Tucholsky Wagner Zola Scott Sydow Fonatne Freud Schlegel
Turgenev Wallace
Twain Walther von der Vogelweide Fouqué Friedrich II. von Preußen
Weber Freiligrath
Kant Ernst Frey
Fechner Fichte Weiße Rose von Fallersleben Richthofen Frommel
Hölderlin
Fehrs Engels Fielding Eichendorff Tacitus Dumas
Faber Flaubert
Maximilian I. von Habsburg Fock Eliasberg Zweig Ebner Eschenbach
Feuerbach Ewald Eliot Vergil
Goethe London
Mendelssohn Balzac Shakespeare Elisabeth von Österreich
Lichtenberg Rathenau Dostojewski Ganghofer
Trackl Stevenson Doyle Gjellerup
Tolstoi Hambruch
Mommsen Thoma Lenz Hanrieder Droste-Hülshoff
von Arnim
Dach Verne Hägele Hauff Humboldt
Reuter
Karrillon Garschin Rousseau Hagen Hauptmann Gautier
Defoe Baudelaire
Damaschke Descartes Hebbel
Wolfram von Eschenbach Dickens Schopenhauer Hegel Kussmaul Herder
Bronner Darwin Melville Grimm Jerome Rilke George
Campe Horváth Aristoteles Bebel Proust
Bismarck Vigny Gengenbach Barlach Voltaire Federer Herodot
Heine
Storm Casanova Lessing Tersteegen Gilm Grillparzer Georgy
Chamberlain Langbein Gryphius
Brentano Lafontaine
Strachwitz Claudius Schiller Kralik Iffland Sokrates
Katharina II. von Rußland Bellamy Schilling
Gerstäcker Raabe Gibbon Tschechow
Löns Hesse Hoffmann Gogol Wilde Gleim Vulpius
Luther Heym Hofmannsthal Klee Hölty Morgenstern
Roth Heyse Klopstock Kleist Goedicke
Luxemburg Puschkin Homer Mörike
La Roche Horaz Musil
Machiavelli
Navarra Aurel Musset Kierkegaard Kraft Kraus
Lamprecht Kind Kirchhoff Hugo Moltke
Nestroy Marie de France
Nietzsche Nansen Laotse Ipsen Liebknecht
Marx Ringelnatz
von Ossietzky Lassalle Gorki Klett Leibniz
May
vom Stein Lawrence Irving
Petalozzi Platon Knigge
Sachs Pückler Poe Michelangelo Kock Kafka
Liebermann Korolenko
de Sade Praetorius Mistral Zetkin

Oxy-Acetylene Welding and Cutting Electric, Forge and Thermit Welding together with related methods and materials used in metal working and the oxygen process for removal of carbon

Harold P. (Harold Phillips) Manly

Imprint

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PREFACE

In the preparation of this work, the object has been to cover not only the several processes of welding, but also those other processes which are so closely allied in method and results as to make them a part of the whole subject of joining metal to metal with the aid of heat.

The workman who wishes to handle his trade from start to finish finds that it is necessary to become familiar with certain other operations which precede or follow the actual joining of the metal parts, the purpose of these operations being to add or retain certain desirable qualities in the materials being handled. For this reason the following subjects have been included: Annealing, tempering, hardening, heat treatment and the restoration of steel.

In order that the user may understand the underlying principles and the materials employed in this work, much practical information is given on the uses and characteristics of the various metals; on the production, handling and use of the gases and other materials which are a part of the equipment; and on the tools and accessories for the production and handling of these materials.

An examination will show that the greatest usefulness of this book lies in the fact that all necessary information and data has been included in one volume, making it possible for the workman to use one source for securing a knowledge of both principle and practice, preparation and finishing of the work, and both large and small repair work as well as manufacturing methods used in metal working.

An effort has been made to eliminate all matter which is not of direct usefulness in practical work, while including all that those engaged in this trade find necessary. To this end, the descriptions have been limited to those methods and accessories which are found in actual use today. For the same reason, the work includes the application of the rules laid down by the insurance underwriters which govern this work as well as instructions for the proper care and handling of the generators, torches and materials found in the shop.

