Table 7.3
Gas Tungsten Arc Process Variables — Independent Effects on Key Surfacing Characteristics

		Influence of change on		
Variable	**Change of Variable[a]**	**Dilution**	**Deposition**	**Deposit Thickness**
Current type	AC DC	Average Lower or higher	Average Lower or higher	Average Lower or higher
Polarity	DCEN DCEP	High Low	High Low	Thick Thin
Shielding gas	Argon Helium	Lowest Highest	Lowest Highest	Thinnest Highest
Amperage	High Low	High Low	High Low	Thick Thin
Technique	Stringer Weave	High Low	No effect No effect	Thick Thin
Bead spacing (pitch)	Narrow Wide	Low High	No effect No effect	Thick Thin
Electrode extension	Short Long	No effect No effect	No effect No effect	No effect No effect
Surfacing wire diameter	Small Large	High Low	Low High	Thin Thick
Voltage	High Low	Low High	No effect No effect	Thin Thick
Travel speed	Fast Slow	High Low	No effect No effect	Thin Thick
Position	Flat Uphill Downhill Horizontal Vertical-up[b] Vertical-up[c]	4 3 4 2-4 1 (Highest) 5 (Lowest)	No effect No effect No effect No effect No effect No effect	4 3 4 1 (Thickest) 5 (Thinnest) 2
Auxiliary wire(s)		Low	High	Thicker

a. This table assumes that only one variable at a time is changed. However, for acceptable surfacing conditions, a change in one variable may require a change in one or more other variables.

b. The arc directed on work (forehand welding).

c. The arc directed on surfacing buildup (backhand welding).

Gas Metal Arc Surfacing

IN GAS METAL arc surfacing, the arc and the weld pool are shielded from the atmosphere by a flow of gas from an external source.[9] Alloying elements used to produce the desired deposit analysis are contained in the electrode, which may be either solid or tubular. Shielding gases including argon, carbon dioxide, and helium may be used singly, in various mixtures, or with small amounts of oxygen. The type of shielding has some effect on deposit composition and other characteristics.

The shielding gases used in this process minimize oxidation and alloy loss. Their use contributes to superior

9. The gas metal arc welding (GMAW) process is described thoroughly in the *Welding Handbook*, Eighth Edition, Volume 2, Chapter 4.

weld quality and makes feasible the deposition of some metals, such as the aluminum bronzes, that cannot be applied by other semiautomatic or automatic methods. Carbon and alloy steel surfacing metals as solid electrodes require proper gas shielding for good quality overlays. In some applications, shielding with carbon dioxide has been found to be satisfactory. Variations of this process that have distinct characteristics include auxiliary wire feed, pulsed arc, and short-circuiting transfer.

The auxiliary wire modification feeds extra surfacing metal into the weld pool; the arc energy absorbed by melting the auxiliary wire reduces penetration and dilution while the deposition rate is increased. By choosing an auxiliary surfacing metal differing in composition from that of the electrode, deposit modifications can be made. This method is likely to be favored over the high-deposition submerged arc process when suitable granular fluxes are not available for the alloy being deposited. A notable application of the gas metal arc auxiliary wire process is artillery shell banding with gilding metal, where dilution by the base metal must be held below 3 percent.

Another variation features short-circuiting metal transfer. Using a small diameter electrode, 0.045 in. (1.2 mm) or smaller, metal transfer occurs only while the arc is extinguished, at a rate from about 20 to 200 times per second. Deposition rates are slightly higher than with covered electrodes, while dilution and workpiece distortion are minimized. This process allows for some out-of-position surfacing and is usually employed with semiautomatic equipment.

The pulsed arc technique also is a suitable method for out-of-position surfacing and for metals that are very fluid in the molten state. This technique produces less dilution than the spray transfer mode; arc stability and the deposition rate are slightly inferior to those of the spray transfer mode. The high-current pulse transfers the molten metal to the workpiece, and the low background current allows the molten metal just transferred to cool rather quickly. Deposition rates are lower than with continuous high-current operation.

