Welding

In many of the more intricate shapes that are hand-forged, resource is had to welding, and if the average smith were told that he could not make a perfect weld he would feel greatly insulted. But from a large number of so-called perfect welds that were examined very few showed a strength equal to 50% of the unwelded section. With the alloy steels it is difficult to get a weld that will even show that percentage, as nickel, chromium, vanadium, tungsten, aluminum, and some other alloys do not lend themselves to the welding process. It is difficult to make welds at all by the hand methods in a blacksmith's forge, when these

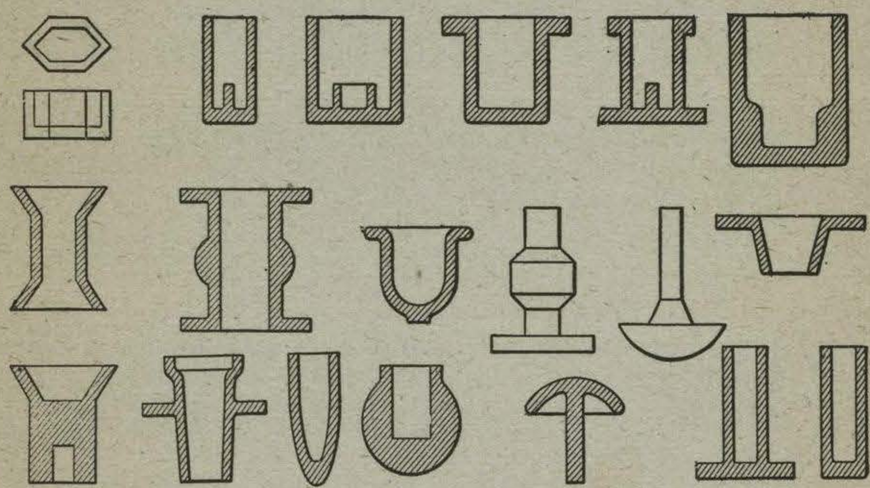

Fig. 75. — More shapes made in hydraulic press with loose die blocks.

elements are ingredients of the steel to be welded. Some of these steels have been welded, but an efficiency of over 25% is seldom obtained.

Carbon, however, is the principal enemy of welds, and with this as low as 0.15% it must be handled with great care at the welding heat, while with 0.20% of carbon the steel is very unreliable, and with 0.50% of carbon the steel is liable to be burnt at a temperature well below the welding heat.

Thus to make hand-forgings where welds are necessary, the pieces must be from two to three times the size of that necessary for the required strength, and with some of the alloyed steels even this will not suffice.

PRINCIPLES INVOLVED

Welding consists of heating two pieces to a high temperature, then dissolving off the iron oxide, which has formed on the surface, by the use of some flux, such as borax, and then firmly pressing the pieces together. Welding plates are sometimes put between the pieces to be welded in place of the borax. These are special preparations which are made for this purpose, and are covered by patents.

The exact temperature at which to heat pieces for welding is not known, but it is near the melting point, as the steel must be in a soft, almost pasty, condition. The pieces are usually upset or enlarged at the ends, so that the section at the weld will be larger than the rest of the piece. In the ordinary weld they are hammered continuously until the metal has cooled to a dull red. This breaks up the coarse crystals which have been produced by the high temperature, and by finishing at a low temperature a small grain is secured.

This small grain is obtained, in the metal close to the weld, by proper welding, but there is always a place within a short distance of the weld that must have been heated to a high temperature, which means overheated, and has not received the mechanical treatment given at the weld by hammering it down to the proper finishing temperature. This will cause the metal to have a coarse grain at this point, which is usually from 4 to 8 inches from the weld, and the steel to break when submitted to strain much less than the original strength of the metal welded. Thus, while the average welder may say that if no break occurs at the weld it is as strong as the original piece, this is not true and welds are seldom made by hand methods that have more than 60% of the efficiency of the original piece. In a large number of tests which were made it was found that the chief cause of damage was the bad crystallization adjacent to the weld.

All steels that have been welded would give better results if they were reheated to a little above 1650° F., as this heating would restore to a large extent the grain size of all parts.