Special attention has been given to definite directions for handling the different metals and alloys which must be handled. The instructions have been arranged to form rules which are placed in the order of their use during the work described and the work has been subdivided in such a way that it will be found possible to secure information on any one point desired without the necessity of spending time in other fields.

The facts which the expert welder and metalworker finds it most necessary to have readily available have been secured, and prepared especially for this work, and those of most general use have been combined with the chapter on welding practice to which they apply.

The size of this volume has been kept as small as possible, but an examination of the alphabetical index will show that the range of subjects and details covered is complete in all respects. This has been accomplished through careful classification of the contents and the elimination of all repetition and all theoretical, historical and similar matter that is not absolutely necessary.

Free use has been made of the information given by those manufacturers who are recognized as the leaders in their respective fields, thus insuring that the work is thoroughly practical and that it represents present day methods and practice.

THE AUTHOR.

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OXY-ACETYLENE WELDING AND CUTTING, ELECTRIC AND THERMIT WELDING

CHAPTER I

METALS AND THEIR ALLOYS—HEAT TREATMENT

THE METALS

Iron.—Iron, in its pure state, is a soft, white, easily worked metal. It is the most important of all the metallic elements, and is, next to aluminum, the commonest metal found in the earth.

Mechanically speaking, we have three kinds of iron: wrought iron, cast iron and steel. Wrought iron is very nearly pure iron; cast iron contains carbon and silicon, also chemical impurities; and steel contains a definite proportion of carbon, but in smaller quantities than cast iron.

Pure iron is never obtained commercially, the metal always being mixed with various proportions of carbon, silicon, sulphur, phosphorus, and other elements, making it more or less suitable for different purposes. Iron is magnetic to the extent that it is attracted by magnets, but it does not retain magnetism itself, as does steel. Iron forms, with other elements, many important combinations, such as its alloys, oxides, and sulphates.

[Illustration: Figure 1.—Section Through a Blast Furnace]

Cast Iron.—Metallic iron is separated from iron ore in the blast furnace (Figure 1), and when allowed to run into moulds is called cast iron. This form is used for engine cylinders and pistons, for brackets, covers, housings and at any point where its brittleness is not objectionable. Good cast iron breaks with a gray fracture, is free from blowholes or roughness, and is easily machined, drilled, etc. Cast iron is slightly lighter than steel, melts at about 2,400 degrees in practice, is about one-eighth as good an electrical conductor as copper and has a tensile strength of 13,000 to 30,000 pounds per square inch. Its compressive strength, or resistance to crushing, is very great. It has excellent wearing qualities and is not easily warped and deformed by heat. Chilled iron is cast into a metal mould so that the outside is cooled quickly, making the surface very hard and difficult to cut and giving great resistance to wear. It is used for making cheap gear wheels and parts that must withstand surface friction.

Malleable Cast Iron.—This is often called simply malleable iron. It is a form of cast iron obtained by removing much of the carbon from cast iron, making it softer and less brittle. It has a tensile strength of 25,000 to 45,000 pounds per square inch, is easily machined, will stand a small amount of bending at a low red heat and is used chiefly in making brackets, fittings and supports where low cost is of considerable importance. It is often used in cheap constructions in place of steel forgings. The greatest strength of a malleable casting, like a steel forging, is in the surface, therefore but little machining should be done.

Wrought Iron.—This grade is made by treating the cast iron to remove almost all of the carbon, silicon, phosphorus, sulphur, manganese and other impurities. This process leaves a small amount of the slag from the ore mixed with the wrought iron.

Wrought iron is used for making bars to be machined into various parts. If drawn through the rolls at the mill once, while being made, it is called "muck bar;" if rolled twice, it is called "merchant bar" (the commonest kind), and a still better grade is made by rolling a third time. Wrought iron is being gradually replaced in use by mild rolled steels.

Wrought iron is slightly heavier than cast iron, is a much better electrical conductor than either cast iron or steel, has a tensile strength of 40,000 to 60,000 pounds per square inch and costs slightly more than steel. Unlike either steel or cast iron, wrought iron does not harden when cooled suddenly from a red heat.