The different types of base metals on which the gas metal arc process can be used for surfacing are numerous. Carbon steels, low-alloy steels, high-alloy steels, and many nonferrous metals can be surfaced with this process. The thickness of the base metals may normally range from about 1/4 in. (6 mm) and up. The surfacing electrodes are too numerous to list except by broad alloy classification. The common classifications for the wires are the high-alloy steels, the chromium-stainless steel alloys, the nickel and nickel alloys, the copper and copper alloys, the titanium and titanium alloys, and the cobalt and cobalt alloys. This surfacing process is basically a high-dilution process when operating in the spray transfer mode and can be expected to deposit 9 to 15 lb/h (4.0 to 7.0 kg/h) at dilution levels of about 30 to 50 percent.

The equipment used for gas metal arc surfacing is the same as that for gas metal arc welding. An exception in numerous surfacing applications, however, is equipment needed to oscillate (or weave) the electrode. The oscillating equipment may be very simple (providing only one basic pattern), or it may be very sophisticated (providing numerous patterns). Oscillators may be mechanical or electronic.

The equipment may be mechanized, automatic, or semiautomatic. The power source output is usually direct current, but pulsed direct current may be used for applications where better control of electrode melting rate and bead shape is required.

Table 7.4 shows how the various gas metal arc conditions affect dilution, deposition rate, and deposit thickness. The table assumes that only one of the listed variables is changed at a time. For example, when the electrode diameter is changed, no compensating changes are made in amperage, voltage, travel speed, wire extension, etc. In actual practice, this assumption may or may not be true, depending on the reason for making the change. Variables in the table unique to surfacing will be discussed.

Technique. A stringer or weave-bead technique greatly influences dilution. If both a stringer bead and a weave bead are deposited on the base material and the dilution is measured, the weave bead would have lower dilution (all other variables, except travel speed, being equal). The reason for this is that weaving allows more liquid metal between the arc and the base material, acting as a cushion and absorbing arc energy that would otherwise cause deeper penetration into the base metal.

Electrode Extension. The length of electrode extension (stickout) beyond the contact tip is very important in surfacing. Depending on the other welding variables, the base material, the surfacing metal, and the desired deposit results, the electrode extension will vary from a normal length of approximately eight times the electrode diameter to approximately 2 in. (51 mm). The long extension accomplishes at least three things:

(1) Increased deposition rate at any given amperage due to I^2R heating of the electrode

(2) Softening of the arc energy impinging on the base material, resulting in less penetration and dilution

(3) Evaporation of contaminants from the electrode surface

Surfacing procedures should be developed with known extensions. A worn contact tip can inadvertently lengthen the electrode extension; an unsuspecting welder or weld-

Table 7.4
Gas Metal Arc Process Variables — Independent Effects on Key Surfacing Characteristics

		Influence of Change on		
Variable	**Change of Variable[a]**	**Dilution**	**Deposition Rate**	**Deposit Thickness**
Polarity	DCEP DCEN[b]	High Low	Low High	Thin Thick
Shielding Gas	Argon Helium Carbon dioxide	Lowest Highest Intermediate	Lowest Highest Intermediate	Thinnest Thickest Intermediate
Arc Transfer	Spray Globular Short circuit Pulsed	1 (Highest) 3 4 (Lowest) 2	1 (Highest) 3 4 (Lowest) 2	1 (Thickest) 3 4 (Thinnest) 2
Amperage	High Low	High Low	High Low	Thick Thin
Technique	Stringer Weave	High Low	No effect No effect	Thick Thin
Bead Spacing	Narrow Wide	Low High	No effect No effect	Thick Thin
Electrode Extension	Short Long	High Low	Low High	Thin Thick
Electrode Diameter	Small Large	High Low	High Low	Thick Thin
Voltage	High Low	Low High	No effect No effect	Thin Thick
Travel Speed	Fast Slow	High Low	No effect No effect	Thin Thick
Position	Flat Uphill Downhill Horizontal Vertical-up[c] Vertical-up[d]	3 2 4 2-4 1 (Highest) 5 (Lowest)	No effect No effect No effect No effect No effect No effect	4 3 4 1 (Thickest) 5 (Thinnest) 2
Auxiliary Wire(s)		Low	High	Thicker

a. This table assumes that only one variable at a time is changed. However, for acceptable surfacing conditions, a change in one variable may require a change in one or more other variables.

b. Applicable for flux cored arc surfacing only.

c. The arc directed on work (forehand welding).

d. The arc directed on surfacing buildup (backhand welding).

ing operator may be unaware of this change in electrode extension and mistakenly increase the amperage.

