel per Lineal Inch

Size	Round	Square	Size	Round	Square	Size	Round	Square
0	18.07	22.950	0	32.13	40.800	0	50.19	63.768
1-16	18.32	23.270	1-16	32.46	41.232	1-16	50.61	64.291
1-8	18.58	23.600	1-8	32.80	41.664	1-8	51.03	64.832
3-16	18.83	23.917	3-16	33.13	42.096	3-16	51.45	65.366
1-4	19.09	24.242	1-4	33.48	42.528	1-4	51.87	65.900
5-16	19.34	24.575	5-16	33.81	42.963	5-16	52.30	66.436
3-8	19.61	24.908	3-8	34.17	43.400	3-8	52.73	66.972
9 7-16	19.87	25.233	12 7-16	34.51	43.833	15 7-16	53.16	67.520
1-2	20.13	25.567	1-2	34.86	44.268	1-2	53.59	68.068
9-16	20.40	25.908	9-16	35.21	44.718	9-16	54.02	68.634
5-8	20.67	26.25	5-8	35.56	45.168	5-8	54.46	69.200
11-16	20.93	26.591	11-16	35.91	45.618	11-16	54.89	69.734
3-4	21.21	26.933	3-4	36.27	46.068	3-4	55.33	70.268
13-16	21.48	27.283	13-16	36.62	46.518	13-16	55.77	70.834
7-8	21.76	27.633	7-8	36.98	46.968	7-8	56.21	71.400
15-16	22.03	27.983	15-16	37.33	47.418	15-16	56.66	71.966
0	22.31	28.333	0	37.70	47.868	0	57.10	72.533
1-16	22.59	28.683	1-16	38.06	48.35	1-16	57.55	73.102
1-8	22.87	29.042	1-8	38.42	48.832	1-8	57.99	73.671
3-16	23.15	29.408	3-16	38.79	49.282	3-16	58.45	74.251
1-4	23.44	29.767	1-4	39.16	49.732	1-4	58.90	74.832
5-16	23.72	30.133	5-16	39.53	50.218	5-16	59.35	75.416
3-8	24.01	30.5	3-8	39.90	50.704	3-8	59.81	76.000
10 7-16	24.30	30.867	13 7-16	40.28	51.168	16 7-16	60.27	76.566
1-2	24.60	31.242	1-2	40.65	51.632	1-2	60.73	77.132
9-16	24.89	31.617	9-16	41.03	52.116	9-16	61.19	77.726
5-8	25.19	31.983	5-8	41.41	52.600	5-8	61.65	78.316
11-16	25.48	32.358	11-16	41.79	53.100	11-16	62.11	78.908
3-4	25.78	32.741	3-4	42.17	53.600	3-4	62.58	79.500
13-16	26.08	33.125	13-16	42.56	54.066	13-16	63.05	80.084
7-8	26.39	33.508	7-8	42.94	54.532	7-8	63.52	80.668
15-16	26.68	33.900	15-16	43.33	55.032	15-16	63.99	81.275
0	27.00	34.283	0	43.72	55.532	0	64.46	81.883
1-16	27.30	34.675	1-16	44.11	56.032	1-16	64.94	82.481
1-8	27.61	35.075	1-8	44.50	56.532	1-8	65.41	83.080
3-16	27.92	35.458	3-16	44.90	57.032	3-16	65.89	83.690
1-4	28.24	35.858	1-4	45.29	57.532	1-4	66.37	84.300
5-16	28.54	36.258	5-16	45.69	58.032	5-16	66.85	84.919
3-8	28.87	36.658	3-8	46.09	58.532	3-8	67.34	85.532
11 7-16	29.19	37.067	14 7-16	46.49	59.058	17 7-16	67.82	86.150
1-2	29.50	37.467	1-2	46.90	59.568	1-2	68.31	86.768
9-16	29.83	37.875	9-16	47.30	60.084	9-16	68.80	87.400
5-8	30.15	38.291	5-8	47.71	60.600	5-8	69.29	88.032
11-16	30.47	38.700	11-16	48.12	61.118	11-16	69.78	88.666
3-4	30.80	39.117	3-4	48.53	61.636	3-4	70.28	89.300
13-16	31.12	39.533	13-16	48.94	62.168	13-16	70.77	89.924
7-8	31.46	39.875	7-8	49.35	62.700	7-8	71.27	90.548
15-16	31.79	40.375	15-16	49.77	63.234	15-16	71.77	91.174

