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Welding And The World Of Metals



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PREFACE

This series of articles entitled “Welding and The World of Metals” first appeared in the Memco News, the official house organ of MILLER Electric Manufacturing Co., beginning in June-July, 1961, issue.

Since that time, a total of seven articles have been written compiling historical data researched from many sources. The articles were intended to bring some light to the welding industry concerning the massive heritage we have received from those who have gone before.

It has been said that “to learn is to know.” If we may judge from comments by schools and students, we have apparently succeeded in a small way in providing some of the material for learning. This is a rich reward indeed.

Note 

The essays in this publication are presented in their original form and are intended to provide a nostalgic, yet accurate account of the origin of welding. The essays may not reflect the latest welding products or practices.



W E L D I N G

... AND THE WORLD OF METALS

THIS series of articles is intended to shed a little more light on a field of endeavor that historians tend to overlook. In the overall analysis, welding has never really been given much credit for advances in technology that would have been impossible without it.

Ask a dozen people, "What is welding?" and more than likely you will get a dozen scrambled answers all the way from "I think it has something to do with metal" to "It's a way to join iron together."

What is *welding*? It is defined by the American Welding Society as "The metal joining process used in making the weld." A *weld* is defined as "A localized coalescence of metal wherein coalescence is produced by heating to suitable temperatures, with or without the application of pressure, and with or without the use of filler metal. The filler metal either has

a melting point approximately the same as the base metals or has a melting point below the base metals but above 800° F."

Further explanation of the term "weld" can be made in less technical language. The AWS Training Manual of Arc Welding says, "A weld is made when the separate pieces of metal to be joined combine and form one piece when heated to a sufficiently high temperature to cause softening or melting. Pressure may be used to force the pieces together, or filler metal may be added to fill the joints. The melting point of the filler metal must be above 800° F or have approximately the same melting point as the base metal."

There is some question in the writer's mind as to the validity of the listed definitions of "welding." Bearing in mind the rapid increase in welding processes now developed or in the



process of being developed, it appears that possibly no single definition can properly define the term "welding." As this series of articles progresses, we may find that we can logically define welding into two or more basic categories.

Now, let us traverse the dusty road of history and see the what, where, when, how, and why of metalworking and welding and how it all started.

Metalworking history goes back to the time when some anonymous Homo sapien found that he could shape one "rock" by hammering on it with another. The "rock" likely was a relatively pure piece of copper or iron that he had found. Ancient manuscripts detail the beautiful metalworking done in the time of the Pharaohs of Egypt. Yet another earlier mention is made of metalworking. In the Book of Genesis, Chapter 4, Verse 22 it says "Zillah bore Tubal-Cain; he

was the forger of all instruments of bronze and iron." From this we can construe that the art of metalworking was one of the earliest forms of endeavor known to man.

Ancient history tells us that all man's higher culture rests on the metals. Gold and silver were some of the earliest metals worked, usually into ornaments. Their intrinsic value was much less than that of iron, copper, tin, or bronze. Pure metals such as copper or meteoric iron were readily available to the tribes living near the Great Lakes area and other Northern Hemisphere areas. Archaeologists agree that accidentally found pure metals were hammered into shapes before they were ever smelted or heated and shaped.

It is interesting to note that the Metals Age manifested itself in different ways in various parts of the world. For instance, research has

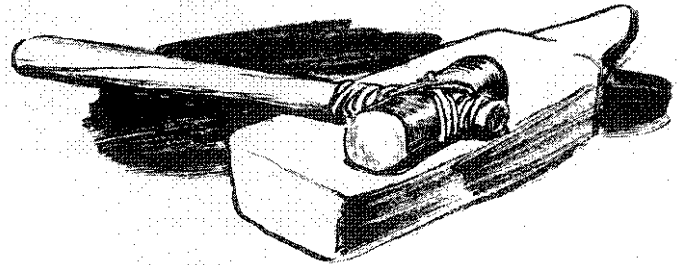
proved that copper, bronze (a combination of copper and tin), and then iron were gradually introduced in Europe in the order named. In Japan, copper and iron apparently came into use about the same time. African Negroes, Malays, and Polynesians used iron immediately after stone. It appears that copper and bronze were unknown to them. The American Indians did not have knowledge of iron until after the discovery of the West Indies by Columbus; however, they did work with pure copper. In Mexico and Peru, the Aztec Indians and the Inca Indians smelted and cast it and also made the alloy bronze. China, India, and Indo-China in the Far East and the principal cities of the Near East all give evidence of having followed the European format of copper, bronze, and then iron.

The metal, copper, is very common in the earth. Large quantities have been found near the surface and, being a relatively soft and ductile metal, it was easy for the primitive craftsman to work, even with his meager tools. It is possible to assume that the Bronze Age was preceded by a period of time in which copper was the prevalent metal. This is especially true in certain areas where the metallurgy of extracting and combining two metals was not known.

Metallurgy arose in a very primitive state, probably because a foreign substance was tossed into a molten broth being smelted in an earthen pot. We can speculate that the material of the pot may have alloyed with the prime metal making it harder. Whatever its origin, it is an archaeological fact that metallurgy was known in the Near East at least as long ago as 4000

B.C. It is known that the copper mines of the Peninsula of Sinai and the Island of Cyprus were worked prior to that time and that alloying had been accomplished.

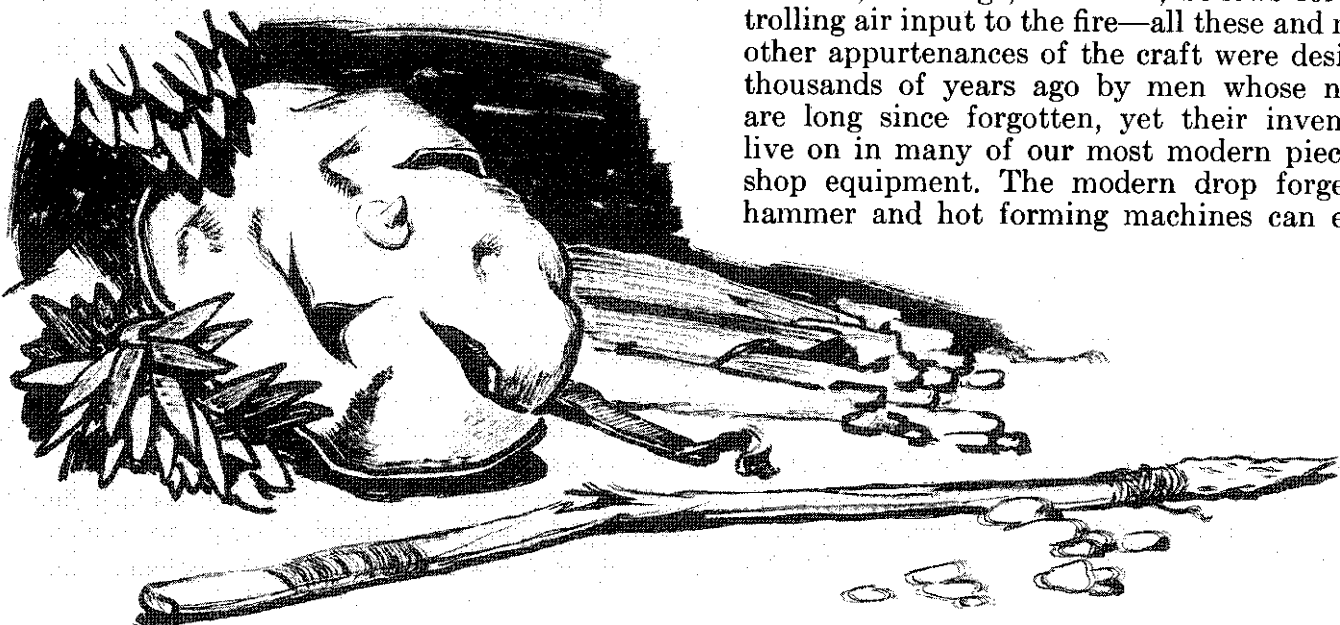
Probably the fact that copper would not hold



an edge due to its extreme malleability led to the discovery that a slight addition of tin would make it tougher. The alloy, called bronze, appears on the archaeologists calendar some time between 3000 and 2000 B.C. First discoveries of bronze artifacts were made in lands bordering the eastern Mediterranean. With the nomadic tendencies of the people and the traders' caravans penetrating Central and West Europe, the "new" metal spread to these areas where it was eagerly accepted as a replacement for copper. After all, who wanted a battle shield that an enemy could hack apart with a battle ax made of a tougher metal?

During the evolution of metals there naturally was a development of talent to work the new-found materials. In Europe, the smith, as he was called, gained increasing stature in society as his talents became broader in the art of shaping and joining metals.

It was these early workers of metal who developed the basic tools for their craft. The hammer, the forge, the anvil, bellows for controlling air input to the fire—all these and many other appurtenances of the craft were designed thousands of years ago by men whose names are long since forgotten, yet their inventions live on in many of our most modern pieces of shop equipment. The modern drop forge, air hammer and hot forming machines can easily



be traced back thousands of years to a burly, sweating individual swinging a huge sledgehammer in a smoky blacksmith shop while his apprentice turned a heated billet on the anvil.

Yet, lest we get too enthralled with the smith's social position, let us see how he fared in other parts of the world. In Africa, some tribes forced the metalworker to live as an outcast at the village edge. This is thought to be that because of his ability to shape the products of the earth, the tribal people feared his "powers." This is strictly supposition and cannot be documented.

In the Far East, the metalworker was accorded a fairly responsible position in society. His stature in the field was determined by the quality of his work and the position of his clients. In the Near East, the metalworker could actually work up to a position of minor prominence, again depending on his craftsmanship and the social stature of his clients.

We have talked of copper and bronze but what of iron, our most used metal today. When did this relatively common material enter into man's way of life?

Iron came into the historic picture at a relatively late date. Historical calendars indicate that iron became known to Europe about 1000 B.C. This was several thousand years after the advent of copper and bronze. However, the people of that era were slow to use iron because their bronze implements were satisfactory and they already knew how to work with the copper-tin alloy.

It is quite a revealing sidelight that the Egyptians called iron "the metal of heaven." This would indicate that they probably obtained the material from meteorites. Egyptian artifacts have conveyed the impression that iron was little used for tools and weapons until approximately 900-850 B.C.

In the Western Hemisphere, iron was unknown before Columbus made his momentous voyage. Its use caught on rapidly among the American Indians and later the Polynesian people. The Polynesians were ignorant of metals and one story in their history tells of obtaining some iron nails from a European trader. Not realizing what they were or what iron was, they planted the nails in hope of raising a new crop!!

The use of iron spread rapidly over the known parts of the world as man traveled and explored. At last, here was a material that was tougher and stronger than copper or even the copper-tin



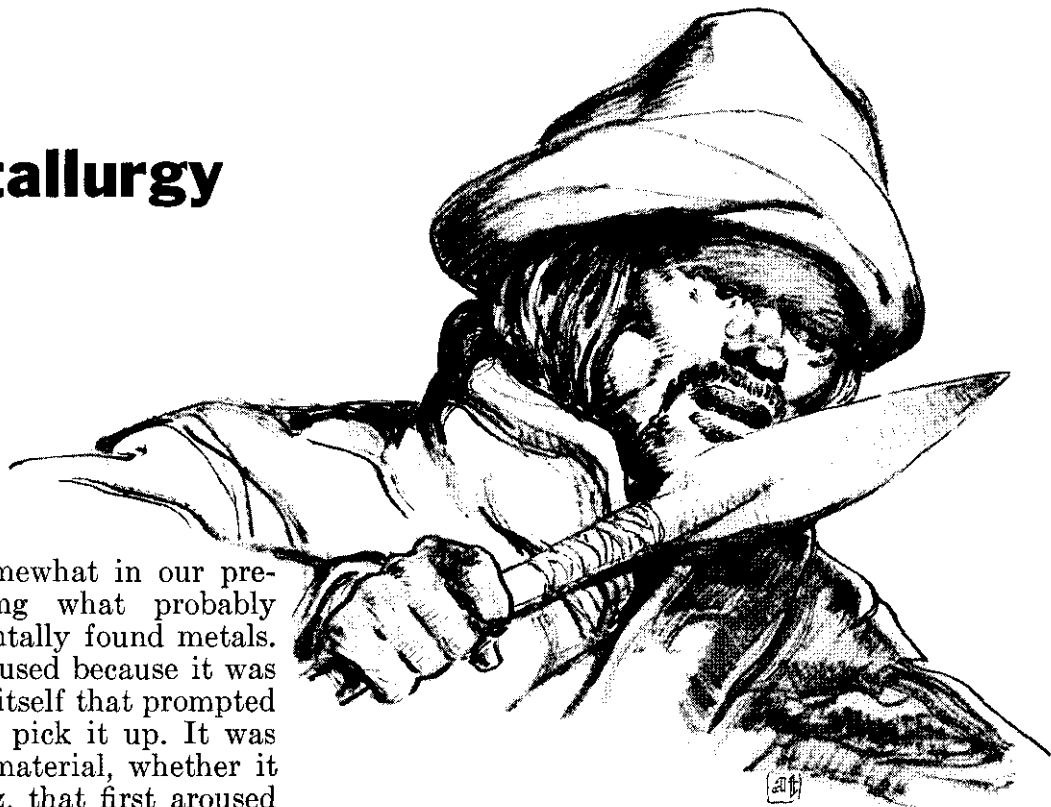
alloy bronze. This was the beginning of an era that has since been named the Iron Age.