Electrode Diameter. For a given amperage, the electrode diameter is critical to the dilution control and deposition rate. At 300 A, for example, a 1/16 in. (1.6 mm) electrode will produce less dilution and a lower deposition rate than a 0.035 in. (0.9 mm) electrode. The effects of electrode diameter on dilution control are caused, in part, by the mode of arc transfer and current density in the electrode (amperes per unit of cross-sectional area). At a given amperage, the 1/16 in. (1.6 mm) electrode may operate with globular transfer; however, at the identical amperage, the smaller electrode may operate with spray transfer. If two electrode diameters operating at a given amperage have the same mode of metal transfer, the small diameter electrode will have a greater dilution and a higher deposition rate because of the higher current density.

Flux Cored Arc Surfacing

THE FLUX CORED arc welding process is a modification of the gas metal arc welding process.[10] Therefore, the base materials on which this process can be used for surfacing are essentially identical to those used for gas metal arc surfacing. Flux cored electrodes are available in the same broad alloy classifications as solid electrodes, but in general, more varieties of flux cored electrodes are available within each class. For some alloys, flux cored electrodes are the only ones available because the alloys are not readily workable into wire form. Alloy powders can easily be added to the core with an appropriate sheath alloy. Sheaths of low-carbon steel, 300 and 400 series stainless steel, nickel, and cobalt can be used to produce flux cored surfacing alloys. Flux cored electrodes may or may not require auxiliary shielding gas, depending upon the specific wire and core formulation.

The equipment used for surfacing by use of the flux cored arc process is the same as that used for gas metal arc surfacing except for the electrode feed rolls, which are modified for the mechanically softer cored wires. In general, all the process variables for flux cored arc surfacing are the same as those for gas metal arc surfacing. Only those process variables where a significant difference occurs are discussed here.

The cost of gases and their handling equipment adds to the expense of surfacing. Where gas shielding is required, its effect should be clearly warranted. When an auxiliary shielding gas is employed, it is usually carbon dioxide or a mixture of carbon dioxide and another gas, such as argon. With carbon dioxide shielding, the transfer mode across the arc is usually globular, not a spray transfer. In general, this method produces more dilution and higher deposition rates than does gas metal arc surfacing.

The flux cored arc surfacing process has three disadvantages in contrast to gas metal arc surfacing:

(1) It produces a slag, similar to shielded metal arc surfacing, that may have to be removed before subsequent beads can be deposited.

(2) It is much more sensitive to electrode extension, especially the self-shielded variation.

(3) The cored electrode cannot be fed around as small a radius as can an equivalent solid electrode.

Although most cored wire deposits contain a slag, there are some wires that contain very little or no fluxing ingredients and are more appropriately described as metal cored wires. These wires are classified as GMAW filler metals. They usually do not require slag removal between subsequent beads and are more appropriate for automatic operation. One advantage of flux cored electrodes is that the manufacturer can tailor, or customize, the electrode chemical composition more easily than can be performed with solid electrodes. Table 7.4 also applies to flux cored arc surfacing.