Steel is burned when the first drops of melted metal begin to form in the interior of the mass. These segregate to the joints between the crystals and cause weakness. The second stage of this is when the molten drops segregate as far as the exterior and leave behind a cavity filled with gas. The third and last stage is reached when gas collects in the interior under sufficient pressure to form miniature volcanoes and break through the skin. This projects liquid steel and produces the well-known scintillating effect of this temperature. Into the openings formed by these miniature explosions air enters and oxidizes the interior. Steel that has been overheated to this extent cannot be fully restored by either mechanical working or heat refining.

ELECTRIC WELDING

The hand method of welding being a slow, laborious process when large pieces were to be welded, and the efficiency of the welds being low, it became necessary to abandon welding, in many cases, as a commercial possibility, or to invent some other means of performing the welding operation. This necessity brought into use two electrical welding processes and several gas processes.

In the electrical resistance process the pieces to be welded are usually butted together and clamped so there will be a pressure against each other. Two electrodes are then placed on each side of the joint to be welded, and the current of electricity passing through these also passes through the steel at the joint. This softens the metal by heating it nearly to the melting point, and the pressure of one piece against the other squeezes them together until they are welded.

This process has many advantages over the hand method. The heating can be localized and held in the immediate vicinity of the weld, and the hand can be held on the metal but a very few inches back from the weld. This prevents the metal from crystallizing 6 or 8 inches back as in the forge-heated piece; the temperature of the surfaces to be welded is always under control, which reduces the danger of overheating the steel to a minimum. The pressure between the abutted pieces may be regulated to any pressure desired and very irregular shapes may be butted together and welded in a very accurate manner. The efficiency of the weld has been increased 50%, and in some cases 100% over that of hand welding.

The other electric welding process is called arc welding. In this a carbon electrode is placed in a holder so it can be held in the hand close to the work, which is placed on an iron or steel-topped table. This table is connected to a rheostat, and that to the power supply, as is also the carbon electrode. A water rheostat is usually used. With the proper connections made, the electric current flows through the rheostat and the carbon electrode and strikes an electric arc, the same as do the arc lamps seen in the street. This creates an intense heat that melts the metal on each side of the joint, and by holding a rod in the other hand, new metal can be fused with the old metal in the joint, and the two pieces stuck together.

This is a process of casting steel into the joint, and hence rolled or forged metal cannot be made as strong as the original stock except by leaving a ridge at the weld, so the metal will be thicker. Even this, however, will make a stronger weld than can be made by the blacksmith with a hammer, anvil, and forge fire. If the arc electric welds were hammered after welding, while the metal was still hot, and before it had cooled to a dull red, the weld could be made much stronger, as this would change the grain from the coarse crystalline one of a casting to the more dense grain that approaches that of a forging.

Alloyed steels that do not lend themselves readily to welding by hand can be successfully welded by the electrical process. The density of the metal is much more uniform when welded by electricity than by the hand method, and the weld is made in a fraction of the time. The amount of work required in finishing after electric welds is very small, as it leaves it comparatively smooth; a slight ridge right at the weld being practically all the deformation there is in the metal.

This has aided greatly in the production of forgings, as they can be made in two, three, or more pieces and afterward welded together. It has also been found in many cases to be a better method than brazing, and is sometimes substituted for this.

WELDING WITH GASES

Several different processes of welding with gases and a blowpipe or torch have recently been developed, and these have become quite a factor in the manufacture and repair of metal parts of all kinds. The gases used for these various processes are acetylene, hydrogen, liquid gas, city gas, and natural gas, which are burned either with oxygen or with air. All of these processes operate in the same way as the arc electric; *i.e.*, they melt new metal into the joint and fuse it with the old.

Of the several gas processes the oxyacetylene has taken the lead, and this consists of heating the metal with a torch, using oxygen and acetylene gas. With this the metal is heated to the melting point, and a steel rod is passed along with the flame, when steel is being welded, and the metal melts off from the rod and flows into the joint until it has been filled.

The flame is largely carbon monoxide, but at the tip where the heating takes place it is converted into carbon dioxide. This gives a flame that will neither carbonize or oxidize the metal. In lighting the blowpipe or torch the acetylene is first turned on full, then the oxygen is added until the flame has only a single cone whose apex has a temperature of about 6300° F. Too much acetylene produces two cones and a white color, while an excess of oxygen is shown by the flame assuming a violet tint and a ragged end. The best welding results are obtainable with 1.7 volumes of oxygen to one of acetylene.