When we speak of the Bronze Age and the Iron Age, we usually consider these times as archaic, ancient, long ago periods in history. But are they?

Imagine, if you will, that all iron and all copper and bronze have been subtracted from everything about you. Your car is gone, your appliances at home are gone, your plant machinery, your air conditioning are all gone. Your wife can't call you on the phone because half of it is gone and the wires are all gone. The result, naturally, is almost beyond comprehension.

No, the Bronze Age and the Iron Age are *not* past history. They are a vital, dynamic part of our lives. Our benefits continue to grow from having these materials and the ability to work with them. Welding stands at the open door of opportunity waiting for you to use its advantages to build a stronger, safer, better world in which to live.

Early Metallurgy



WE have theorized somewhat in our previous discussion concerning what probably occurred when Man accidentally found metals. The term “accidentally” is used because it was not the knowledge of metal itself that prompted our unknown individual to pick it up. It was probably the color of the material, whether it was in pure form or quartz, that first aroused Man’s curiosity. Once aroused, that curiosity has progressed and developed into modern technology as we know it today.

In the first part of this series of articles we spoke of the use of copper, the discovery of bronze and the advent of iron. In this article we would like to focus the light of our attentions on the uses of these materials.

The use of metals goes beyond the realm of recorded history. We must, therefore, rely to a great extent on the information obtained from archeologists’ excavations to determine the dates and times of various types of artifacts found.

Herodotus, who was a historian in Grecian times, about 484-425 B.C., notes the fact that “100 gates and lintels in the city of Babylon were made of bronze castings.” The estimated time in our historical chronology places these bronze castings in the City-State of Babylon about 7000 B.C.

Copper utensils and weapons have been found in archeological excavations in Egypt and Mesopotamia dating as early as 4000 B.C. These artifacts are relatively crude in some cases but demonstrate the fact that the people of this era had the knowledge to mine and smelt the copper ores.

Excavations are currently being conducted in the north-central part of the state of Wisconsin which indicate that a copper culture existed about 5000 years ago in this area. Artifacts found in these excavations include arrowheads, a type of short, jointed harpoon and other utensils made of copper.

Earlier we stated that the alloy bronze appears on the archeologists calendar sometime

between 3000 and 2000 B.C. Information since gathered shows that bronze weapons and other artifacts have been found in Egypt dating back as far as 3200 B.C. The artifacts were in the form of spearheads and daggers and, by their location with relationship to the placement of the body in the tombs of the Pharaohs, it may be assumed that they were very highly valued.

You have probably noticed that this story has dealt thus far with areas that fringe the Mediterranean Sea, notably in the Tigres-Euphrates Valley area, Egypt and Mesopotamia. The Tigres-Euphrates Valley area is historically believed to be the fountainhead of our civilization. We will not delve into the sociological and historical aspects of civilization except as it effects the development of metal working or vice versa.

About 3000 B.C. Hissarlik, Mesopotamia and Egypt had the metal iron. Usually, the metal was in the form of beads and other types of ornaments, indicating that it was very rare and quite valuable. From the artifacts found in this area, the material is assumed to be meteoric in origin. Such metals were usually found in lumps at the ground surface and, because of its very high nickel content, the material was very malleable. In this respect it was much like some of our steels of today. Literary and archeological findings show that this metal was used very sparingly and was very highly valued.

Many accounts of supernatural powers have

been attributed to iron. It is assumed by archeologists and historians alike that the celestial origin of the metal probably accounts for its so-called "power."

It is a fact that iron was valued as a talisman by the northern Europeans. In this respect the horseshoe, which we value as a good luck piece today, was valued not because of the shape of the horseshoe, but because of the iron material from which it was made. The folklore of the northern Europeans states that the fairies, trolls and evil spirits in which they believed were powerless in the presence of iron.

From this point on much of the information we have concerning the working of metal and the development of civilization through the use of metals is based on writings in the Old and New Testaments of the Bible. It is interesting to note at this time that the Old Testament mentions the metal iron some seventy times whereas the New Testament mentions it just four times. From this fact we may conjecture that Man placed great importance on the metals in pre-Christian times. It also forms a basis for the belief that the advancement of civilization as we know it today greatly depended on metal work and metal technology.

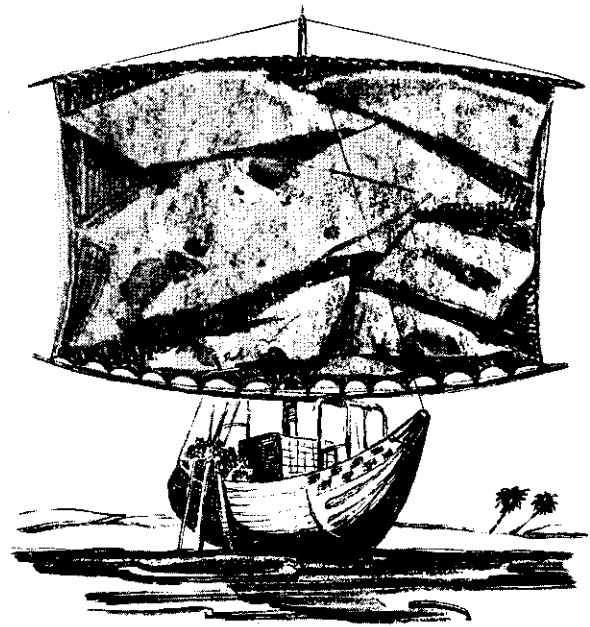
An event in history occurred about 2500 B.C. that seems to be entirely out of context with the development of materials and metallurgy as we have thought about it in recent years. It has become evident that ancestors of the Indo-European speaking Aryans, who invaded western Europe several centuries later, had developed an extraordinarily high state of the art in metallurgy and metal craftsmanship, especially in the manufacture of weapons. These people lived in the southern Russian plains and were semi-nomadic. Among some of the weapons and armor found have been very fine spearheads, arrowheads, armor, helmets and shields of excellent bronze manufacture. Apparently, from all that can be ascertained, these people had no intercourse with the people of the Mediterranean area in any way.

In the Old Testament of the Bible, it is noted, beginning in Deuteronomy 8:9, that the Holy land was extolled as "a land whose stones are iron, and out of whose hills thou mayest dig copper." This cannot be modern Palestine which contains no ores of any moment. The "stones of iron" may refer to the black basaltic rocks which are east of Jordan. The "hills of copper" probably refers to Lebanon, where mining was practiced at that time. We know that copper was mined about 3000 B.C. in the Mt. Sinai peninsula. Traces of old copper and iron mines occur north of Beirut which is in the Kesravan range.

Jeremiah 15:12 speaks of "iron from the north" which would also place the iron mines somewhere in the Lebanon area. While the Lebanon ore quantities were not large they were apparently quite rich.

Continuing with our chronological table, the period from 2500 B.C. to 1300 B.C. saw Egyptian metal workers producing six foot rip saws of copper for sawing planks. These artificers also produced saws for cutting the one-ton blocks of stone for the pyramids. The investigations of ruins and the perusal of ancient writings note also that copper drain pipes were used in this era.

The Israelites did not have the metals in their own homeland apparently but they did obtain them from neighboring countries and learned the art of working them. They soon found that the ores must have the impurities cleaned out of them in order to get the pure metal and this



was done by smelting. To facilitate the preparation of the materials in pure form, they added vegetable alkaline salts, such as carbonate of potash from wood ashes, or a mineral alkaline salt to their smelting vats. This is referred to by Isaiah and Ezekial of the Old Testament.

2000 B.C. is accepted by most historians and archeologists as the beginning of the Bronze Age. The Bronze Age referred to is in Europe and the Afro-Asian countries. Much later this event occurred in North and South America, as we know it today, among the Mexicans and Peruvians but the developmental characteristics were much the same as in Europe.

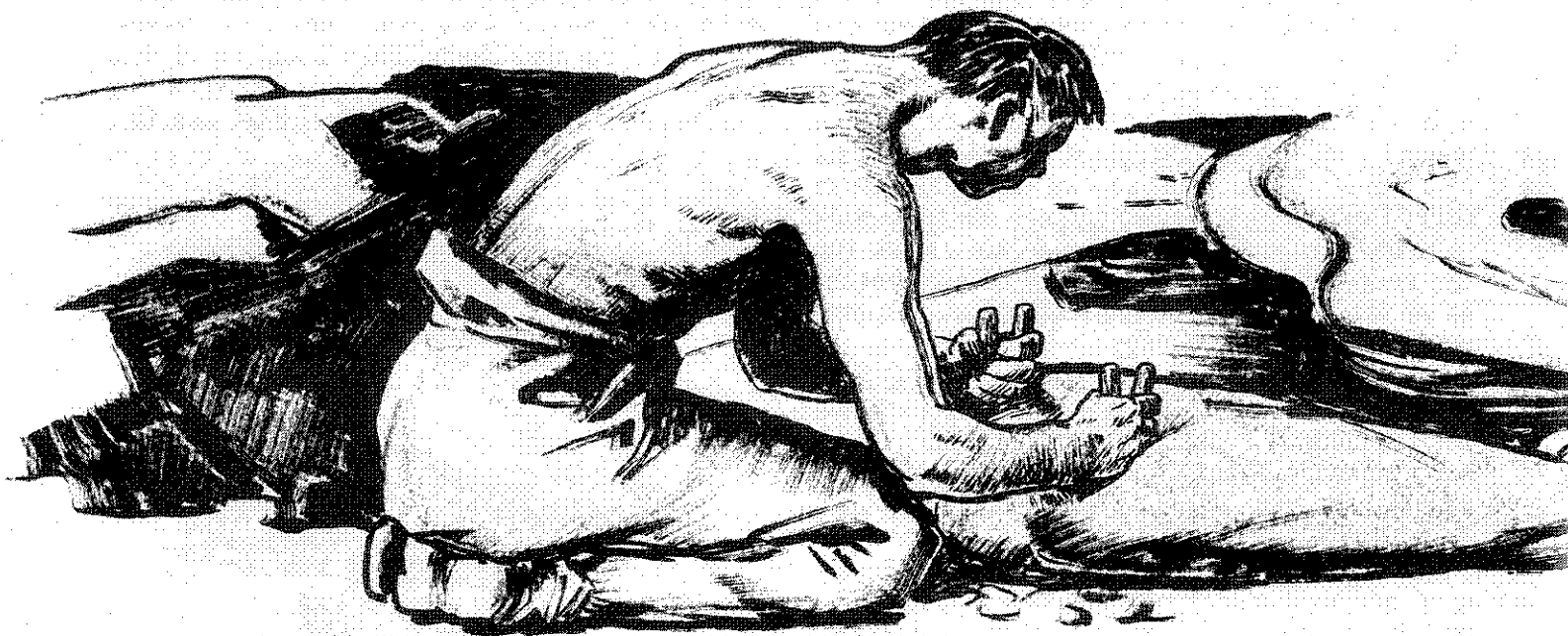
The great bronze center of activity was His-

sarlik (Troy) which is located on the Dardanelles. From this great port and center of industrial activity, Cretan trade ships carried bronze throughout the Mediterranean area, probably bringing back tin from Spain, and eventually, from the "Tin Islands" which are now the area of Cornwall in what we know as the British Isles. Within two centuries the knowledge of bronze had traveled to Britain in the west and as far as China in the east. The material was mostly used for weapons and ornaments for the rich at this particular time.

About 2000 B.C. saw a great restlessness in the peoples of the European continent. It was

which indicates that during the Shang Dynasty in China which occurred 1523-1027 B.C., bronze statues and decorations of very excellent quality and highly esthetic value were being cast using what is known as the "lost wax" method. The lost wax method of casting will be described in greater detail in Part 3 of this series of articles.

We have mentioned that iron was in use as early as 3000 B.C. but it wasn't until about 1500 B.C. that the first intentional production of iron was effected in an area on the southern slope of the Caucasus mountains. By 1350 B.C. knowledge of the metal iron had spread to Mesopotamia, Egypt and Palestine. From there its



Smelting Iron

at this time that the first Aryan invasion was made by the Achaeans who invaded Greece. As you will remember, by having read the reference to their ancestors, these people at that time had a very high state of the art of metallurgy and consequently had superior weapons to the Greeks of that era.