Submerged Arc Surfacing

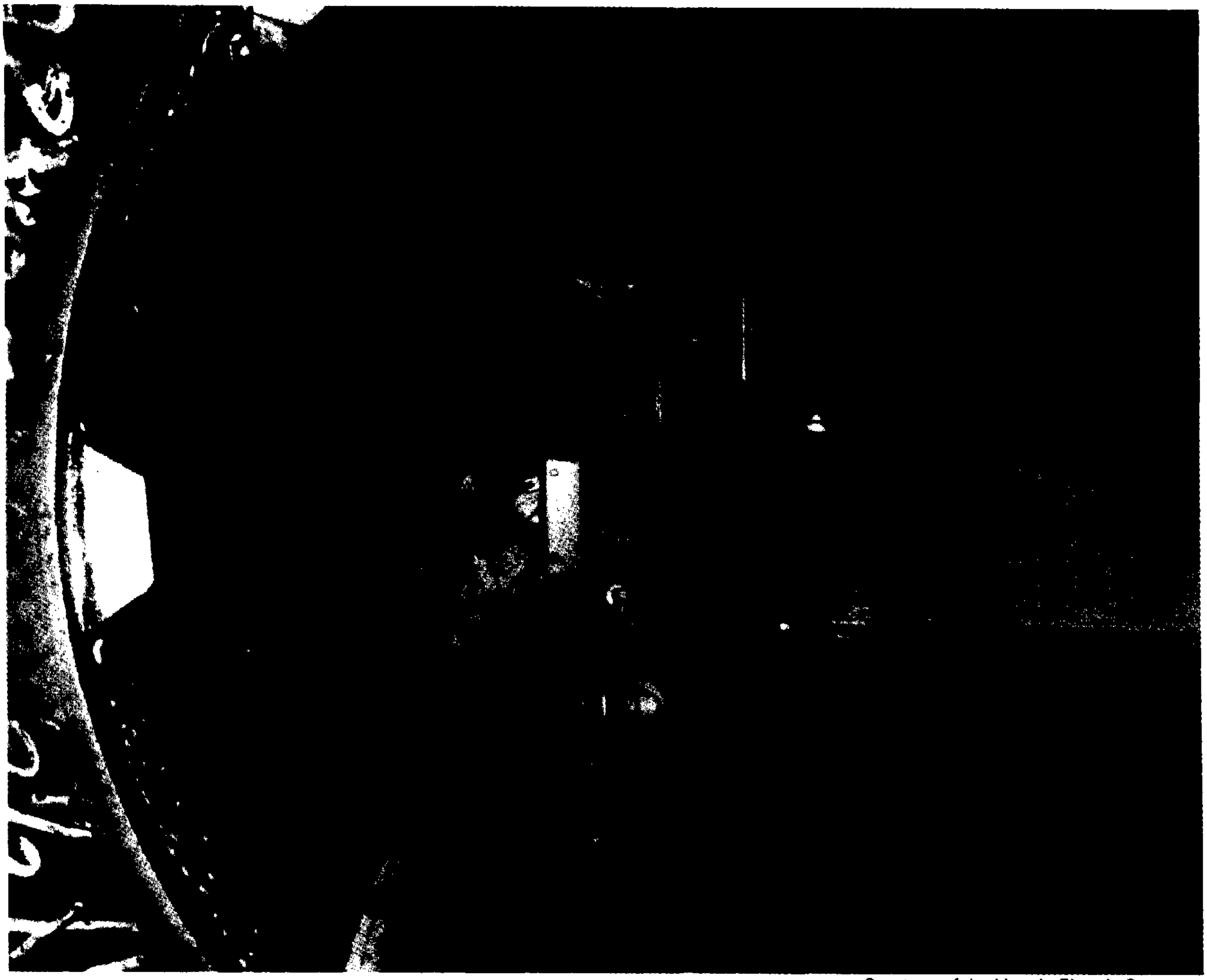
FOR THIS METHOD, the electrode is a continuous wire, either solid or tubular, or either solid or composite (cored) strip, and the arc zone is protected by a blanket of granular flux.[11] The electrode compositions are usually formulated to work with a specific flux grade. Because of its many advantages, the submerged arc, single electrode process is the most widely used automated technique for surfacing. It utilizes high welding currents and has the advantage of very high deposition rates. A wide range of electrode types gives good results, and they can usually be used with either direct or alternating current. Deposits are of high quality and with many surfacing metals are practically flawless. There is no spatter that might require cleaning, and the absence of the ultraviolet radiation from an exposed arc is advantageous in a shop. The process may be readily adapted to many applications that can utilize larger electrodes than are used in the semiautomatic method.