Weight of Round and Square Steel per Lineal Inch

Size	Round	Square	Size	Round	Square	Size	Round	Square
0	72.27	91.800	0	98.37	124.968	0	128.48	163.2
1-16	72.77	92.439	1-16	98.94	125.718	1-16	129.17	164.064
1-8	73.28	93.079	1-8	99.54	126.468	1-8	129.82	164.928
3-16	73.78	93.739	3-16	100.13	127.200	3-16	130.49	165.792
1-4	74.29	94.400	1-4	100.72	127.932	1-4	131.17	166.656
5-16	74.80	95.034	5-16	101.32	128.682	5-16	131.85	167.520
3-8	75.31	95.668	3-8	101.91	129.432	3-8	132.53	168.384
18 7-16	75.82	96.318	21 7-16	102.51	130.198	24 7-16	133.20	169.248
1-2	76.34	96.968	1-2	103.11	130.964	1-2	133.89	170.112
9-16	76.86	97.634	9-16	103.71	131.732	9-16	134.57	170.982
5-8	77.38	98.300	5-4	104.31	132.500	5-8	135.26	171.852
11-16	77.90	98.966	11-16	104.91	133.266	11-16	135.94	172.726
3-4	78.42	99.632	3-4	105.52	134.032	3-4	136.63	173.600
13-16	78.94	100.282	13-16	106.13	134.816	13-16	137.32	174.466
7-8	79.47	100.932	7-8	106.73	135.600	7-8	138.02	175.332
15-16	79.99	101.600	15-16	107.35	136.366	15-16	138.71	176.202
0	80.52	102.268	0	107.96	137.132	25	139.41	177.072
1-16	81.05	102.950	1-16	108.57	137.916			
1-8	81.59	103.632	1-8	109.19	138.700			
3-16	82.12	104.316	3-16	109.81	139.5			
1-4	82.66	105.000	1-4	110.43	140.300			
5-16	83.19	105.682	5-16	111.05	141.066			
3-8	83.73	106.364	3-8	111.67	141.832			
19 7-16	84.27	107.048	22 7-16	112.29	142.632			
1-2	84.82	107.732	1-2	112.92	143.432			
9-16	85.36	108.432	9-16	113.55	144.232			
5-8	85.91	109.132	5-8	114.18	145.032			
11-16	86.45	109.832	11-16	114.81	145.832			
3-4	87.00	110.532	3-4	115.44	146.632			
13-16	87.56	111.232	13-16	116.08	147.450			
7-8	88.11	111.932	7-8	116.72	148.268			
15-16	88.66	112.632	15-16	117.35	149.068			
0	89.22	113.333	0	118.00	149.868			
1-16	89.78	114.032	1-16	118.64	150.684			
1-8	90.34	114.732	1-8	119.28	151.500			
3-16	90.90	115.450	3-16	119.93	152.332			
1-4	91.47	116.168	1-4	120.57	153.164			
5-16	92.03	116.900	5-16	121.22	153.982			
3-8	92.60	117.632	3-8	121.87	154.800			
20 7-16	93.17	118.350	23 7-16	122.52	155.634			
1-2	93.74	119.068	1-2	123.18	156.468			
9-16	94.31	119.800	9-16	123.84	157.300			
5-8	94.88	120.532	5-8	124.50	158.132			
11-16	95.46	121.266	11-16	125.15	158.816			
3-4	96.04	122.000	3-4	125.82	159.500			
13-16	96.62	122.734	13-16	126.48	160.500			
7-8	97.20	123.468	7-8	127.14	161.500			
15-16	97.78	124.218	15-16	127.81	162.350			