About this time we find the Phoenicians also beginning to play an important part in the history of Man. The Phoenicians were excellent sailors and made many very hazardous trips in their rather primitive craft joining the trade routes all around the Mediterranean Sea one to the other. It was through the travels of these people that the knowledge of metals was spread to the known world.

We have mentioned that the metal bronze became known in China soon after the beginning of the Bronze Age. Evidence has been procured

use and knowledge spread to the rest of the known world. Until about 1400 A.D. all the iron manufactured was by what is known as the "direct process."

The direct process of manufacturing iron was accomplished by smelting the iron and bringing it forth from the smelters in what was known as "sponge iron." This sponge iron had some of the impurities smelted out of it but it was not of a quality that could be cast as we know it today.

The reason the material was not cast is quite simple. The smelting procedures used at that time and the fuel used were not capable of producing a hot enough molten bath to fully reduce the iron to its purest state. Therefore, the sponge iron was hammered and worked by force into the shapes desired and to gain the quality requisite to the part being made.

We do not wish to infer that the knowledge of working iron was not known at an early date. What we are trying to develop here is the *type* of iron that was used for the various artifacts and by the various peoples. Most of the early iron artifacts that have been found—weapons, beads, vessels—were made of meteoric iron which has, as we have said, a very high nickel content. It is a known fact that nowhere on the face of this earth is there a native iron ore which contains the high nickel content we have mentioned here.

In our development of the state of the art of metals and metal working, we find that gold

however, used chiefly for ornaments such as rings, chains, jewels, drinking vessels, cups, etc.

In the earliest times gold was less precious than silver which had to be purified by smelting. But the visits of the Phoenicians to Spain, and their finding there of the great silver deposits in and around Cadiz, changed all that.


The historian Pliny reports that when the Phoenicians made their first visit to Spain, the great abundance of silver caused them to have silver anchors cast for their ships. Upon bringing this great wealth of silver back to the known areas of civilization, the very abundance of the metal caused its price and worth to deteriorate and it has ever since been less valuable than gold.

It is an interesting sidelight to note how the value of gold to silver was ascertained. Silver is called the "Moon" metal and gold classed as the "Sun" metal. The ratio of value of silver to gold was $13\frac{1}{2}$ to 1. This is the ratio of the moon's revolutions to those of the sun. While this may seem like a rather loose way to evaluate the worth of one metal to another it served the purpose for which it was intended at the time.

While we are speaking of the value of metals we certainly cannot overlook the value of copper which was the most common material known in ancient times. The value of copper was in the ratio of sixty to one as compared to silver. That is, sixty parts of copper equalled one part of silver in value.

Referring once again to the Old Testament of the Bible, we find in I Samuel 17:5 the details of the armor and weapons that the giant, Goliath, had in his possession at the time of his battle with the youth, David. It is said that Goliath had bronze weapons. His armor, his greaves (which were arm, shoulder and upper arm shields) and his shield were all of bronze metal; the spearhead alone was made of iron. As biblical history tells us, all these fine weapons and armor did him no good because David overcame him with a well placed rock from a sling.

During this period in history we find reference to many articles made of bronze. The bow, shield, spear and greaves are all mentioned in II Samuel 21:16 and 22:35. Furthermore, household cooking utensils, mirrors, chains, bars, doors and sacred images were all made of bronze. The Bible is very emphatic in making bronze the symbol of hardness and stability.



was one of the earliest metals from which ornaments and other utensils were made. Several reasons may be advanced for the early use of gold, the most prominent of which is the fact that gold is frequently found in its pure form and does not require extensive smelting and working to bring it to a usable state. It is also easily mined and, of course, has a characteristic bright color which would attract early Man. From the most ancient times gold has been a much sought after material because of its extreme malleability and great beauty. Many jeweled clips and intricate hand-wrought pieces of art have been recovered from excavations of ancient areas.

Even in early times gold was employed as a medium of exchange. It had its fixed forms in the shapes of bars, wedges, (sometimes called tongues) and rings of defined weight. It was,

“They that Live by the Sword . . . ”

We have thus far discussed iron from the standpoint of the ancient people who considered it a “heavenly metal” or as a metal having power over the mischievous fairies, trolls and evil spirits of their folk lore. While it is true that it had been intentionally smelted as early as 1500 B.C., the product was at best only a semi-smelted mass of slag and iron produced by the direct process, explained in Part 2 of this series of articles.

Iron came to the Babylonians in the period between 1100 B.C. and about 880 B.C. Actually, iron weapons have been found dating from about 900 B.C. For other implements such as farming equipment and household utensils, iron was employed along with bronze. After about 800 B.C. iron replaced bronze as the metal used in the manufacture of utensils and armor and for other practical applications.

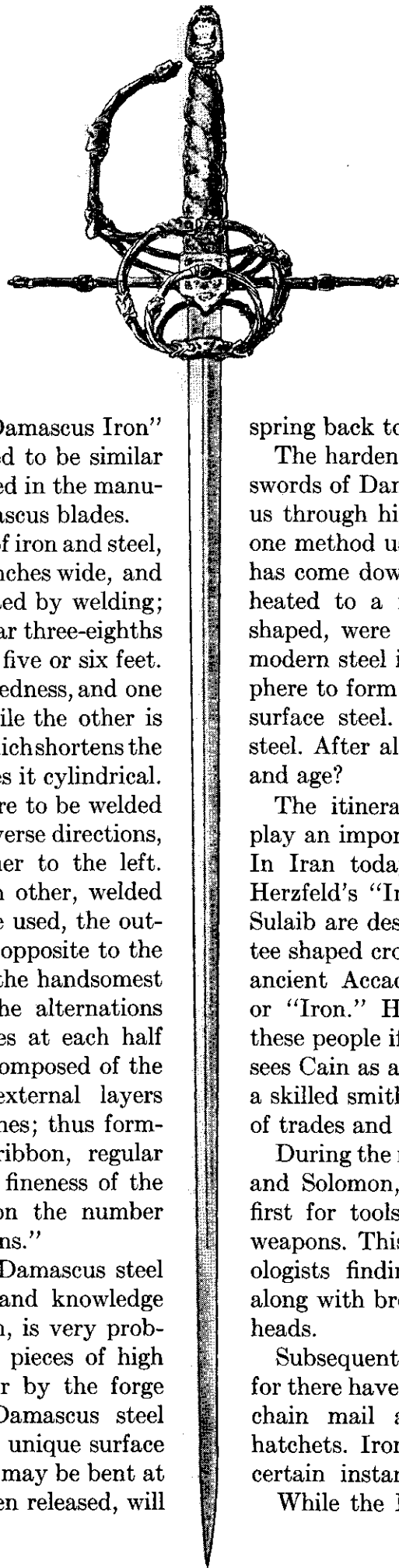
The metal iron was considered very mysterious by the Egyptians of 1350 B.C. and before. This is borne out by the findings of gold, copper and bronze artifacts in the tomb of King Tutankhamen. But most significantly, an iron dagger was found close to his body, apparently denoting that this was a prized and valuable possession. It is also known that because of the high regard the Egyptians had for their metal-smiths, they assigned a major god, Ptah, to be responsible for the metal workers.

We find that about 1300 B.C. the Philistines had domination over the Hebrews of Israel. In this time the Philistines had four iron furnaces and a factory for producing swords, chisels, daggers, and spearheads at Gerar. Arms manufacture was forbidden to the Hebrews by the Philistines, according to I Samuel in the Old Testament of the Bible.

Approximately 1300 B.C. in Damascus, Syria, swords and daggers of steel were being made that were famous for their strength and toughness. These famous weapons, used among nations that had little or no skill in metallurgical fields, long defied all attempts of imitation. These weapons were in use long before the Christian era and were made familiar to European nations about the time of the crusades when the knights who went on the crusades returned with these very fine swords. History tells us that carbonized iron, or wootz, from India was used in the manufacture of these swords. The iron was exported from the region of Golconda in Hindustan, (where it is still manufactured by the original “rude process”), and brought to Damascus where it was converted into weapons. The weapons were particularly distinguished for their keen edge, capable of severing heavy iron spears or cutting the most delicate gossamer fabric floating in the air. The steel blades had a peculiar watered appearance which was covered with delicate black, white and silvery veins parallel to each other or actually interlaced. The “Damascus” appearance may be given to iron by welding together bars of different degrees of hardness, drawing them down and then repeating the process several times. It has been suggested that by the use of bars of good steel, the best Oriental blades may have been fashioned in this way.

The “mosaic” process differed from the aforementioned by cutting the bar into short lengths and fagoting these pieces, the cut surfaces always being placed so as to face outward. Blades of great excellence were thus produced, but were still inferior to the genuine Damascus steel.

The following recitation of a procedure for



producing what is known as "Damascus Iron" or "Damascus Twist" is reputed to be similar to the process anciently followed in the manufacture of the celebrated Damascus blades.

"Twenty-five alternate bars of iron and steel, each about two feet long, two inches wide, and one quarter inch thick are united by welding; the fagot being drawn into a bar three-eighths inch square is cut into lengths of five or six feet. One of these pieces is heated to redness, and one end is held firmly in a vise, while the other is twisted by a wrench or tongs, which shortens the rod to half its length and makes it cylindrical. If two of these twisted pieces are to be welded together, they are turned in diverse directions, one to the right and the other to the left. These are laid parallel to each other, welded and flattened. If three rods are used, the outside rods turn in the direction opposite to the middle one and this produces the handsomest figure. By these operations the alternations of iron and steel change places at each half revolution of the square rod, composed of the twenty-five laminants, the external layers winding around the interior ones; thus forming, when flattened into a ribbon, regular eccentric ovals or circles. The fineness of the Damascus blade depends upon the number and thickness of the alternations."

A truly fine and authentic Damascus steel blade, from the descriptions and knowledge that we have in our possession, is very probably constructed of very thin pieces of high grade steel laminated together by the forge welding process. The true Damascus steel sword can easily be told by its unique surface designs and by the fact that it may be bent at a ninety degree angle and, when released, will

spring back to its true straight shape.

The hardening methods used for these steel swords of Damascus were not carried down to us through history from antiquity. However, one method used for hardening this steel that has come down to us is this: the blades were heated to a red heat and, after they were shaped, were placed in camel dung much as modern steel is heated in an ammonia atmosphere to form a thin layer of nitrogen-bearing surface steel. Today we call it nitriding of steel. After all, who keeps camels in this day and age?

The itinerant or wandering tinker-smiths play an important role through Bible history. In Iran today they are named Sulaib (see Herzfeld's "Iran in the Ancient East"). The Sulaib are despised nomadic people who wear tee shaped crosses on their foreheads which in ancient Accadian cuneiform denoted "God" or "Iron." Herzfeld asks in his account of these people if this is the "Mark of Cain." He sees Cain as a metallurgist and Tubal-Cain as a skilled smith and their offspring as founders of trades and crafts.

During the reign of the Hebrew kings, David and Solomon, iron seems to have been used first for tools of husbandry prior to use as weapons. This intelligence is based on archeologists findings of iron hooks and sickles along with bronze knives, daggers and arrow-heads.

Subsequently, iron became more prevalent for there have been found doors with iron bars, chain mail armor, chains, axe-heads, and hatchets. Iron nails have also been found in certain instances from this period of time.

While the Israelites had knowledge of iron

furnaces for smelting the ore, they did not cast iron. In their time, about 1000 to 850 B.C., the skilled craftsman always used bronze, not iron. Investigation has shown that the Israelites did not know how to harden iron or make it into steel.

Of the other metals that were known at that time, lead, tin and antimony were known and used in antiquity, although little mention is made of them in historical writings.

Tin was seldom used alone. It was usually used as an alloying agent for the making of bronze.

Lead was used as a plumb or "plummet" in carpentry and masonry building. Lead lines were also used for making soundings by sailors when they were in shallow water. Job 19:23 tells of using leaden tablets for writing purposes.

Antimony was used in preparing a black powder that was used by the women in paint-

skill of tempering bronze to a steel-like edge. This last bit of information is not generally known because when people have thought of tempering copper or bronze, they thought of the ancient Incan or Mayan Indians and their ability to temper copper which has also been lost in antiquity. Iron, however, certainly had its value as one may read in Homer's "Illiad" chapter 23 where a mass of iron is given as a prize at some games, of which the Greeks were very fond.

700 B.C. is generally credited with being the beginning of the first phase of the Iron Age in Europe. Iron was becoming quite common at this time and was being used for husbandry implements, household utensils and, of course, arms and armor for warriors. The art of metal working has burgeoned from very simple beginnings to the extremely complex manufacturing methods known today. We have indicated in our history that forging and the joining of materials by forge welding had been accomplished by about 1300 B.C. We also know that casting of materials or metals is probably one of the more primitive forms of metal work.