A good example is shown in Figure 7.13, which illustrates the rebuilding of a ball mill using the automatic submerged arc process.

The high quality of the deposit is advantageous for overlays requiring strength, corrosion resistance, or

10. The flux cored arc welding (FCAW) process is described thoroughly in the *Welding Handbook*, Eighth Edition, Volume 2, Chapter 5.

11. The submerged arc welding (SAW) process is described thoroughly in the *Welding Handbook*, Eighth Edition, Volume 2, Chapter 6.



Courtesy of the Lincoln Electric Company

Figure 7.13—Rebuilding the Interior of a Ball Mill Using the Automatic Submerged Arc Process to Deposit a Near-Eutectic White Iron Deposit

toughness. It should be realized that this method, with its relatively deep penetration and protective flux cover, puts more heat into the workpiece than other arc welding processes. With the dilution that takes place and the gain or loss of elements from the molten flux, the full properties of the surfacing metal are ordinarily not attained until two or more layers are deposited.

Though quality is assured, in the sense of freedom from porosity and slag pockets, the high thermal gradients may cause cracking. Crack avoidance may require preheating and postheating, usually with special equipment. With some surfacing deposits, such as the high-carbon chromium irons, a fine pattern of surface cracking is normal on large parts and on those parts subjected to high restraint. This behavior is characteristic of brittle hardfacing alloys and is not always undesirable.

Those methods that feed extra surfacing metal to the arc zone make more efficient use of the heat of the arc, while increasing deposition rates and decreasing dilution from the base metal. The extra surfacing metal may be one or more wires or strips, the latter being used primarily for stainless steels and nickel alloys.

A variation of the process feeds a granular powder of alloy onto the surface of the work ahead of the arc, then the blanketing flux is added. The arc heat melts the granular mix as well as the electrode and the base metal; all three materials combine to make the deposited metal. The powder metal is formulated for this admixture, on the basis of a fixed set of welding conditions. Arc power, bead size, travel speed, electrode feed speed, and alloy powder metering must all be correct and carefully controlled if the intended composition is to be obtained. Weaving of the electrode during deposition reduces dilution and melting of the base metal. Expected advantages of the process are less expensive surfacing metal, high deposition rates, low penetration, and little dilution from the base metal.

Materials. The different types of base materials for which the submerged arc process is normally used for surfacing are carbon and low-alloy steels, stainless steel, cast iron, and nickel and nickel alloys. The thickness range of the base metal can vary from approximately 1/2 in. (13 mm) and up. The materials used for surfacing are as follows:

(1) Consumable electrodes (bare or composite)
(2) Surfacing metal (bare, composite, or metal powder)
(3) Flux

The electrode and surfacing metal may be any alloy that can be produced in the required filler metal form. The most common are the high-alloy steels, the austenitic stainless steels, the nickel alloys, the copper alloys, and the cobalt alloys. The fluxes used for surfacing are essentially the same as those used for submerged arc welding.

Equipment. The equipment used for surfacing is the same as that used for welding. However, an oscillator and surfacing metal feeding equipment may be needed if the techniques that require them are used. The submerged arc process is basically an automatic process for surfacing.

Process Variations. When using a single 1/8 in. (3.2 mm) electrode to deposit stringer beads, one can reasonably expect to deposit about 13 lb/h (6 kg/h) at approximately 15 to 50% dilution using 350 A. The oscillating technique using higher current can typically deposit 26 lb/h (12 kg/h) with 25 to 40% dilution. Beads as wide as 3.5 in. (90 mm) may be made with oscillation.

Using a strip rather than a round electrode, the submerged arc welding process is capable of depositing a relatively thin, flat surfacing bead at deposition rates up to 100 lb/h (45 kg/h). Dilution is typically about 20 percent. The technique also works well when an auxiliary strip is fed into the arc to provide additional surfacing metal. With this refinement, the deposition rate is increased, and the dilution can be held to between 10 and 15 percent. Strip dimensions for the electrode usually are 2 in. (50 mm) or 4 in. (100 mm) wide and 0.04 in. (1 mm) or 0.06 in. (1.5 mm) thick. Cold strip dimensions are 1-5/8 in. (41 mm) wide by 0.05 to 0.06 in. (1.25 mm to 1.5 mm) thick.