Bar Steel

Weight per Lineal Foot in Pounds

Size	Round	Square	Hexagon	Octagon
1/8″	.04	.05	.05	.04
3/16″	.09	.12	.10	.10
1/4″	.17	.21	.19	.18
5/16″	.26	.33	.29	.28
3/8″	.38	.48	.42	.40
7/16″	.51	.65	.57	.54
1/2″	.67	.85	.75	.70
9/16″	.85	1.08	.94	.89
5/8″	1.04	1.33	1.17	1.10
11/16″	1.27	1.61	1.41	1.33
3/4″	1.50	1.92	1.68	1.58
13/16″	1.76	2.24	1.97	1.83
7/8″	2.04	2.60	2.29	2.16
15/16″	2.35	3.06	2.62	2.48
1″	2.67	3.40	2.99	2.82
1 1/8″	3.38	4.30	3.78	3.56
1 1/4″	4.17	5.31	4.66	4.40
1 3/8″	5.05	6.43	5.65	5.32
1 1/2″	6.01	7.65	6.72	6.34
1 5/8″	7.05	8.98	7.89	7.32
1 3/4″	8.18	10.40	9.14	8.64
1 7/8″	9.38	11.90	10.50	9.92
2″	10.71	13.60	11.95	11.28
2 1/8″	12.05	15.40	13.49	12.71
2 1/4″	13.60	17.20	15.12	14.24
2 3/8″	15.10	19.20	16.85	15.88
2 1/2″	16.68	21.20	18.66	17.65
2 5/8″	18.39	23.50	20.58	19.45
2 3/4″	20.18	25.70	22.59	21.28
2 7/8″	22.06	28.20	24.69	23.28
3″	24.10	30.60	26.88	25.36
3 1/8″	26.12	33.13	29.16	27.50
3 1/4″	28.30	35.90	31.55	29.28
3 3/8″	30.45	38.64	34.00	32.10
3 1/2″	32.70	41.60	36.59	34.56
3 5/8″	35.20	44.57	39.24	37.05
3 3/4″	37.54	47.80	42.00	39.68
4″	42.72	54.40	47.78	45.12
4 1/4″	48.30	61.40	53.95	50.84
4 1/2″	54.60	68.90	60.48	56.96
4 3/4″	60.30	76.70	67.39	63.52
5″	66.80	85.00	74.66	70.60
5 1/4″	73.60	93.70	82.32	77.80
5 1/2″	80.80	102.80	90.36	85.15
5 3/4″	88.30	112.40	98.76	93.12
6″	96.10	122.40	107.52	101.45
6 1/2″	113.20	143.60	126.20	117.12
7″	130.80	166.40	146.36	138.24
8″	170.88	217.60	191.12	180.48
9″	218.40	275.60	241.92	227.84
10″	267.20	340.00	298.64	282.40
11″	323.00	411.20	361.44	340.60
12″	384.00	489.60	470.08	405.80

For High Speed add 12 per cent to above weights.

FLAT BAR STEEL—WEIGHT PER LINEAL FOOT

	½	⅝	¾	⅞	1	1⅛	1¼	1⅜	1½	1¾	2	2¼
⅛	.213	.266	.320	.372	.426	.479	.530	.585	.640	.745	.850	.955
3/16	.319	.399	.480	.558	.639	.718	.790	.878	.960	1.12	1.28	1.43
¼	.425	.533	.640	.743	.852	.958	1.06	1.17	1.28	1.49	1.70	1.91
5/16	.531	.665	.800	.929	1.06	1.20	1.33	1.46	1.60	1.86	2.13	2.39
⅜	.638	.798	.960	1.12	1.28	1.33	1.59	1.75	1.91	2.23	2.55	2.87
7/16	.744	.931	1.12	1.30	1.49	1.67	1.86	2.05	2.33	2.60	2.98	3.35
½	......	1.07	1.28	1.49	1.70	1.91	2.13	2.34	2.55	2.98	3.40	3.83
9/16	......	1.20	1.44	1.67	1.91	2.15	2.39	2.63	2.87	3.35	3.83	4.30
⅝	......	......	1.60	1.86	2.12	2.39	2.66	2.92	3.19	3.72	4.26	4.79
11/16	......	......	1.76	2.04	2.34	2.63	2.92	3.22	3.51	4.09	4.68	5.26
¾	......	......	......	2.23	2.55	2.86	3.19	3.50	3.83	4.46	5.10	5.74
13/16	......	......	......	2.41	2.76	3.11	3.45	3.80	4.14	4.83	5.53	6.22
⅞	......	......	......	......	2.98	3.34	3.72	4.09	4.46	5.21	5.96	6.70
15/16	......	......	......	......	3.19	3.59	3.98	4.38	4.78	5.58	6.38	7.17
1	......	......	......	......	......	3.82	4.25	4.68	5.10	5.96	6.80	7.66
1⅛	......	......	......	......	......	......	4.78	5.27	5.74	6.71	7.65	8.61
1¼	......	......	......	......	......	......	......	5.85	6.38	7.45	8.50	9.57
1½	......	......	......	......	......	......	......	7.02	7.67	8.94	10.21	11.49