The art of casting metals has actually passed through three stages. Number one was solid casting. Most of these are solid metal castings, very heavy and were made in rather ancient times.

The second phase of the casting business came with the advent of iron. At this stage iron was relatively inexpensive and actually not too workable. However, it was used as a core for bronze castings to conserve the more valuable metal bronze. The British Museum possesses an interesting Etruscan or Archaic Italian example of this primitive process. It is a small bronze statuette about two feet high of a standing female. The presence of the iron core has been made visible by the splitting of the figure because of the unequal contraction of the two metals. The forearms of the statuette, which are extended, have been cast separately and *soldered* or *brazed* to the elbows of the statuette.

The third stage in the development of casting was the employment of a core, which was usually of clay, around which the metal is cast as a skin with just enough thickness to meet the strength



Corinthian Helmet

ing their eyelids and eyebrows. This material is still used in the Near East at this writing.

Up to this time we have shown that the Assyrians, the Egyptians, and the Greeks used iron, whether it be cast or wrought, in a very limited manner, bronze being the favorite metal for almost all purposes. The reasons for this are varied, one being the difficulty in smelting iron as well as the now forgotten

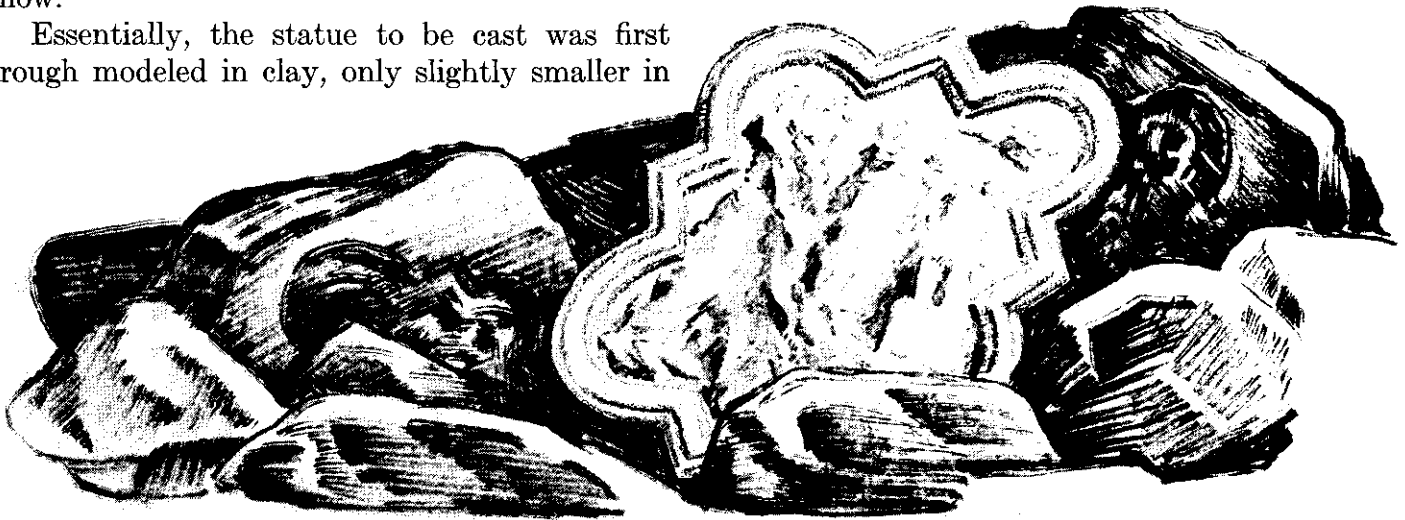
requirements without waste of metal.

The Greeks and Romans had exceptional skill in this last process. While their exact procedure is not known, it appears to closely follow the procedure outlined by the great Italian sculptor, Cellini, in his *Trattato della Scultura*. This very famous method has been called the "Lost wax" method which we will describe in greater detail now.

Essentially, the statue to be cast was first rough modeled in clay, only slightly smaller in

shell to the inner core while the clay was still moist.

At this juncture the bronze was cast into the mold until it was full. After allowing a slow cooling period, the outer shell was carefully broken away from the outside of the statue. The inner core was broken up and raked out as much



Florentine bronze panel and its 'lost wax' mold

size than the intended bronze article. Over all of this, the sculptor laid a skin of wax using modeling tools to obtain the final form and, most important, the *exact* finish he wished the completed work to have. A mixture of pounded brick, ashes and clay were ground very fine and mixed with water to the consistency of thick cream. Successive coats of this mixture were painted onto the wax, care being taken to fill each indentation and to etch every line.

The second skin was covered by soft clay of relatively thick cross section until the whole thing was a shapeless blob of clay. Iron hoops were bound around the clay to hold it together. The assembly was then carefully dried, placed in a hot oven and baked. The inner clay core and the outer clay shell were baked to a hard finish while the wax melted and ran out of holes made for that purpose in the bottom of the statue.

The hollow mold left by the melted wax was held in a proportional relationship by bronze "pins" that had been driven from the outer

as possible, usually through a foot opening in the statue.

Skilled sculptors had very little finishing work to do on their works of art. Such rubbing and polishing as was necessary to smooth out the work on the statue surface was of a "touch-up" nature. Less skillful sculptors sometimes lost the entire casting through faulty mold preparation.

Further enrichment of the art object was done by applying enamels and inlaid metals. The Assyrians, Greeks and Egyptian metalworkers practiced this form of art at a very early period. Later, the artists of Persia and Medieval Europe applied these processes to their own works of art.



Time Moves on Winged Feet

In the time of the Roman Empire, iron was in general use all over Europe, in the Near East and in the Far East. The Romans manufactured considerable iron but still imported steel from India where the iron workers of Hyderabad manufactured steel of a high quality, as we have seen, from a very early date. This material was known as "Seric Iron" to which Pliny alludes in his Natural History. The Roman Empire was at this time riding the crest of conquest and was the great center of metal manufacturing. With the fall of the Roman Empire to the Goths and the Barbarians there was, naturally, a great decline in the metalworking arts.

At this point, let us briefly recapitulate the facts we have learned. We know that the working of metals—copper, bronze, silver, gold, tin, lead, and iron—closely followed one another. As techniques in crafting one type of metal were perfected, those same techniques were tried on various other types of metals. Where they could be utilized in their entirety, this was done. Obviously, it would be more difficult to work the harder materials and, therefore, modified techniques were developed. We have shown that the knowledge of iron manufacturing was known at an early date (about 1500 B.C.) by the people in the area between the Black and Caspian Seas on the southern slope of the Caucasus Mountains and also by the people of India and Hindustan. We have also shown that the Damascus steel blades were welded together in laminated strips which gave them the supple strength for which they were so justly famous. We have discussed the fact that bronze was welded and/or soldered at an early date.

Much of the work that was done by the ancient

and venerable smiths and metallurgists has not, to this day, been duplicated. Most notable among their very considerable metallurgical feats was their ability to harden bronze to steel-like tempers. Another was their ability to laminate and manufacture the Damascus Steel blade which was not duplicated until 1823 and then only for a brief time (approximately thirty years) under the direction of one man. Yes, we can truly say that we owe these ancient peoples very much for the technology they pioneered and the procedures which they have one way or another passed down to us.

Lest we, in our modern air-conditioned offices and well-equipped plants, get too complacent with the feeling that the ancient metal smiths did "yes, beautiful work but only on small articles," the following story is told.

In the ancient city of Delhi, India, there is an iron pillar which shows unmistakable signs of having been welded. It is of a total length of approximately 62 feet of which 22 feet rises above the earth's surface and 40 feet is below ground level. It is approximately 16 inches in diameter and is apparently made from iron blooms of about 70 pounds weight apiece which are forge welded together. The joints are nearly perfectly forge welded although they must have been done by hand for the date of the manufacture of this article of iron, the Delhi Pillar, has been set by archeologists at about the time of Christ which would be about 4-40 A.D.

For the purposes of this series of articles it would be repetitious for us to discuss the advancements of the metalworking and welding arts during the period from the time of Christ to about the 16th Century. We may, however, indicate some of the significant advances which did occur. This information comes to us from a variety of sources.

Most of the history written during the latter part of the ancient and first part of the medieval period has religious or classical connotations. Unfortunately, the writers did not show the same zeal for documenting the advances in the metalworking arts as they did for chronicling the deeds of their patrons and their patrons' causes. Because of this, much of the metalworking information we have today has been deduced by experts from fragmentary writings and from relics and artifacts found by investigators and related to specific time periods.

A chronological time table from about the Year 1 A.D. to 1800 A.D. would reveal all of the following information and some which this

writer undoubtedly has overlooked in the interest of brevity.

It is apparent that the ancient Chinese had the ability to make steel from wrought iron and molten cast iron during the Sui Dynasty in China. This is evident by statuary and weapons found dating from that time. The Sui Dynasty was in power from the years 589 A.D. to 618 A.D.

On the European Continent, the art and science of working steel and iron progressed rather slowly. Evidences of iron foundries and work places have been found in Europe, notably in Belgium. Some of the foundries found in Belgium date from the time of the Roman occupation.

The Belgians have been famous armorers for many centuries. Because of their acquired knowledge, the skilled workmen of this country have often been enticed to emigrate, especially to England and Sweden and it is not unusual to trace the founders of some of the finest steel industries in those countries to the Belgians. The skilled workers thus enticed to emigrate were the Walloon Belgians rather than the Flemish Belgians. At one time the exodus of skilled workmen was so great that it was stopped by Belgium law.

In the Far East there had been close contact between Western Japan and the Korean Peninsula since the first century A.D. By the end of the 4th Century, feudal Japanese armies were taking part in the struggles between Korean kingdoms. These kingdoms were under strong Chinese influence and about 400 A.D. the Japanese began to use the Chinese script learned from Korean tutors. This was an important factor in the development of the Japanese culture since it enabled the Japanese to adopt many of the important features of Chinese culture such as iron manufacture. It is a fact that by the 8th Century the Japanese had the knowledge to manufacture steel by repeated welding and forging and also the ability to control carbon in steel by the use of fluxes. Their abilities to manufacture iron is testified to by the presence of iron armor dating from that time. The armor referred to was a corselet of iron plates riveted together. At this time, also, the warriors wore a conical shaped iron helmet.

In the matter of weapons, the Samurai warriors' most valued possession was his sword. The Katana, or long sword, was maintained with religious care in a wrapping of the finest silk cloth and secreted in the confines of lacquered and inlaid boxes. To be allowed a view of its sheath and blade was a mark of intimate friend-

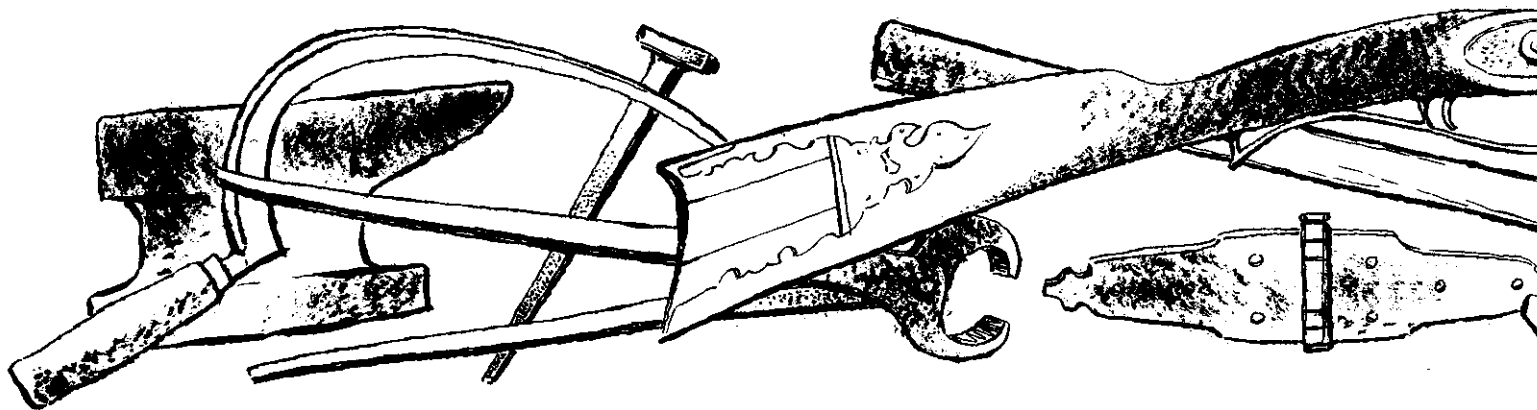
ship and high regard, especially for a foreigner. The Japanese blades were of excellent quality and superior workmanship.