The large cross section of the strip electrode permits currents as high as 1500 A to be used. Normal conditions call for approximately 1200 A, 32 V, and a travel speed of 15 in./min (6.3 mm/s), which will produce a cladding thickness of 3/16 in. (4.8 mm). Thickness can be varied between 5/32 and 3/8 in. (4 and 9 mm) by adjusting the travel speed, the electrode feeding rate, and the dimensions of the cold strip. Savings are derived not only from higher deposition rates but also from lower surfacing metal consumption. Flux consumption is reduced by about 66 percent compared to surfacing with conventional electrodes. The low penetration of the process reduces dilution and permits a thinner weld cladding to be deposited.

Direct current electrode positive or negative polarity is used, although alternating current can be used. In any case, a constant potential power source is the most suitable.

Another version of submerged arc surfacing provides additional surfacing metal in the form of powder. The granular metal powder is metered onto the work ahead of the flux covering. The arc, which is usually oscillated, melts all the granular metal and the electrode to produce the deposit. Arc power, bead size, travel speed, electrode feed speed, and alloy powder metering must all be correct and carefully controlled if the intended composition is to be obtained. This method is very useful to produce alloy compositions that cannot be economically fabricated into wire or strip form. The amount of granular metal applied bears a fixed relationship to the electrode used and normally ranges from 1.5 to 3 times the weight of the electrode. Most frequently, the electrode is mild steel and the granular metals supply the other elements to produce a specific alloy.

The granular metal process features deposition rates up to four times the rate possible with an electrode alone, with no increase in welding current. Penetration can be controlled to give about 15% dilution, because the arc does not impinge directly on the base metal. Most of the available power is used to melt the surfacing metal and electrode. Deposition rates in excess of 100 lb/h (45 kg/h) may be obtained. Advantages of the process are less expensive surfacing metal, high deposition rates, low penetration, and minimum dilution with the base metal. One significant limitation is the need for very precise process control; less control can lead to variations in composition and hardness and to consequent variations in abrasion or corrosion resistance.

Yet another variation of the submerged arc process, applied mainly to hardfacing, uses a bonded flux containing metal powders within the flux particles so that, with a mild steel wire, an alloyed hardfacing deposit can be produced. Alloy recovery in this variation depends upon the ratio of the flux melted to the wire melted. With careful control of this ratio, primarily by controlling wire feed speed and voltage, consistent quality hardfacing results can be obtained in a variety of compositions including buildup alloys, martensitic stainless steels, and high-chromium irons.

Effect of Process Variables. Table 7.5 shows the effect of changing the welding variables on dilution, deposition rate, and deposit thickness. The table assumes that only one variable at a time is changed. The effects of changing some variables for submerged arc surfacing are the same as those with gas metal arc surfacing.

The submerged arc fluxes used for surfacing are important to the success of the operation. In addition to the variables listed in Table 7.5, the fluxes used also affect dilution, deposition rate, and deposit thickness. The flux controls the molten weld pool fluidity. Fluidity and some of the other variables control bead shape. One of the major effects of fluidity is the control of bead edge-wetting characteristics due to the molten weld pool surface tension. Surface tension determines whether or not the liquid meniscus wets, like water, or rolls over, like mercury. A flux that is suitable for single electrode surfacing may not be acceptable for multiple electrode or strip electrode surfacing applications because of the higher amperages used and the difference in fluidity of the molten weld metal. Basically, the flux, the electrode(s), and the process variation (single electrode, multiple electrode, strip, etc.) must be selected and controlled for a given application.