Flat Bar Steel—Weight per Lineal Foot

	2½	2¾	3	3½	4	5	6	7	8	9	10	11	12
⅛	1.07	1.18	1.28	1.49	1.70	2.13	2.56	2.98	3.40	3.84	4.26	4.68	5.10
3/16	1.60	1.76	1.92	2.24	2.55	3.20	3.83	4.47	5.10	5.74	6.38	7.02	7.65
¼	2.13	2.34	2.56	2.98	3.40	4.26	5.11	5.96	6.80	7.65	8.50	9.34	10.20
5/16	2.66	2.92	3.19	3.72	4.25	5.32	6.38	7.44	8.50	9.56	10.62	11.68	12.75
⅜	3.20	3.51	3.83	4.46	5.10	6.40	7.66	8.92	10.20	11.48	12.75	14.03	15.30
7/16	3.72	4.09	4.46	5.21	5.95	7.44	8.92	10.40	11.90	13.40	14.88	16.36	17.85
½	4.26	4.68	5.10	5.96	6.80	8.52	10.20	11.90	13.60	15.30	17.00	18.70	20.40
9/16	4.78	5.26	5.74	6.69	7.65	9.56	11.50	13.40	15.30	17.22	19.14	21.02	22.95
⅝	5.32	5.86	6.39	7.44	8.52	10.64	12.78	14.90	17.00	19.13	21.25	23.38	25.50
11/16	5.84	6.43	7.01	8.18	9.35	11.70	14.00	16.40	18.70	21.04	23.38	25.70	28.05
¾	6.40	7.02	7.65	8.92	10.20	12.80	15.30	17.90	20.40	22.96	25.50	28.05	30.60
13/16	6.91	7.60	8.29	9.67	11.10	13.80	16.60	19.30	22.10	24.86	27.62	30.40	33.15
⅞	7.46	8.19	8.94	10.42	11.92	14.92	17.88	20.80	23.80	26.78	29.75	32.72	35.70
15/16	7.97	8.77	9.56	11.20	12.80	15.90	19.10	22.40	25.50	28.69	31.88	33.06	38.25
1	8.52	9.36	10.20	11.92	13.60	17.04	20.40	23.80	27.20	30.60	34.00	38.40	40.80
1⅛	9.59	10.54	11.48	13.41	15.30	19.17	22.95	26.80	30.60	34.43	38.25	42.08	45.90
1¼	10.65	11.71	12.76	14.90	17.00	21.30	25.61	29.76	34.00	38.26	42.50	46.76	51.00
1½	12.78	14.04	15.30	17.88	20.40	25.56	30.60	35.70	40.80	45.09	51.00	56.10	61.20

Typical Tensile Strengths of Heat Treated Steel of Different Carbon Content

Carbon per Cent.	Approximate Tensile Strength in Lbs. per Square Inch.
.05 to .10	47,040 to 60,480
.10 to .15	53,760 to 64,960
.15 to .20	60,480 to 71,680
.20 to .25	64,690 to 76,160
.25 to .30	67,200 to 78,400
.30 to .35	69,440 to 82,800
.35 to .40	78,400 to 91,840
.40 to .45	87,360 to 100,800
.45 to .50	96,320 to 107,520
.50 to .55	105,280 to 118,920
.55 to .60	112,000 to 123,200
.60 to .65	116,480 to 127,680
.65 to .70	123,200 to 134,400
.70 to .75	129,920 to 138,880
.75 to .80	134,400 to 143,360
.80 to .85	136,640 to 145,600
.85 to .90	141,120 to 150,800