Grades of Irons.—The mechanical properties of cast iron differ greatly according to the amount of other materials it contains. The most important of these contained elements is carbon, which is present to a degree varying from 2 to 5-1/2 per cent. When iron containing much carbon is quickly cooled and then broken, the fracture is nearly white in color and the metal is found to be hard and brittle. When the iron is slowly cooled and then broken the fracture is gray and the iron is more malleable and less brittle. If cast iron contains sulphur or phosphorus, it will show a white fracture regardless of the rapidity of cooling, being brittle and less desirable for general work.

Steel.—Steel is composed of extremely minute particles of iron and carbon, forming a network of layers and bands. This carbon is a smaller proportion of the metal than found in cast iron, the percentage being from 3/10 to 2-1/2 per cent.

Carbon steel is specified according to the number of "points" of carbon, a point being one one-hundredth of one per cent of the weight of the steel. Steel may contain anywhere from 30 to 250 points, which is equivalent to saying, anywhere from 3/10 to 2-1/2 per cent, as above. A 70-point steel would contain 70/100 of one per cent or 7/10 of one per cent of carbon by weight. The percentage of carbon determines the hardness of the steel, also many other qualities, and its suitability for various kinds of work. The more carbon contained in the steel, the harder the metal will be, and, of course, its brittleness increases with the hardness. The smaller the grains or particles of iron which are separated by the carbon, the stronger the steel will be, and the control of the size of these particles is the object of the science of heat treatment.

In addition to the carbon, steel may contain the following:

Silicon, which increases the hardness, brittleness, strength and difficulty of working if from 2 to 3 per cent is present.

Phosphorus, which hardens and weakens the metal but makes it easier to cast. Three-tenths per cent of phosphorus serves as a hardening agent and may be present in good steel if the percentage of carbon is low. More than this weakens the metal.

Sulphur, which tends to make the metal hard and filled with small holes.

Manganese, which makes the steel so hard and tough that it can with difficulty be cut with steel tools. Its hardness is not lessened by annealing, and it has great tensile strength.

Alloy steel has a varying but small percentage of other elements mixed with it to give certain desired qualities. Silicon steel and manganese steel are sometimes classed as alloy steels. This subject is taken up in the latter part of this chapter under *Alloys*, where the various combinations and their characteristics are given consideration.

Steel has a tensile strength varying from 50,000 to 300,000 pounds per square inch, depending on the carbon percentage and the other alloys present, as well as upon the texture of the grain. Steel is heavier than cast iron and weighs about the same as wrought iron. It is about one-ninth as good a conductor of electricity as copper.

Steel is made from cast iron by three principal processes: the crucible,
Bessemer and open hearth.

Crucible steel is made by placing pieces of iron in a clay or graphite crucible, mixed with charcoal and a small amount of any desired alloy. The crucible is then heated with coal, oil or gas fires until the iron melts, and, by absorbing the desired elements and giving up or changing its percentage of carbon, becomes steel. The molten steel is then poured from the crucible into moulds or bars for use. Crucible steel may also be made by placing crude steel in the crucibles in place of the iron. This last method gives the finest grade of metal and the crucible process in general gives the best grades of steel for mechanical use.

[Illustration: Figure 2.—A Bessemer Converter]

Bessemer steel is made by heating iron until all the undesirable elements are burned out by air blasts which furnish the necessary oxygen. The iron is placed in a large retort called a converter, being poured, while at a melting heat, directly from the blast furnace into the converter. While the iron in the converter is molten, blasts of air are forced through the liquid, making it still hotter and burning out the impurities together with the carbon and manganese. These two elements are then restored to the iron by adding spiegeleisen (an alloy of iron, carbon and manganese). A converter holds from 5 to 25 tons of metal and requires about 20 minutes to finish a charge. This makes the cheapest steel.

[Illustration: Figure 3.—An Open Hearth Furnace]

Open hearth steel is made by placing the molten iron in a receptacle while currents of air pass over it, this air having itself been highly heated by just passing over white hot brick (Figure. 3). Open hearth steel is considered more uniform and reliable than Bessemer, and is used for springs, bar steel, tool steel, steel plates, etc.

Aluminum is one of the commonest industrial metals. It is used for gear cases, engine crank cases, covers, fittings, and wherever lightness and moderate strength are desirable.