The use of a type of blast furnace for melting iron and other materials first became prominent about the years 1000-1200 A.D. One particular type of furnace used at that time was called the Catalan furnace. The furnace derives its name from its birthplace in the north part of Spain in the Province of Catalonia.

The several descriptions that have been found in research data give the major details of the Catalan furnace as follows: "It consists of a four sided cavity or hearth, which is always placed within a building and separated from the main

ing. About the turn of the 16th Century saw the first cast iron cannon successfully produced. The ensuing two-hundred years saw coal tried as a fuel for blast operations for producing iron. The trials were not very successful. The middle of the 17th Century saw the use of chimneys come into being to develop greater furnace draft. This enabled the founders to maintain an even, constant furnace heat; also, coke as a fuel came into general use about this time.

Up to a point just past the 18th Century, Western European people continued to use the same motive power, the same materials that were known in Roman times. Few mechanical inventions had been made and water wheels,



wall by a thinner interior wall which in part constitutes one side of the furnace. The blast-pipe comes through the wall and enters the fire area through a pipe which slants downward. The bottom of the hearth is formed of a type of refractory stone which is replaceable. The furnace has no chimney. The air blast is produced by means of a fall of water, usually from 22 to 27 feet high, through a rectangular tube into a cistern below. The upper part of the blast-pipe is connected to the rectangular tube. This apparatus is exterior to the building and is said to afford a continuous blast of substantial regularity. The air passing into the furnace is quite heavily impregnated with moisture. Although by modern standards, the Catalan furnace may be considered somewhat crude, it is a fact that it was in use in the United States during Colonial times."

The 14th and 15th Centuries saw further improvements on blast type furnaces and also reverberatory furnaces for iron and bronze melt-

ing. animal power, and the muscles of men furnished the power with which men did their work and moved their goods.

About the middle of the 18th Century, however, a series of inventions were made in England which revolutionized the then known methods of industry and introduced what has come to be known as the Industrial Revolution. Just why the Industrial Revolution should have occurred at this particular time in history or in England, rather than on the European continent are questions that are academic. It is known, however, that considerable progress had been made in the physical and chemical sciences and it was probably as much a matter of necessity as anything else that caused this phenomena.

The basic tenets of the Industrial Revolution brought many changes in industrial manufacture. Where before, a man had a limited productive factor, by the use of machinery his productivity was raised many fold. With the development of new machinery and equipment,

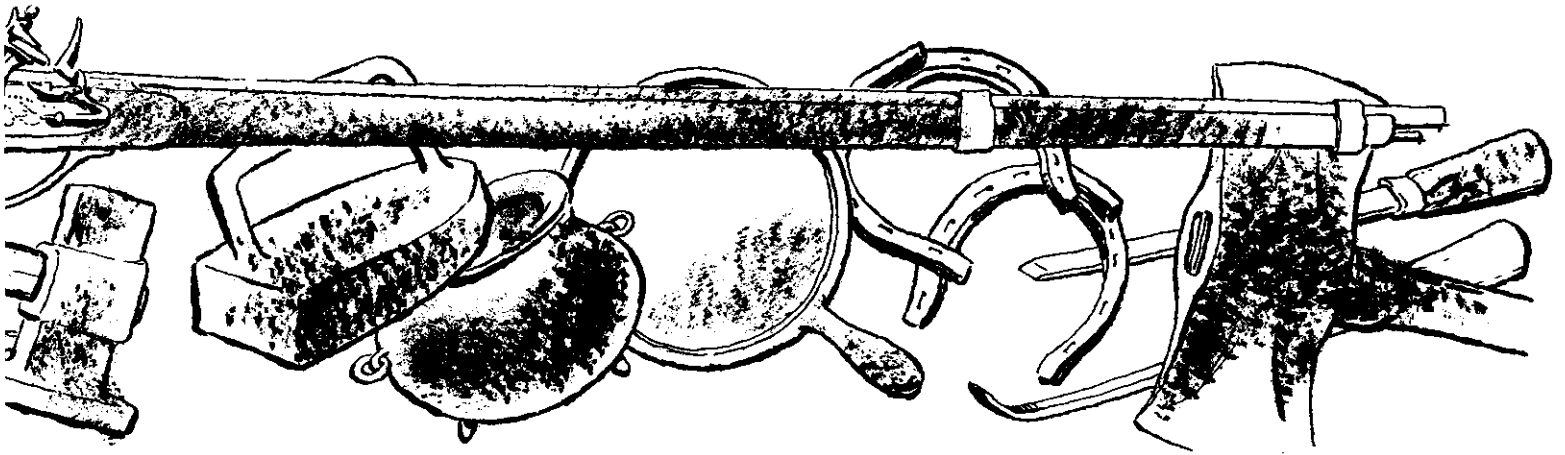
there also had to be a new development in the distribution of labor. Instead of having one master craftsman fashion each article from beginning to end, it became necessary to train semi-skilled people to do a portion, or a phase, of the manufacture of various parts. This type of labor division was called the "shop system" and was developed very greatly toward the end of the 18th Century. The key to the system was that the skill required for each separate operation in the manufacture of an item was less than that required to make the whole piece and the division of labor materially increased the workers' productivity per day.

One thing was lacking, however, in the manu-

likened to the rising of a warm sun after a cold and dreary night.

It took about a hundred years for the Industrial Revolution to really hit its stride. At the beginning of the 19th Century, Edmund Davy discovered acetylene and Humphrey Davy, through experiments with a battery, produced an arc between two carbon points. Davy was concerned primarily with the possibilities of the use of arc as a method of illumination and by 1809 he had shown that it was possible to maintain a high voltage arc for reasonable periods of time.

Experiments in electricity continued through the 19th Century with names like Ampere, Oersted, Wheatstone, Faraday, Ohm, Henry,



facturing sequences of that era and that was interchangeability of parts. Up to this time every complicated article had to be finish-worked by a master craftsman so that they fitted together in a unique piece. It was an American, Eli Whitney, who developed the idea of interchangeable parts. He did this in the manufacture of muskets. By the beginning of the 19th Century, precision working of iron had developed to the point where dies and molds could be made and exactly copied with close enough tolerances to satisfy the requirements for that time.

With the invention of new machinery and other work saving devices there was a rising need for some type of non-human power. This became a vital feature in the Industrial Revolution. It was in 1769 that James Watt invented the improvement for a steam engine originally invented in 1705 by Newcomen.

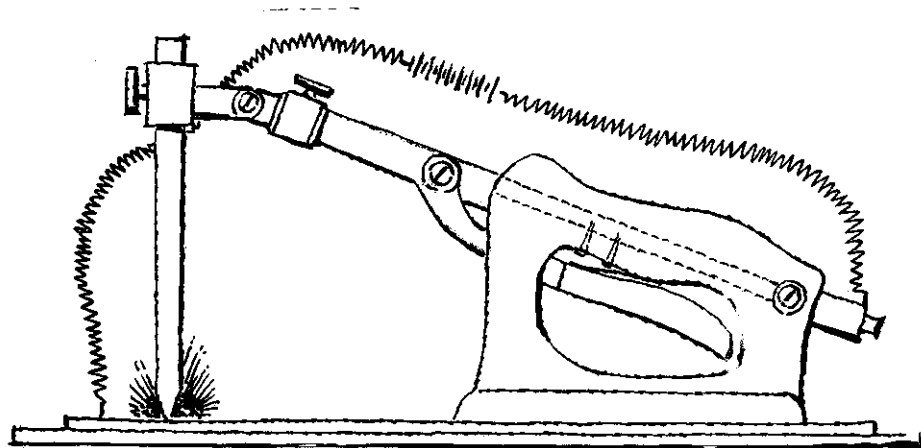
With a ready source of power and plentiful supplies of fuel, inventive genius blossomed in every type of industry. It may poetically be

Gauss, etc. known today wherever electrical theory is taught. However, it wasn't until about the mid 19th Century that workable electrical generating devices were invented and developed to the extent of being practical.

It is interesting to note that the first company in the United States to produce and sell electric power to the public was organized in 1879 in San Francisco, California, and was named the California Electric Light Company.

With the advent of commercial electrical generators capable of supplying high voltage-low current power to the consumers, the development of electric welding was quite rapid.

Electricity—the Sleeping Giant



*Original Benardos
Carbon Electrode
Apparatus—1885*

For 3,000 or more years, welding was done by hammering hot or cold metals to obtain a forge weld by molecular diffusion. The soldering and brazing used in ancient times was more of a casting of filler metal into joints than true soldering or brazing as we know it today.

With the Industrial Revolution in full swing, many new inventions were being made and, as might well be imagined, duplication of effort was fairly common. This may be attributed to many reasons, the most significant of which was lack of communications between people in different countries and even different communities within countries.

As we will see, the duplicated effort extended to the field of welding equipment and the welding processes. This indicates an increasing awareness of the possibilities of the “new” metal joining medium in several areas of the world simultaneously.

It will be good news for battery manufacturers

that the first documented instance of intentional fusion welding was done by Auguste de Meritens in 1881. M. de Meritens used a carbon electrode to weld lead battery plates together. While he was apparently unconcerned with the process of joining the material from the aspect of discovering a new method for uniting the lead, his pupils, N. Benardos and S. Olszewski, saw the immense possibilities engendered by the simple welding act. Their curiosities were excited by the possibility of using the electric arc as a heat source for joining materials with higher melting points.

Experiments were conducted by the two scientists for a period of approximately four years, utilizing the arc provided by electricity from batteries which were charged from high voltage dynamos.

Finally, in 1885, they were issued British patent 12984 for a welding process using carbon electrodes and an electric power source.

The Benardos-Olszewski patent discusses the

use of the equipment for the fusion welding of metals and, also, how it could be used to sever metals. In addition, the patent notes that the equipment may be used to "punch" holes in metals.

For electrodes, they considered either a solid or hollow carbon rod. The solid carbon was multi-purpose and could be used for cutting, gouging, piercing or welding. The hollow electrodes were filled with powdered metals. It was the intent of the inventors that this metal would melt and flow into the weld while it was being made. As close as this writer can ascertain, the use of hollow carbons never gained much acceptance in industry.

Because of the forementioned hollow carbon portion of their patent, Benardos and Olszewski have been credited with inventing metallic arc welding by some welding historians. The facts of the matter indicate this assumption is not true. This decision is based on the apparent use intent, and the physical characteristics, of the Benardos-Olszewski electrode. Common sense tells us that the carbon tube, filled with powdered metal, would have to have paper thin walls in order to function as a consumable filler metal electrode. In addition, the carbon build up in the weld metal would probably embrittle the weldment. Last, the fact that the electrode casing was non-metallic undoubtedly influenced the decision to disallow the credit to Benardos and Olszewski.

The use of carbon electrodes and an electrical power source for repair welding was the primary goal of the inventors. Welding power came from banks of large batteries which were charged by a dynamo. Although extremely cumbersome, the welding current was very stable direct current (d-c).

According to Russian claims, N. G. Slavianoff disclosed a method of electric welding ferrous metals with a bare metal electrode in 1888. The first mention of his discovery in the western press was the publishing of an abstract of a paper written by Slavianoff in the Journal of the English Iron and Steel Institute of 1892. Most weld-

ing historians thus accord Mr. Slavianoff the credit for discovering the use of bare metal electrodes for arc welding.

It is interesting to note that, while Benardos promoted his carbon arc process for actual structural welding of ferrous metals, Slavianoff states in his patent that "two pieces of metal may be united by casting metal into the space between them." The process was developed for filling holes and repairing cracks in castings and certainly is more of an arc casting process for localized defects than a welding fabrication process.



Welding with power from banks of batteries—1890

While the research and development of welding equipment and processes was progressing rather rapidly in Europe, some activity was occurring in the United States.

C. L. Coffin of Detroit, Michigan was one of the pioneers of the Welding Industry. In 1889, he received a patent on the equipment and process for flash-butt welding. In 1890, he received additional patents for spot welding equipment. Thus, it was a man versed in the welding science of the day who patented a bare metal stick electrode arc welding process in 1892. Coffin apparently acted without knowledge of Slavianoff's work or process. How much faster would have been the progress of welding had communications been as they are today!

After the turn of the century, welding began to gain some use, mainly as a method of repair. Unfortunately, wire used for electrodes was not formulated to provide the properties required in strength weldments. Welding procedures had not been developed and, of course, welding with bare electrodes produced a very unstable arc. Not the least problem was a lack of development of power sources for welding.

Just how the idea developed that coating the electrodes would enhance the arc characteristic is not clear. One story has it that welding operators found they could get a more stable arc when welding with rusty electrodes. This could be true because the oxide would act as a fluxing agent.