Working Temperatures for Carbon Steels

NAME	Carbon Content	Approx. Critical Temp.	Forging Temp.	Quenching Temp.
Machinery......	0.25	1475	1650	1525–1575
Machinery......	0.35	1395	1650	1450–1500
Machinery......	0.45	1385	1650	1435–1485
Crucible Machy.	0.50	1380	1625	1430–1480
Crucible Machy.	0.55	1375	1625	1425–1475
Tool Steel......	0.60	1365	1600	1400–1460
Tool Steel......	0.70	1355	1600	1400–1460
Tool Steel......	0.80	1350	1600	1375–1450
Tool Steel......	0.90	1350	1575	1375–1450
Tool Steel......	1.00	1350	1575	1375–1450
Tool Steel......	1.10	1350	1500	1375–1430
Tool Steel......	1.20	1350	1500	1375–1420
Tool Steel......	1.30	1350	1500	1375–1420

Millimeter Equivalents in Inches

Millimeters		Inches	Millimeters		Inches	Millimeters		Inches
.10	=	.0039	29	=	1.1417	66	=	2.5984
.20	=	.0079	30	=	1.1811	67	=	2.6378
.30	=	.0118	31	=	1.2205	68	=	2.6772
.40	=	.0157	32	=	1.2599	69	=	2.7165
.50	=	.0197	33	=	1.2992	70	=	2.7559
.60	=	.0236	34	=	1.3386	71	=	2.7953
.70	=	.0276	35	=	1.3780	72	=	2.8346
.80	=	.0315	36	=	1.4173	73	=	2.8740
.90	=	.0354	37	=	1.4567	74	=	2.9134
1	=	.0394	38	=	1.4961	75	=	2.9528
2	=	.0787	39	=	1.5354	76	=	2.9921
3	=	.1181	40	=	1.5748	77	=	3.0315
4	=	.1575	41	=	1.6142	78	=	3.0709
5	=	.1969	42	=	1.6536	79	=	3.1102
6	=	.2362	43	=	1.6929	80	=	3.1496
7	=	.2756	44	=	1.7323	81	=	3.1890
8	=	.3150	45	=	1.7717	82	=	3.2283
9	=	.3543	46	=	1.8110	83	=	3.2677
10	=	.3937	47	=	1.8504	84	=	3.3071
11	=	.4331	48	=	1.8988	85	=	3.3465
12	=	.4724	49	=	1.9291	86	=	3.3858
13	=	.5118	50	=	1.9685	87	=	3.4252
14	=	.5512	51	=	2.0079	88	=	3.4646
15	=	.5906	52	=	2.0472	89	=	3.5039
16	=	.6299	53	=	2.0866	90	=	3.5433
17	=	.6693	54	=	2.1260	91	=	3.5827
18	=	.7087	55	=	2.1654	92	=	3.6221
19	=	.7480	56	=	2.2047	93	=	3.6614
20	=	.7874	57	=	2.2441	94	=	3.7008
21	=	.8268	58	=	2.2835	95	=	3.7402
22	=	.8661	59	=	2.3228	96	=	3.7795
23	=	.9055	60	=	2.3622	97	=	3.8189
24	=	.9449	61	=	2.4016	98	=	3.8583
25	=	.9843	62	=	2.4409	99	=	3.8976
26	=	1.0236	63	=	2.4803	100	=	3.9370
27	=	1.0630	64	=	2.5197	...	..	......
28	=	1.1024	65	=	2.5591	...	..	......

Typical Formulæ for Carbonizing

Chrome Nickel Steel SAE 3120:

Carbonize at 1625 to 1700 degrees.
Cool in box and remove.
Re-heat to 1550 to 1600 degrees.
Quench in oil.
Re-heat to 1300 to 1400 degrees.
Quench in oil or water.
Draw to from 300 to 450 degrees.