The oxygen for the process is obtained by either using a special generator that generates oxygen from chemicals, or by buying the oxygen that is stored in steel bottles and sold in the open market. It is used at a pressure of about 15 pounds per square inch. The acetylene gas is manufactured in the ordinary way from calcium carbide, and used at a pressure of 2 or 3 pounds.

Through a system of piping, the flame is easily carried to the work, which saves the labor of moving large pieces of work to a forge or hammer for welding. Pieces one inch thick have been successfully welded with this process, but its best application is in welding thinner sheet metal, as joints of great length can be easily welded. In fact, its only limit is the length of the joint and the time needed, and this latter can be carried out indefinitely.

Oxyacetylene welding gives its best results in the welding of steel, but cast iron is being welded successfully as well as copper, brass, and bronze.

The different metals can also be welded together as is shown in Fig.

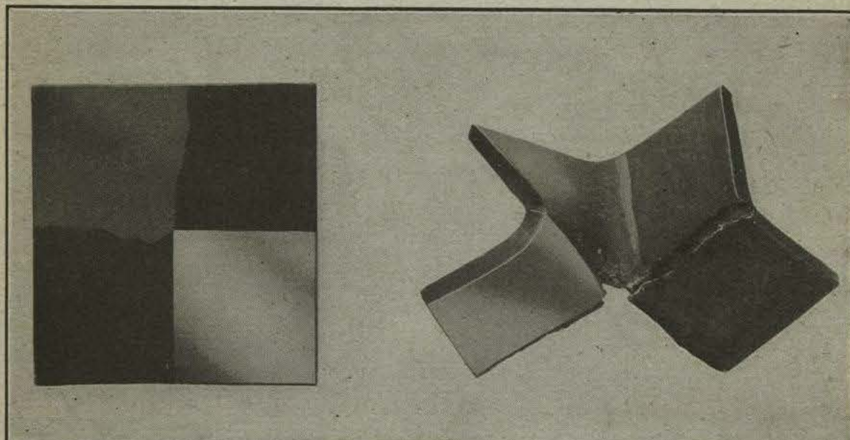

FIG. 76. — Steel, copper, brass, and bronze welded together.

76, in which four plates were butted together and welded. One plate was steel, as shown by the white square; another brass, as shown by the darker square in the diagonally opposite corner; and the two very dark squares were copper and bronze respectively. After welding these they were bent and broken at the joints to see if they were thoroughly welded, and from the appearance of the fractures they would indicate a perfect weld. The steel welded to the copper and bronze as well as the brass did. Owing to the high heat of the flame, however, some of the lead and zinc in the brass and bronze melted out, leaving holes in the metal.

This welding process, as well as all the other gas processes, makes the weld by casting metal into the joint in the same way as does the arc electric welding process. Therefore, on rolled or forged metal the joint is not as strong as the original metal, but it is stronger than a weld made

with a forge fire, hammer and anvil, and metals can be welded that it is impossible to weld in the latter way. In some cases an efficiency of 90% has been claimed, but if the work is properly done an efficiency of at least 80% can be obtained with any metal.

The oxyhydrogen process only differs from the oxyacetylene in that hydrogen gas replaces the acetylene gas. The oxygen and hydrogen are used in the proportion of from 2 to 4 parts hydrogen to 1 of oxygen, and the hottest part of this flame is about $\frac{3}{8}$ of an inch from the point of the burner.

Two parts hydrogen to one of oxygen will give a flame with a temperature of about 4350° F., but if a flame is desired with a reducing action it is necessary to use 4 parts of hydrogen to 1 of oxygen, and this will have a temperature of about 3450° F. This flame will melt iron or steel, and cause it to weld even if the surfaces are not clean, as any rust present will be reduced. It is also a very good flame to use for the cutting up of metals. This lower temperature of the flame is really better for sheets up to $\frac{1}{8}$ of an inch thick, as the melting of the metal is less rapid and less explosive, giving a welded joint that is cleaner and with fewer scars and blisters.