The question was pretty well settled about 1907 when a Swedish inventor, Kjellberg, patented the electrode coating process. His original patent was followed in 1912 by another patent which specifically described the coating materials and the alloying materials that could be put in the flux coatings.

As with any new process, welding had to overcome many prejudices. In retrospect, we can see that the prejudice was primarily caused by lack of knowledge of the welding process. Unfortunately, some of this "head in the sand" prejudice against welded fabrication design is still in evi-

dence today in some of the archaic manufacturing and construction codes imposed in some areas of industry.

About 1906, the LaGrange-Hoho method of welding was developed. This is a form of welding where one end of the article to be welded is connected to a current producing machine and the other end is immersed in a water bath. When current flows through the part, a partially ionized gas is formed in the water surrounding the immersed part. The function of the gas is to protect the part from oxidation while encouraging heating in the part due to the ionized condition of the gas. Thus, the resistance of the part to electrical current flow combined with the ionization of the gas created a situation where energy was imparted to the weldment in the form of heat. When the part reached a welding heat, it was withdrawn from the bath and welded similar to a forge weld. The difference is in the method of bringing the ferrous metal to the welding temperature. This particular method of welding never reached any commercial magnitude because of its rather involved equipment requirements.

About 1908, Benardos patented a process that didn't arouse much interest but which has since



*German ships repaired at
Scapa Flow—1919*

been exploited quite a good deal, especially in the past four or five years.

Benardos' patent covered the electro-slag process. The basic idea was to weld thick plates in one pass. The weld was set up vertically with graphite molds at each side of the joint to be welded. The slag, or flux cover, was built up to a depth of about two inches. As the slag was added, the welding voltage rose to the desired level of 50-55 volts. A consumable wire electrode was used.

were developed along with the process and equipment for extruding the coatings on the electrode surface. In addition, the chemistry of the core wire was being developed so that the deposited weld metal would have approximately the same constituents as the base material.

The design of welding machines still showed a tendency toward being built like smaller editions of large dynamos. Some work was done with transformer type welder design, but the units manufactured were bulky and difficult to weld



Welding technology progressed rather slowly until World War I. At that time, the war effort demanded accelerated fabrication methods and welding began to be used as a construction tool rather than for just maintenance and repair. The spotlight of world attention shone brightly on arc welding when the dynamited cylinders of the German ships interred at Scapa Flow were successfully repaired by arc welding. The ships were put into service as troop carriers for the Allies.

After 1919, the acceptance of welding as a fabricating method was rapid and widespread. Generally speaking, progress was held up by slow advances in electrode manufacturing techniques, especially coatings. Welding machine design was in its infancy, too.

Research and development for electrodes continued through the 1920's. New electrode coatings

with. Welding equipment manufacturers and industry representatives were used to using the dc power as drawn from the battery banks previously mentioned. It was this experience that dictated the type of current that would be used in welding. Again, it is evident that lack of knowledge of the welding arc and processes caused the advancement of the art and science of welding to be delayed considerably.

The manner in which dc current was provided at the welding machine secondary terminals evolved like this. First, a three phase electric motor was used to furnish mechanical power to rotate an armature in a welding generator. The electric motor furnished the mechanical power to turn the rotor or armature in the welding generator.

Contrary to popular belief, a welding generator

does *not* generate dc power. Every generator ever made makes Alternating Current. The ac is changed to dc through a commutator-brush arrangement where a series of carbon brushes picks up the welding current from the commutator surface. Starting back at the primary input to this type of welder, then, it is an electrical-mechanical-electrical transition of power from primary input to welding output.

Not everyone was satisfied that dc power was the only way to weld. Some experimentation was done with ac transformer type welding machines by several individuals and companies, but there was little effort expended in selling ac power to the welding industry.

This was the status of the welding industry when Niels Miller decided that (1) good welding could be done with ac power and (2) he could design and build a better, more rugged, heavy duty ac transformer type welding machine than was then available.

Mr. Miller built the first prototype ac welder of his design in early 1929. All the component parts of the machine were handmade by Mr. Miller and the machine was tested by him in his basement workshop. After testing the machine, Mr. Miller's next move was to find a market for it.

He decided that his first sales target would be the numerous blacksmith shops in the central Wisconsin area. It was a fortunate choice for both the manufacturer and the consumer. The blacksmiths were able to fabricate more and larger welded components at greater profit to themselves. Mr. Miller was able to purchase more raw materials with which to build additional welders. And so began MILLER Electric Manufacturing Company of Appleton, Wisconsin.

This story now takes on some of the personal character of MILLER Electric for, as welding grew in use and stature with industry, so did MILLER Electric. By the achievements of this company we can see how welding equipment developed in use and utility.

Mr. Miller soon found that he could not do the manufacturing of welding machines and be

on the road selling them at the same time. In mid 1929, Mr. Miller went into association with Mr. John H. Mulder, at this time employing three men to work on the production of MILLER welders. Mr. Mulder became the outside salesman calling on prospects and customers while Mr. Miller concentrated on developing production line techniques for the manufacture of the MILLER welding machines.

Through the early 1930's the sales of MILLER-built welding machines increased because of word of mouth advertising. Owners and users of MILLER welders were quick to tell others of their practical, economical, productive abilities. Soon there were MILLER welding machines in all parts of Wisconsin, Upper Michigan and Minnesota.

In the year 1936 MILLER Electric made an outstanding contribution to the welding industry with the introduction of a high frequency stabilized ac industrial welding machine. The very first unit of this manufacture went to the University of Wisconsin Engineering Department. The reason that this was such a forward advancement in ac welding machines was that the development of ac welding electrodes was only then in its early stages and so the welding operator was required to use dc electrodes with ac power. Because of the types of coatings used on dc electrodes, there was created a certain amount of arc instability. The reason that dc electrodes could be used with ac welding machines as built by MILLER Electric was that the open circuit voltage and the reactance in the machine itself provided stability in the arc. With the advent of high frequency superimposed on the ac welding current, the deeper penetration and faster weld metal deposition rates of ac welding current was fully utilized for the first time. Of course, it was recognized early that there was no magnetic arc blow with ac welding as there was with dc welding. The absence of magnetic arc blow in the ac welding arc made it an excellent tool for confined, close-quarter welding applications. This factor, coupled with its greater deposition rate, made it an exceedingly

valuable and much sought after tool during the mid and late 1930's.

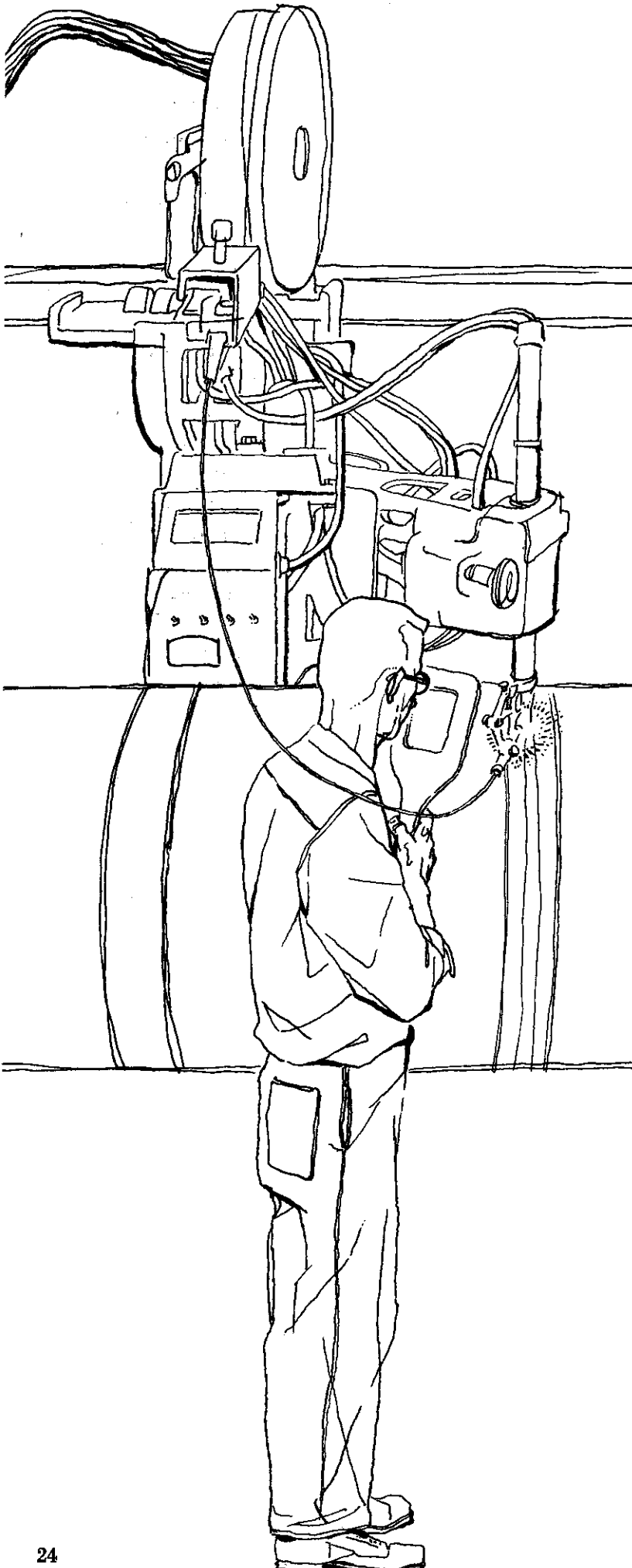
This was a period of time when many ships, structural steel buildings, pipe lines, bridges, and other structures were welded successfully with the electric arc. As the obvious advantages of welding became more and more apparent, metal fabricators began to use the various welding processes to greater degrees. It was during this period of time that the ac welding machine really began to be utilized in industrial plants. Coupled with the fact of no magnetic arc blow and its ability to beat dc welding machines in weld metal per hour deposited was the greater efficiency and higher power factor of the MILLER ac welding machine.

With the advent of World War II in 1939, there was a sudden and urgent need for better metal joining techniques. MILLER Electric participated in the war effort to a very great degree

by producing thousands of ac transformer type welders during the war years. Many of these welding machines are still in active operation today. This fact brings out one of the salient points of MILLER-built transformer type welders in that it is almost impossible to wear them out.

One of the factors that led to the increased use of ac industrial type welding machines was the development of welding electrodes for ac use. The ac electrodes had a specially formulated flux compound extruded onto the wire. The latent development of ac electrodes, coupled with the ruggedly built MILLER ac industrial type welder, and the acceptance of ac welding by the metal fabricating industry, proved Niels Miller right when he stubbornly went ahead with ac welding machine development even though the then-leading manufacturer of welding equipment told him that "ac power will never sell to the welding industry."

Enter:



Welding in an inert gas atmosphere was first considered in the late 1920's. In 1930, a patent was issued to Hobart and Devers covering the use of an electric arc within an inert gas atmosphere. The process was not developed during the 1930's for several reasons. Argon and helium gas was very expensive, for one thing. Torch equipment was not developed because the process was apparently not recognized as a major contribution to the welding industry.

It was about 1939 that Mr. Russell Merideth was assigned the problem of developing a process for welding magnesium aircraft frames. Up to, and including this time, all aircraft welding was done with oxygen-fuel torches. Mr. Merideth had the job of coming up with something entirely new that was faster, easier and that would provide better metallurgical characteristics in the weldment. Quite an order and Mr. Merideth's employer, Northrop Aircraft, expected an answer!!

Various companies had experimented with the use of argon and helium as shielding gases but cost considerations were against the adoption of the process. With World War II coming on fast, the problem of welding light gauge aluminum and magnesium became acute, especially in the aircraft industry. As the result of the pressures building up, research on new welding processes and techniques was intensified.

A Major Technical Development

In 1941, Mr. Merideth devised a method for hand-feeding magnesium wire through a capped nozzle in which an inert gas was introduced through copper tubing. This was not satisfactory because of the high burnoff rate of the magnesium. Additional research indicated that a refractory, non-consumable electrode would be better suited to the process.

The first tungsten inert gas torch was simply a standard electrode holder of the type used for metallic arc welding. A $\frac{1}{8}$ " tungsten was inserted in the jaws of the holder. This passed through an improvised copper tubing nozzle that had helium induced through an attached copper tube.

A patent was applied for in October, 1941, by Mr. Merideth and was issued to him in February, 1942.

In the meantime, further development work had been done on the torch itself and a workable unit was designed. It was air cooled and had a 75 ampere capacity.

It is interesting to note that the development work was done with dc reverse polarity. This follows the pattern of thought then in use, namely, that dc reverse polarity was *THE* type of current to use. Remember, this was in 1942, just a few years ago in comparison with welding's long history.