Aluminum is about one-third the weight of iron and about the same weight as glass and porcelain; it is a good electrical conductor (about one-half as good as copper); is fairly strong itself and gives great strength to other metals when alloyed with them. One of the greatest advantages of aluminum is that it will not rust or corrode under ordinary conditions. The granular formation of aluminum makes its strength very unreliable and it is too soft to resist wear.

Copper is one of the most important metals used in the trades, and the best commercial conductor of electricity, being exceeded in this respect only by silver, which is but slightly better. Copper is very malleable and ductile when cold, and in this state may be easily worked under the hammer. Working in this way makes the copper stronger and harder, but less ductile. Copper is not affected by air, but acids cause the formation of a green deposit called verdigris.

Copper is one of the best conductors of heat, as well as electricity, being used for kettles, boilers, stills and wherever this quality is desirable. Copper is also used in alloys with other metals, forming an important part of brass, bronze, german silver, bell metal and gun metal. It is about one-eighth heavier than steel and has a tensile strength of about 25,000 to 50,000 pounds per square inch.

Lead.—The peculiar properties of lead, and especially its quality of showing but little action or chemical change in the presence of other elements, makes it valuable under certain conditions of use. Its principal use is in pipes for water and gas, coverings for roofs and linings for vats and tanks. It is also used to coat sheet iron for similar uses and as an important part of ordinary solder.

Lead is the softest and weakest of all the commercial metals, being very pliable and inelastic. It should be remembered that lead and all its compounds are poisonous when received into the system. Lead is more than one-third heavier than steel, has a tensile strength of only about 2,000 pounds per square inch, and is only about one-tenth as good a conductor of electricity as copper.

Zinc.—This is a bluish-white metal of crystalline form. It is brittle at ordinary temperatures and becomes malleable at about 250 to 300 degrees Fahrenheit, but beyond this point becomes even more brittle than at ordinary temperatures. Zinc is practically unaffected by air or moisture through becoming covered with one of its own compounds which immediately resists further action. Zinc melts at low temperatures, and when heated beyond the melting point gives off very poisonous fumes.

The principal use of zinc is as an alloy with other metals to form brass, bronze, german silver and bearing metals. It is also used to cover the surface of steel and iron plates, the plates being then called galvanized.

Zinc weighs slightly less than steel, has a tensile strength of 5,000 pounds per square inch, and is not quite half as good as copper in conducting electricity.

Tin resembles silver in color and luster. Tin is ductile and malleable and slightly crystalline in form, almost as heavy as steel, and has a tensile strength of 4,500 pounds per square inch.

The principal use of tin is for protective platings on household utensils and in wrappings of tin-foil. Tin forms an important part of many alloys such as babbitt, Britannia metal, bronze, gun metal and bearing metals.

Nickel is important in mechanics because of its combinations with other metals as alloys. Pure nickel is grayish-white, malleable, ductile and tenacious. It weighs almost as much as steel and, next to manganese, is the hardest of metals. Nickel is one of the three magnetic metals, the others being iron and cobalt. The commonest alloy containing nickel is german silver, although one of its most important alloys is found in nickel steel. Nickel is about ten per cent heavier than steel, and has a tensile strength of 90,000 pounds per square inch.

Platinum.—This metal is valuable for two reasons: it is not affected by the air or moisture or any ordinary acid or salt, and in addition to this property it melts only at the highest temperatures. It is a fairly good electrical conductor, being better than iron or steel. It is nearly three times as heavy as steel and its tensile strength is 25,000 pounds per square inch.

ALLOYS

An alloy is formed by the union of a metal with some other material, either metal or non-metallic, this union being composed of two or more elements and usually brought about by heating the substances together until they melt and unite. Metals are alloyed with materials which have been found to give to the metal certain characteristics which are desired according to the use the metal will be put to.

The alloys of metals are, almost without exception, more important from an industrial standpoint than the metals themselves. There are innumerable possible combinations, the most useful of which are here classed under the head of the principal metal entering into their composition.

Steel.—Steel may be alloyed with almost any of the metals or elements, the combinations that have proven valuable numbering more than a score. The principal ones are given in alphabetical order, as follows:

Aluminum is added to steel in very small amounts for the purpose of preventing blow holes in castings.