3½% Nickel Steel SAE 2320:

Carbonize at 1625 to 1675.
Cool in boxes and remove.
Re-heat to 1550 to 1575.
Quench in oil.
Re-heat to 1300 to 1400 degrees.
Quench in oil or water.
Draw to from 300 to 450 degrees.

Carbon Steel SAE 1020:

Carbonize at 1650 to 1700.
Cool in boxes and remove.
Re-heat to 1550 to 1600.
Quench in oil.
Re-heat to 1400 to 1450.
Quench in oil or water.
Draw to about 400 degrees.

The above formulæ are approximate and will be subject to change according to the size of pieces being carbonized and also the depth of penetration required. The final drawing temperature will have to be modified, depending on the degree of hardness required in the finished article.

As in all other heat treating operations, definite formulæ for carbonizing can best be obtained by actual experiment and a little time and money spent in this way will be well invested inasmuch as it will save the possible damaging of valuable work.

S. A. E. SPECIFICATIONS

CARBON STEELS

S. A. E. Specification No.	CARBON		MANGANESE		Phosphorus (Maximum)	Sulphur (Maximum)
	Minimum and Maximum	Desired	Minimum and Maximum	Desired		
1010	0.05 to 0.15	0.10	0.30 to 0.60	0.45	0.045	0.05
1020	.15 to .25	.20	.30 to .60	.45	.045	.05
1025	.20 to .30	.25	.50 to .80	.65	.045	.05
1035	.30 to .40	.35	.50 to .80	.65	.045	.05
1045	.40 to .50	.45	.50 to .80	.65	.045	.05
1095	.90 to 1.05	.95	.25 to .50	.35	.04	.05

NICKEL STEELS

S. A. E. Specification No.	CARBON		MANGANESE		Phosphorus (Maximum)	Sulphur (Maximum)	NICKEL	
	Minimum and Maximum	Desired	Minimum and Maximum	Desired			Minimum and Maximum	Desired
2315	0.10 to 0.20	0.15	0.50 to 0.80	0.65	0.04	0.045	3.25 to 3.75	3.50
2320	.15 to .25	.20	.50 to .80	.65	.04	.045	3.25 to 3.75	3.50
2330	.25 to .35	.30	.50 to .80	.65	.04	.045	3.25 to 3.75	3.50
2335	.30 to .40	.35	.50 to .80	.65	.04	.045	3.25 to 3.75	3.50
2340	.35 to .45	.40	.50 to .80	.65	.04	.045	3.25 to 3.75	3.50
2345	.40 to .50	.45	.50 to .80	.65	.04	.045	3.25 to 3.75	3.50

SILICO-MANGANESE STEELS

S. A. E. Specification No.	CARBON		MANGANESE		Phosphorus (Maximum)	Sulphur (Maximum)	SILICON	
	Minimum and Maximum	Desired	Minimum and Maximum	Desired			Minimum and Maximum	Desired
9250	0.45 to 0.55	0.50	0.60 to 0.80	0.70	0.045*	0.045	1.80 to 2.10	1.95
9260	.55 to .65	.60	.50 to .70	.60	.045*	.045	1.50 to 1.80	1.65

*Steel made by the acid process may contain maximum 0.05 phosphorus.

CHROMIUM STEELS

S. A. E. Specification No.	CARBON		MANGANESE		Phosphorus (Maximum)	Sulphur (Maximum)	CHROMIUM	
	Minimum and Maximum	Desired	Minimum and Maximum	Desired			Minimum and Maximum	Desired
5120	0.15 to 0.25	0.20	*	*	0.04	0.045	0.60 to 0.90	0.75
5140	.35 to .45	.40	*	*	.04	.045	.60 to .90	.75
5165	.60 to .70	.65	*	*	.04	.045	.60 to .90	.75
52100	.95 to 1.10	1.00	0.20 to 0.50	0.35	0.03	0.03	1.20 to 1.50	1.35

*Two types of steel are available in this class, one with manganese 0.25% to 0.50% (0.35% desired), and silicon not over 0.20%, the other with manganese 0.60% to 0.80% (0.70% desired), and silicon 0.15% to 0.50%.