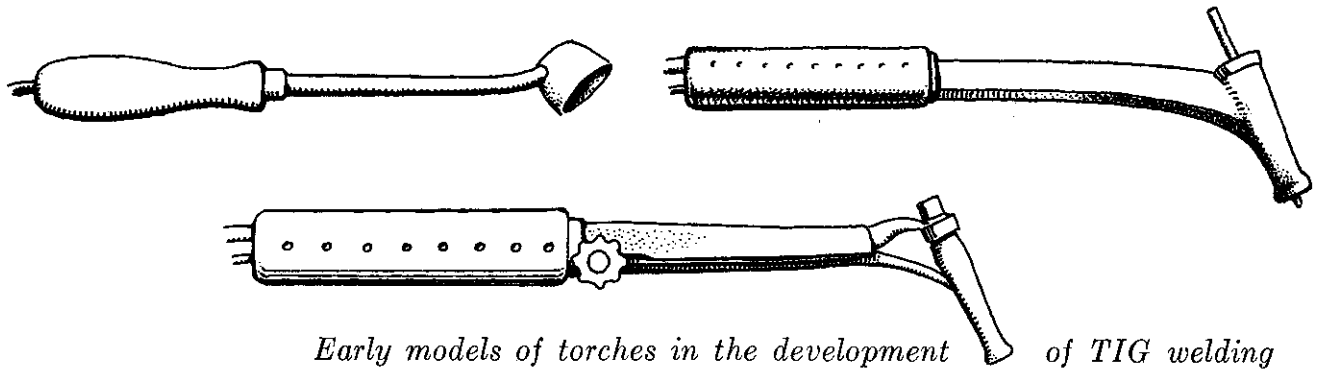
Since that time, as we shall see, the use of dc

reverse polarity has disappeared almost entirely from tungsten inert gas (TIG) welding applications. The reason is the type of electrode used with this process. Let us explore this thought a bit further.

Stick electrode metallic arc welding depends on massive heat at the electrode tip to superheat the filler metal. This superheated metal is transferred across the arc to the relatively cold base metal where the heat dissipates into the base metal bringing it up to a temperature where fusion can occur. Dc reverse polarity is good for this type of welding because approximately 65% of the welding heat energy is in the electrode. Thus, our hypothesis works very well.

Now, however, let us look at the tungsten electrode for TIG welding. Contrary to metallic arc welding, we do not want to melt the electrode. Indeed, the inclusion of tungsten particles in the weld is usually very harmful. Yet, with dc reverse polarity, we find that a very large tungsten is required for relatively low amperages. For example, it requires a $\frac{1}{4}$ " diameter tungsten to operate at 125 amperes dc reverse polarity and that is the maximum amperage one can use with this setup. This is because the electron flow is from the negative-charged base metal to the positive-charged electrode with dc reverse polarity.

So we have the phenomena of one type of cur-



Early models of torches in the development of TIG welding

rent being excellent for one process and rather undesirable for another process.

Later in 1942 the Linde Company was granted a license to develop the tungsten inert gas process. Their research and development group produced a water-cooled torch capable of handling 250 amperes. Later developments increased the current carrying capacity to 500 amperes.

The first tungsten inert gas welding was done with dc welding machines of the rotating type. This fact helped to keep the process from rapid development because of the slow response of rotating type machines to changing arc conditions.

As most TIG welding was initially done on aluminum and magnesium alloys, it wasn't long before industry tried the MILLER high-frequency stabilized ac arc welder with the process. The results were far superior to the existing dc power sources for these non-ferrous metals and alloys.

As a result of this experimentation, several large manufacturers of welding process equipment approached MILLER Electric Mfg. Company and requested a welder built especially for use with the tungsten inert gas process. The request was reasonable because the existing machines did not have the duty cycle required for the TIG process.

The first MILLER welders built especially for the TIG process were ac units with built-in high frequency. Some explanation is due the reader here because, as we know, MILLER had been building a high frequency stabilized ac welder for over 10 years. What, then, was "new" about this ac high frequency welder?

First, it is important that the reader understand that a *standard transformer ac welder with high frequency* produces a relatively high dc component *when used with tungsten inert gas*. With metallic arc stick electrode welding, the dc component is not a factor, since no rectifi-

cation takes place at the arc.

With TIG and ac, which was used primarily on aluminum and magnesium, the rectification was caused by the inability of the current to flow through the surface refractory oxide layer, thereby causing partial rectification. This factor, in turn, caused the standard ac transformer core to have more saturation with the consequent problem of the core accumulating more heat than could be dissipated properly. The net result was high primary amperage draw and possible damage to the welder.

MILLER Electric recognized the problem almost immediately with the advent of the TIG process. With the pioneering foresight which has made MILLER the standard of comparison for the welding industry, the MILLER Engineering Staff set to work to whip the problem and produce a welder for the TIG process.

Basically, this is what was done. The high frequency circuit was completely re-designed to meet the stringent requirements of the TIG process. The internal circuitry of the proposed welder was modified to provide reduction of dc component to a nominal amount. The arc characteristics of the welder was smoothed out and made more stable. One result of these modifications was to reduce the transformer load enabling the unit to perform at 100% duty cycle at rated load.

Because of the 100% duty cycle rating of the MILLER welder, automatic TIG welding was given great impetus. Entirely new welding tooling concepts were developed along with specialized automatic torches and controls.

Like a giant snowball, TIG applications produced new equipment which, in turn, triggered new applications. Although the welding equipment manufacturers and welding industry have made tremendous strides forward, we have only scratched the surface of possibilities of tungsten inert gas welding.

The MILLER TIG welders were made of heavier components than the standard machine in keeping with Mr. Niels Miller's pledge to "always give a 20% plus factor in welder quality and current characteristics."

It soon became evident that the TIG process had more uses than just welding aluminum and magnesium. Stainless steel, copper, low alloy steel, nickel, titanium, molybdenum, zirconium, uranium and many other metals applications demanded better TIG process equipment and more sophisticated welding machines. The dc welders of 1950 were not much different than those of 1935, relying on a "missing link" high frequency unit to make them usable with the TIG process. Unfortunately, if the high frequency unit was not properly shielded on the rotating motor generator equipment, the high frequency high voltage would feed back through the commutator, the armature and arc across to the field windings. Obviously, this caused the motor generator units to short circuit and burn out windings of one type or another.



Such was the situation when MILLER Electric Mfg. Company of Appleton, Wisconsin, entered the dc power source field with especially designed rectifier type dc welding machines. It was in 1950 the first MILLER SR, dc rectifier welder, was produced.

From the very first, the MILLER dc welders had electric amperage control. In addition, the machine response to arc changes was very fast due to a current and voltage feedback circuit. Probably most important to the welding operator was the fact that dc welding current was produced easily and quietly for the first time.

There was no screaming electric motor and rotating armature to cause men to lose their tempers and patience with their jobs, their friends and their families. Indeed, the only moving part was a cooling fan which drew air over the transformer coils and rectifier.

The outstanding success of the rectifier type dc welder created another question. Could a welding machine be built that had ac and dc output? Obviously, it could but what of the arc characteristics? The MILLER Engineering Staff set out to find the answers.

In 1955, the first ac/dc welder came off the production lines. Two models were available, one having built-in high frequency for TIG welding. Many of these units are in shops all over the world, putting out steady, dependable welding current.

Since 1955 several different model power sources have been developed for the TIG process. MILLER's most sophisticated models, which provide for program controlled dc TIG welding, are described as the Analog 300 Series offering direct linear current calibration and built-in line voltage compensation. Its fast response time makes it particularly suited for pulsed TIG applications. This can encompass a range of more difficult to weld metals described as "exotic" by the industry.

The demand for this type of welding originated with the aircraft industry. Soon aluminum and other fabricators gained enough confidence to follow suit. Process design has since attained momentum.

MILLER offers ac power sources for the non-ferrous applications and dc for the ferrous.

At this writing, there are those who say that TIG welding has reached its maximum use in industry. This same type of individual forecast the demise of metallic arc welding when tungsten inert gas first became prominent. Not only is stick electrode popular but the gas metal-arc welding (MIG) process using wire control/feeders are solidly entrenched in many industries.

Welding, as a joining medium, is starting to come of age. A look at the Master Chart of Welding Processes will show several processes that have been added in the past few years. This writer fully expects to see more processes added to the chart in the future.

Not the End

METAL INERT GAS! MIG! PLASMA!
CONSTANT POTENTIAL! ELECTRON
BEAM!

The headlines depicted above may sound like a new language or formula far removed from today's work-a-day world—but they aren't.

Since World War II, the welding industry has demanded better welding machines, new processes for welding exotic metals, welding technology for joining materials considered unweldable and equipment for spraying, cutting and joining metallics and non-metallics alike! Manufacturers have been hard pressed to keep up with the demand for new equipment and, indeed, many new manufacturing companies have come into being based on new inventions, or concepts, of welding equipment.

This last chapter of "Welding and The World of Metals" will discuss some of these new welding techniques and processes. Our intent is to give you a hint of the tremendous advances and possibilities of the new welding processes and machines.

After the inception of Gas Tungsten-Arc (TIG) welding in 1942, the welding industry relaxed somewhat. After all, TIG could do anything! Aluminum, magnesium, stainless steel—all were easily and competently welded by the TIG process.

After the war, the use of aluminum and magnesium increased substantially. Both metals exhibited strength to weight ratios very competitive to steel. Thus, a manufacturer could afford to use $\frac{3}{8}$ " thick aluminum rather than $\frac{1}{4}$ " thick steel. There was not the corrosion problem with aluminum that was prevalent with steel.

Welding was the way to join aluminum but with thicknesses above $\frac{1}{4}$ ", TIG welding required a pre-heat. This was not a feasible operation, especially on large weldments such as PT boat hulls. The heat transfer rate of aluminum

and magnesium is such that the entire mass would act as a gigantic heat-sink. There was no method of welding known that would supply sufficient controllable heat in a small enough area to weld thick aluminum and magnesium.

Naturally, much research was being done by the manufacturers of welding process equipment to supply an answer. In 1948, a patent was issued for consumable electrode welding equipment and the Gas Metal-Arc (MIG) welding process was born.

The MIG process provided an entirely new concept in welding. The basic MIG equipment consists of a reel of level-wound electrode wire; a wire drive mechanism (usually an idler roll and a powered drive roll with an electric variable-speed motor) and a control panel to regulate the drive motor speed as well as control all the electrical functions of the apparatus. In addition, some type of gun or torch is required and, of course, a power source. The process was designed for use with the conventional dc welding machines available in 1948. These machines had what is known as a drooping volt-ampere curve characteristic. We will discuss this in more detail a little later in the article.

The new facet of MIG welding is the current density at the tip of the electrode wire. Do not confuse *current density* and *arc density*. We will briefly explain the difference in the two.

Current density is measured at the electrode tip. It is the product of amperes times the cross sectional area of the wire in square inches.

Let us consider the fact that 0.030" diameter wire has 0.00071 square inches of area. If you were welding at 100 amperes, then you would have to factor the area to 1.000 square inches and use the same factor for your amperage. As you can see, the amperage per square inch reaches astronomical figures (approximately 140,000 amperes per square inch).

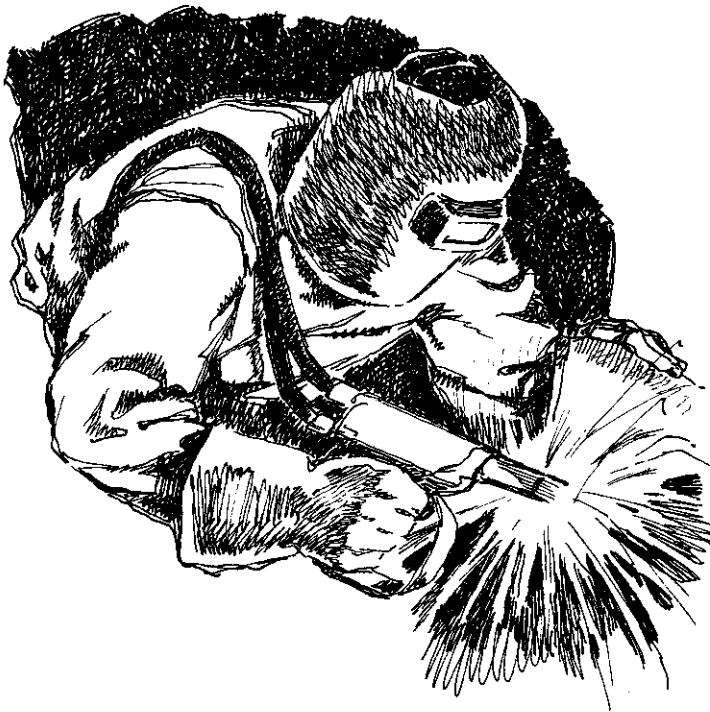
Arc density may be defined as the amperage times the cross sectional area of the arc stream in square inches.