Boron increases the density and toughness of the metal.

Bronze, added by alloying copper, tin and iron, is used for gun metal.

Carbon has already been considered under the head of steel in the section devoted to the metals. Carbon, while increasing the strength and hardness, decreases the ease of forging and bending and decreases the magnetism and electrical conductivity. High carbon steel can be welded only with difficulty. When the percentage of carbon is low, the steel is called "low carbon" or "mild" steel. This is used for rods and shafts, and called "machine" steel. When the carbon percentage is high, the steel is called "high carbon" steel, and it is used in the shop as tool steel. One-tenth per cent of carbon gives steel a tensile strength of 50,000 to 65,000 pounds per square inch; two-tenths per cent gives from 60,000 to 80,000; four-tenths per cent gives 70,000 to 100,000, and six-tenths per cent gives 90,000 to 120,000.

Chromium forms chrome steel, and with the further addition of nickel is called chrome nickel steel. This increases the hardness to a high degree and adds strength without much decrease in ductility. Chrome steels are used for high-speed cutting tools, armor plate, files, springs, safes, dies, etc.

Manganese has been mentioned under *Steel*. Its alloy is much used for high-speed cutting tools, the steel hardening when cooled in the air and being called self-hardening.

Molybdenum is used to increase the hardness to a high degree and makes the steel suitable for high-speed cutting and gives it self-hardening properties.

Nickel, with which is often combined chromium, increases the strength, springiness and toughness and helps to prevent corrosion.

Silicon has already been described. It suits the metal for use in high-speed tools.

Silver added to steel has many of the properties of nickel.

Tungsten increases the hardness without making the steel brittle. This makes the steel well suited for gas engine valves as it resists corrosion and pitting. Chromium and manganese are often used in combination with tungsten when high-speed cutting tools are made.

Vanadium as an alloy increases the elastic limit, making the steel stronger, tougher and harder. It also makes the steel able to stand much bending and vibration.

Copper.—The principal copper alloys include brass, bronze, german silver and gun metal.

Brass is composed of approximately one-third zinc and two-thirds copper. It is used for bearings and bushings where the speeds are slow and the loads rather heavy for the bearing size. It also finds use in washers, collars and forms of brackets where the metal should be non-magnetic, also for many highly finished parts.

Brass is about one-third as good an electrical conductor as copper, is slightly heavier than steel and has a tensile strength of 15,000 pounds when cast and about 75,000 to 100,000 pounds when drawn into wire.

Bronze is composed of copper and tin in various proportions, according to the use to which it is to be put. There will always be from six-tenths to nine-tenths of copper in the mixture. Bronze is used for bearings, bushings, thrust washers, brackets and gear wheels. It is heavier than steel, about 1/15 as good an electrical conductor as pure copper and has a tensile strength of 30,000 to 60,000 pounds.

Aluminum bronze, composed of copper, zinc and aluminum has high tensile strength combined with ductility and is used for parts requiring this combination.

Bearing bronze is a variable material, its composition and proportion depending on the maker and the use for which it is designed. It usually contains from 75 to 85 per cent of copper combined with one or more elements, such as tin, zinc, antimony and lead.

White metal is one form of bearing bronze containing over 80 per cent of zinc together with copper, tin, antimony and lead. Another form is made with nearly 90 per cent of tin combined with copper and antimony.

Gun metal bronze is made from 90 per cent copper with 10 per cent of tin and is used for heavy bearings, brackets and highly finished parts.

Phosphor bronze is used for very strong castings and bearings. It is similar to gun metal bronze, except that about 1-1/2 per cent of phosphorus has been added.

Manganese bronze contains about 1 per cent of manganese and is used for parts requiring great strength while being free from corrosion.

German silver is made from 60 per cent of copper with 20 per cent each of zinc and nickel. Its high electrical resistance makes it valuable for regulating devices and rheostats.

Tin is the principal part of *babbitt* and *solder*. A commonly used babbitt is composed of 89 per cent tin, 8 per cent antimony and 3 per cent of copper. A grade suitable for repairing is made from 80 per cent of lead and 20 per cent antimony. This last formula should not be used for particular work or heavy loads, being more suitable for spacers. Innumerable proportions of metals are marketed under the name of babbitt.