CHROMIUM VANADIUM STEELS

S. A. E. Specification No.	CARBON		MANGANESE		Phosphorus (Maximum)	Sulphur (Maximum)	CHROMIUM		VANADIUM	
	Minimum and Maximum	Desired	Minimum and Maximum	Desired			Minimum and Maximum	Desired	Minimum	Desired
6120	0.15 to 0.25	0.20	0.50 to 0.80	0.65	0.04	0.04	0.80 to 1.10	0.95	0.15	0.20
6125	.20 to .30	.25	.50 to .80	.65	.04	.04	.80 to 1.10	.95	.15	.20
6130	.25 to .35	.30	.50 to .80	.65	.04	.04	.80 to 1.10	.95	.15	.20
6135	.30 to .40	.35	.50 to .80	.65	.04	.04	.80 to 1.10	.95	.15	.20
6140	.35 to .45	.40	.50 to .80	.65	.04	.04	.80 to 1.10	.95	.15	.20
6145	.40 to .50	.45	.50 to .80	.65	.04	.04	.80 to 1.10	.95	.15	.20
6150	.45 to .55	.50	.50 to .80	.65	.04	.04	.80 to 1.10	.95	.15	.20
6195	.90 to 1.05	.95	.20 to .45	.35	.03	.03	.80 to 1.10	.95	.15	.20

NICKEL CHROMIUM STEELS

S. A. E. Specification No.	CARBON		MANGANESE		Phosphorus (Maximum)	Sulphur (Maximum)	NICKEL		CHROMIUM	
	Minimum and Maximum	Desired	Minimum and Maximum	Desired			Minimum and Maximum	Desired	Minimum and Maximum	Desired
3120	0.15 to 0.25	0.20	0.50 to 0.80	0.65	0.04	0.045	1.00 to 1.50	1.25	0.45 to 0.75*	0.60
3125	.20 to .30	.25	.50 to .80	.65	.04	.045	1.00 to 1.50	1.25	.45 to .75*	.60
3130	.25 to .35	.30	.50 to .80	.65	.04	.045	1.00 to 1.50	1.25	.45 to .75*	.60
3135	.30 to .40	.35	.50 to .80	.65	.04	.045	1.00 to 1.50	1.25	.45 to .75*	.60
3140	.35 to .45	.40	.50 to .80	.65	.04	.045	1.00 to 1.50	1.25	.45 to .75*	.60
3220	.15 to .25	.20	.30 to .60	.45	.04	.04	1.50 to 2.00	1.75	.90 to 1.25	1.10
3230	.25 to .35	.30	.30 to .60	.45	.04	.04	1.50 to 2.00	1.75	.90 to 1.25	1.10
3240	.35 to .45	.40	.30 to .60	.45	.04	.04	1.50 to 2.00	1.75	.90 to 1.25	1.10
3250	.45 to .55	.50	.30 to .60	.45	.04	.04	1.50 to 2.00	1.75	.90 to 1.25	1.10
3415	.10 to .20	.15	.45 to .75	.60	.04	.04	2.75 to 3.25	3.00	.60 to .95	.80
3435	.30 to .40	.35	.45 to .75	.60	.04	.04	2.75 to 3.25	3.00	.60 to .95	.80
3450	.45 to .55	.50	.45 to .75	.60	.04	.04	2.75 to 3.25	3.00	.60 to .95	.80
3320	.15 to .25	.20	.30 to .60	.45	.04	.04	3.25 to 3.75	3.50	1.25 to 1.75	1.50
3330	.25 to .35	.30	.30 to .60	.45	.04	.04	3.25 to 3.75	3.50	1.25 to 1.75	1.50
3340	.35 to .45	.40	.30 to .60	.45	.04	.04	3.25 to 3.75	3.50	1.25 to 1.75	1.50

*Another grade of this type of steel is available with chromium content of 0.15% to 0.45%. It has somewhat lower physical properties.