While it is true that the arc is very sharply defined in MIG welding, it is still larger in diameter than the welding wire. We can, therefore, conclude that *arc density is always lower in value than current density.*

The unanswered question is, of course, how does current density help cut welding costs and improve weld deposits? Let's probe this idea a bit and see what we can conclude.

A high density arc has high density concentrated on one focal point. You may compare it to the pinpoint of concentrated sunlight focused through a magnifying glass. A stick electrode, conversely, has relatively low arc density with a rather soft and wide spread arc plasma.

Thus, we would expect an intense arc stream from the MIG process with deep penetration, narrow bead width, restricted heat-affected zone and faster welding speeds. Referring to the stick electrode process, we would have relatively shallow penetration, a wider bead formation, wider heat-affected zones and slower welding speeds. With the latter process, we could antici-



pate a more parabolic shape to the weld cross section and, possibly, excessive grain growth in the parent material heat-affected zone.

If we carry our hypothesis further, we can conclude that stick electrode welding will have more heat applied per linear inch of weld than the MIG process. This is because the stick electrode has low current and arc densities. Logically, we may also conclude that the MIG process will produce less warpage and distortion of

the weldment than will stick electrode because of the deeper penetration with generally faster welding speeds.

When considering welding costs, the welding industry has found that weld clean-up time is a high cost item. With MIG welding, there is little or no post-weld cleaning required. As an example, a manufacturer required two men to spend full time on weld clean-up of machine bases joined with stick electrode. When this operation was changed to use the MIG process, clean-up time was reduced to approximately two-man hours per week!

Constant potential and constant voltage, as applied to welding machines, are rather misleading since both terms are technically incorrect. Their acceptance and use by the welding industry stems from a need for some type of unique description for such welding machines.

We would clarify one point concerning the terms "constant potential" and "constant voltage." As used in the description of welding machines, they are synonymous.

One may well wonder why the trend has been to use constant potential type welding machines with the MIG process. The answer is actually a matter of welding, and operator training-time, costs.

The MIG process was developed for the constant current type, or drooping volt-ampere characteristic, welding machine. This put four variables into the process that the operator had to control. These variables are wire feed speed, travel speed, amperage and arc voltage. As you can see, the operator *had* to be a very highly skilled, steady-nerved man.

The open circuit voltage of the constant current type welder is approximately 80 volts. This provides the force to strike, and re-strike, a stick electrode arc. With MIG welding, however, this much force is not required because of the high current density at the wire tip. In addition, the constant current welder has a fixed slope, or directional shape, to its volt-ampere curve.

Now let us consider the constant potential type welders and how the welding machines have been built to fulfill specific MIG process requirements.

The concept of MIG welding indicates that a load voltage range of 10-42 volts is all that is required. Because of the high current density inherent in the process, relatively low open circuit voltages may be used. Very seldom will a constant potential welder have more than 50 volts open circuit. This fact, plus the variable voltage and variable slope as used in MILLER-built constant potential welders, provides a much broader range of welding conditions than standard constant current welders.

With a constant potential welder, the four variables previously mentioned become automatically controlled, with one exception. *Arc voltage* is pre-set in the welding machine and is the key effect in maintaining amperage at a proper level to burn off the wire as it is fed. *Amperage* is controlled by the inches per minute of wire feed. *Wire feed speed* is usually set with a variable speed electric motor arrangement. Only *travel speed* is left to the operator's discretion and judgment. We can see, therefore, that an operator may be trained to use the MIG process in a relatively short time.

Cutting welding costs is possible in many ways when using the MIG consumable electrode process. We have mentioned that operator training time is much less than for other types of welding. It is not unusual for new operators to become very proficient with MIG equipment in 40 hours or less.

Pre-weld joint preparations is usually much less with MIG than with other processes. This is because the arc has such a penetrating deposition pattern that extensive joint design and preparation is not required. In any case, the amount of weld deposit per linear inch is usually less than with other welding processes. This effects savings in application time, shielding gas and welding wire costs.

It is well known that welding machines must be manufactured with characteristics that complement one or more welding processes. MILLER Electric has met the requirements of the MIG process, as they have become more complex, through the manufacture of a full line of constant potential type welders. We would stress that the various models of MILLER welders have been developed to fill a need, such development being requested by process equipment manufacturers.

To this end, MILLER Electric now has in the constant potential type welder line both three phase and single phase welders. Thus, even though a shop or plant may have only single phase electrical service, they can still take advantage of the technical advances in MIG welding.

Some of the newer models of MILLER constant potential welders have variable voltage and variable slope. This means that the welding operator can adjust the voltage while welding to obtain the best welding condition possible.

Slope was first controlled in MILLER constant potential type welders with a three position switch. This allowed the operator to choose minimum, medium or maximum slope to suit the welding condition he needed. This proved highly successful because by changing the slope range, the operator could limit short circuit cur-

rent. With minimum slope, short circuit current could go to several thousand amperes because the volt-ampere curve is almost flat. With medium slope, the volt-ampere curve reaches a predictable short circuit current of considerably less value than at minimum slope. Maximum slope provides even greater angle to the volt-ampere curves with resulting lower short circuit current values.

The next demand by the welding industry was for a constant potential type welder with greater slope variation. MILLER Electric brought out models with a 14 terminal slope control board. The welders have five voltage ranges with 14 slope positions available in each range.

The next obvious request, once the 14 terminal slope board was developed and in use, was for a variable slope control operable from the face plate of the welder. Once again, MILLER Electric Engineers answered the requirement with the models which allowed continuous voltage and slope variation *while welding*. Thus, an operator can go from full spray metal transfer for heavy metals to the short circuiting type of transfer, used with light gauge metals, with no trouble at all.

Engine driven welding machines are now a big factor in bringing gas metal-arc welding to the field construction business. MILLER Electric provides the rugged Trailblazer V for use with either the MIG processes or for stick electrode work. Rated at 300 amps, 100% duty cycle for stick and 400 amps, 35 load volts, 100% duty cycle for MIG, the Trailblazer V is available with either a liquid cooled gas engine or a rugged diesel engine. In addition, MILLER Electric builds other models of engine driven welders which may be used with MILLERMATIC process equipment.

MILLER Electric was among the first to enter the process equipment field with a full line of semi-automatic MILLERMATIC MIG equipment. The MILLERMATIC line includes both push and pull type guns, water cooled and air cooled guns and torches, complete packages of equipment for short circuit transfer and heavy duty equipment for fluxcore wire welding.

The range of wire sizes usable with MILLERMATIC process equipment show a minimum size of 0.030" diameter to 1/8" diameter. Thus MILLER Electric provides the finest constant potential welding machines and an excellent line of wire drive equipment (MILLERMATIC) in one source of supply for the consumer. The "Built by MILLER" label assures the consumer of high quality and excellent welding operating characteristics.

In our discussion of new processes, we cannot overlook the vital development of plasma spraying and cutting of metals and non-metallics.

Several companies have worked on the development of this important process.

MILLER Electric has engineered high output power sources to provide the necessary voltage and amperage to develop the arc temperatures required by the process. Arc temperatures of 60,000°F to 90,000°F are presently being used to cut thick stainless steel plate as easily as slicing butter.

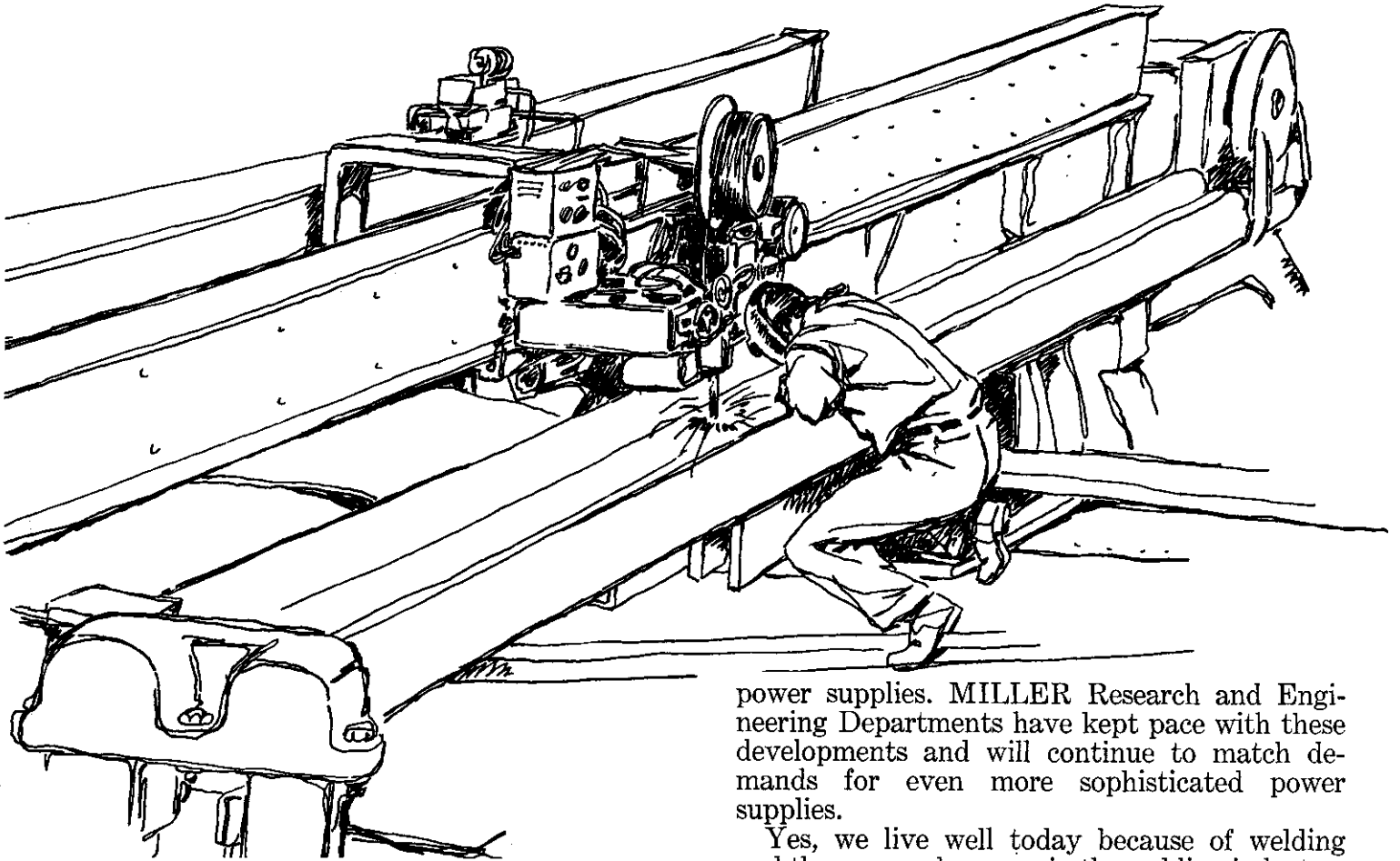
Another process, developed during World War II, was the air-carbon-arc-cutting process for gouging and cutting metals. High voltage transients are common when using this process, especially with $\frac{5}{8}$ " , $\frac{3}{4}$ " and $\frac{7}{8}$ " diameter carbon electrodes. The peak voltage transients have caused many rectifier welder manufacturers to

definition for welding. Welding today is more than bringing metal to a "heat" and letting intergranular diffusion, percussive blows or molecular attraction cause a weld.

To weld means to join two separate entities of some material into a cohesive unit. Normally, we think of metals being welded, but it is entirely feasible to weld glass, ceramics or even gases into a cohesive unit.

We know that welding methods that were new in 1940 are obsolete today. Metals that were in the "exotic" class in 1942 are commonly welded today.

Today much of our success in space exploration is directly traceable to modern welding techniques and advanced concepts of welding



forbid the use of the air-carbon-arc-cutting process with their machines due to an excessive rectifier failure rate. MILLER Electric has recommended using the MILLER Gold Star Selenium Rectifier for air-carbon-arc-cutting and has furnished hundreds of welders for this purpose. In recent years, a series of heavy duty models have been installed in foundries all over the world for combination use with the air-carbon-arc-cutting process and stick electrode welding.

At the beginning of this series of articles, we questioned the validity of the presently known

power supplies. MILLER Research and Engineering Departments have kept pace with these developments and will continue to match demands for even more sophisticated power supplies.

Yes, we live well today because of welding and the men and women in the welding industry. But let us not forget the massive heritage that is ours, left to us by the ancient smiths, the sculptors, the alchemists, the gold and silver-smiths of antiquity, the physicists, metallurgists and engineers who have made welding and the world of metals what they are today.

We can rejoice in the knowledge that what we know, or think we know, is not the ultimate! There is more to come, for as we perfect one method and process, another comes along just a little better and with more application.

It is in this secure knowledge that we regretfully close this series of articles.

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