Solder is made from 50 per cent tin and 50 per cent lead, this grade being called "half-and-half." Hard solder is made from two-thirds tin and one-third lead.

Aluminum forms many different alloys, giving increased strength to whatever metal it unites with.

Aluminum brass is composed of approximately 65 per cent copper, 30 per cent zinc and 5 per cent aluminum. It forms a metal with high tensile strength while being ductile and malleable.

Aluminum zinc is suitable for castings which must be stiff and hard.

Nickel aluminum has a tensile strength of 40,000 pounds per square inch.

Magnalium is a silver-white alloy of aluminum with from 5 to 20 per cent of magnesium, forming a metal even lighter than aluminum and strong enough to be used in making high-speed gasoline engines.

HEAT TREATMENT OF STEEL

The processes of heat treatment are designed to suit the steel for various purposes by changing the size of the grain in the metal, therefore the strength; and by altering the chemical composition of the alloys in the metal to give it different physical properties. Heat treatment, as applied in ordinary shop work, includes the three processes of annealing, hardening and tempering, each designed to accomplish a certain definite result.

All of these processes require that the metal treated be gradually brought to a certain predetermined degree of heat which shall be uniform throughout the piece being handled and, from this point, cooled according to certain rules, the selection of which forms the difference in the three methods.

Annealing.—This is the process which relieves all internal strains and distortion in the metal and softens it so that it may more easily be cut, machined or bent to the required form. In some cases annealing is used only to relieve the strains, this being the case after forging or welding operations have been performed. In other cases it is only desired to soften the metal sufficiently that it may be handled easily. In some cases both of these things must be accomplished, as after a piece has been forged and must be machined. No matter what the object, the procedure is the same.

The steel to be annealed must first be heated to a dull red. This heating should be done slowly so that all parts of the piece have time to reach the same temperature at very nearly the same time. The piece may be heated in the forge, but a much better way is to heat in an oven or furnace of some type where the work is protected against air currents, either hot or cold, and is also protected against the direct action of the fire.

[Illustration: Figure 4.—A Gaspipe Annealing Oven]

Probably the simplest of all ovens for small tools is made by placing a piece of ordinary gas pipe in the fire (Figure 4), and heating until the inside of the pipe is bright red. Parts placed in this pipe, after one end has been closed, may be brought to the desired heat without danger of cooling draughts or chemical change from the action of the fire. More elaborate ovens may be bought which use gas, fuel oils or coal to produce the heat and in which the work may be placed on trays so that the fire will not strike directly on the steel being treated.

If the work is not very important, it may be withdrawn from the fire or oven, after heating to the desired point, and allowed to cool in the air until all traces of red have disappeared when held in a dark place. The work should be held where it is reasonably free from cold air currents. If, upon touching a pine stick to the piece being annealed, the wood does not smoke, the work may then be cooled in water.

Better annealing is secured and harder metal may be annealed if the cooling is extended over a number of hours by placing the work in a bed of non-heat-conducting material, such as ashes, charred bone, asbestos fibre, lime, sand or fire clay. It should be well covered with the heat retaining material and allowed to remain until cool. Cooling may be accomplished by allowing the fire in an oven or furnace to die down and go out, leaving the work inside the oven with all openings closed. The greater the time taken for gradual cooling from the red heat, the more perfect will be the results of the annealing.

While steel is annealed by slow cooling, copper or brass is annealed by bringing to a low red heat and quickly plunging into cold water.

Hardening.—Steel is hardened by bringing to a proper temperature, slowly and evenly as for annealing, and then cooling more or less quickly, according to the grade of steel being handled. The degree of hardening is determined by the kind of steel, the temperature from which the metal is cooled and the temperature and nature of the bath into which it is plunged for cooling.

Steel to be hardened is often heated in the fire until at some heat around 600 to 700 degrees is reached, then placed in a heating bath of molten lead, heated mercury, fused cyanate of potassium, etc., the heating bath itself being kept at the proper temperature by fires acting on it. While these baths have the advantage of heating the metal evenly and to exactly the temperature desired throughout without any part becoming over or under heated, their disadvantages consist of the fact that their materials and the fumes are