The oxyliquid gas welding process consists of replacing the acetylene or hydrogen with liquid gas, and as this combination generates a heat of about 4000° F., it will make welds that are equal to either of the above processes, and for all practical purposes it is as good. The liquid gas is a product that is made from crude oil and stored in steel bottles, similar to oxygen, at a high pressure. At this pressure it is a liquid, but when allowed to expand to the 15 pounds pressure required for welding, it becomes a gas, and is mixed with the oxygen in a torch, the same as the other processes.

Another process uses city or natural gas and oxygen. These are combined in a torch, to get the proper mixture and generate the necessary heat for welding. For many purposes this is very useful, but the flame does not have as high a temperature as the others.

Still another process consists of combining city or natural gas with two blasts of air; one of which has a high pressure and the other a low pressure. These are sent through a special torch and have been used to successfully weld cast iron and the non-ferrous metals. It does not seem to develop enough heat to weld steel, and therefore its field seems to be limited to metals of a lower fusing temperature than steel. Acetylene has also been used in addition to the above gas and air with good results.

THERMIT WELDING

The thermit process of welding is radically different from all the other processes, and is useful for an entirely different class of work.

In this process, a sand mold is built around the pieces to be welded and the metal poured in this. The mold is made of sand and clay, which should be mixed thoroughly stiff and as dry as possible, as the less moisture there is in the mold the better will be the results obtained. For this reason the mold should be dried in a furnace or oven at a low temperature for from six to eight hours. To test the dryness of the mold, two or three wires can be rammed up in the thickest section of it and these pulled out after drying to see if any moisture remains.

With the mold completed the thermit is placed in a special receptacle which is located over the mold. The thermit consists of aluminum and oxide of iron. A little ignition powder is placed in this and lighted with a match. Immediately there sets up a tremendous chemical action, which produces a superheated liquid steel and superheated liquid slag consisting of aluminum oxide. When the mass is entirely molten it attains a temperature of 5400° F. The bottom of the receptacle is then tapped and the liquid metal runs into the mold and into and around the joint to be welded. The high temperature of the liquid mass causes the ends of the pieces to be welded, to become molten and pasty, and fuse with the thermit.

Welds were made with this process on a bar of rolled steel, 2 by 4½ inches, which was broken, then welded, and afterwards tested. The tests showed an efficiency of 97% in tensile strength and 88% in elastic limit.

The greatest usefulness of this method of welding is for the stern frames of steamships which have broken, locomotive side frames, driving wheels, connecting rods, and other things of a similar nature, but the building of the mold makes it commercially prohibitive where autogeneous or electric welding can be used economically.

CHAPTER VIII

Furnaces and Fuels Used for Heat-Treatment

In working steels it is very important that they be properly heat-treated, as poor workmanship in this regard will produce working parts that are not good even though the stock used be the highest grade of steel that is procurable. And by improperly heat-treating them it is possible to make high-grade steels more brittle and less able to support a load or withstand stresses than ordinary carbon steels. All steels are improved in tensile strength, elastic limit, elongation, or reduction of area by annealing, hardening, or tempering them. The different treatments are divided into three distinct classes, the first of which is hardening, the second annealing and reheating, and the third case-hardening, carbonizing, or cementing.

The theory of heat-treatment rests upon the influence of the rate of cooling on certain molecular changes in structure occurring at different temperatures in the solid state. These changes are of two classes, critical and progressive; the former occur periodically between certain narrow temperature limits, while the latter proceed gradually with the rise in temperature, each change producing alterations in the physical characteristics. By controlling the rate of cooling, these changes can be given a permanent set, and the physical characteristics can thus be made different from those in the metal in its normal state.

The results obtained are influenced by certain factors as follows: First, the original chemical and physical properties of the metal. Second, the composition of the gases and other substances which come in contact with the metal in heating and cooling. Third, the time in which the temperature is raised between certain degrees, or the temperature-rise curve. Fourth, the highest temperature attained. Fifth, the length of time the metal is maintained at the highest temperature. Sixth, the time consumed in allowing the temperature to fall to atmospheric or the temperature-drop curve.

The third and sixth are influenced by the size and shape of the piece; by the difference in temperature between it and the heating and cooling mediums, and by the thermal capacity and conductivity of the latter. Each of these may vary widely within the temperature range to which the piece will be subjected.