Plasma Transferred Arc Surfacing

THE PLASMA TRANSFERRED arc welding process is used for hardfacing and surface cladding operations. This process is the plasma arc welding mode in which the constricted arc is between the electrode and the workpiece, as opposed to between the electrode and the constricting nozzle (nontransferred arc).[12]

Powder Surfacing. Plasma transferred arc powder surfacing uses ultrahigh temperatures of 10 000 to 40 000 °F (5500 to 22 000 °C) to deposit hardfacing materials. The arc is struck between the electrode and the workpiece while surfacing metal is supplied in powder form. The method differs from thermal spraying processes in that deposits are metallurgically fused to the base metal.

The resurfacing of a feed screw using this process is shown in Figure 7.14.

Properly fused plasma-deposited layers are similar in metallurgical structure to gas tungsten arc welded overlays. A number of cobalt, nickel, and iron alloys are available as homogeneous powders. Tungsten carbide particles may be added, under different conditions, to the alloy powders being applied, or directly to the weld pool.

When surfacing round or curved items, plasma transferred arc powder surfacing is performed in the horizontal rolled (1G) position. The arc is offset slightly from the vertical centerline, as with other processes. Layers can be applied in a considerable range of thicknesses, with deposit thickness, dilution, and deposition rate being interrelated. These variables are, to a considerable extent, dependent upon the characteristics of the alloy being applied. While heat input into the base metal is low compared to other welding processes, some distortion can be expected and must be considered. As with other surfacing methods, procedures to prevent cracking are generally determined by the properties of the alloy and the size of the part.

Advantages of plasma arc powder surfacing are:

(1) The ability to deposit a wide range of engineering materials

(2) Suitability for surfacing lower melting point base materials

(3) Controlled application of very thin as well as relatively thick layers

(4) Close control over surface finish that helps to minimize grinding and machining

Normal deposition rates of about 5 lb/h (2.3 kg/h) are reported.

Equipment costs for the plasma process are relatively high, and considerable exacting technology is involved. When fully mechanized, the process is particularly suited to high-production hardfacing of new parts. Applications include hardfacing of flow control valve parts, cutting tools, extruder screws, lawn mower components, and components for automotive and aircraft engines.

Hot Wire Surfacing. The plasma arc hot wire surfacing process is capable of applying surfacing at high deposition rates and very low dilution levels. The process consists of two basic systems combined to form and fuse a surfacing deposit to the base metal. One system heats the surfacing metal to almost melting temperature and deposits it on the surface of the base metal. The plasma torch (second system) melts the surfaces of the base metal and the surfacing metal to completely melt and fuse the molten metal to the base plate.

The main advantage gained by combining the two systems is that molten metal is deposited on the surface of the base metal with minimal dilution. The amount of heat added by the plasma torch can be held to the tem-

12. The plasma arc welding (PAW) process is described thoroughly in the *Welding Handbook*, Eighth Edition, Volume 2, Chapter 10.

Table 7.5
Submerged Arc Process Variables — Independent Effects on Key Surfacing Characteristics

Variable	Change of Variable[a]	Influence of Change on		
		Dilution	Deposition Rate	Deposit Thickness
Power supply and connection	AC DCEP DCEN	Intermediate Highest Lowest	Intermediate Lowest Highest	Intermediate Thinnest Thickest
Amperage	High Low	High Low	High Low	Thick Thin
Technique	Stringer Weave	High Low	No effect No effect	Thick Thin
Bead spacing	Narrow Wide	Low High	No effect No effect	Thick Thin
Electrode extension	Short Long	High Low	Low High	Thin Thick
Electrode diameter	Small Large	High Low	High Low	Thick Thin
Voltage	High Low	Low High	No effect No effect	Thin Thick
Travel speed	Fast Slow	High Low	No effect No effect	Thin Thick
Position	Flat Uphill Downhill	Intermediate Highest Lowest	No effect No effect No effect	Intermediate Thickest Thinnest
Process variations	1 electrode 1 electrode & surfacing wire 1 electrode & hot surfacing wire 2 wire series 2 wire series & cold wire Multiple wire Strip electrode Hot and cold strip Powder addition	2 3 4 3 4 2 1 (Highest) 5 (Lowest) 4	5 (Lowest) 5 4 4 3 2 2 1 (Highest 3	5 (Thinnest) 4 4 4 3 2 3 1 (Thickest) 3

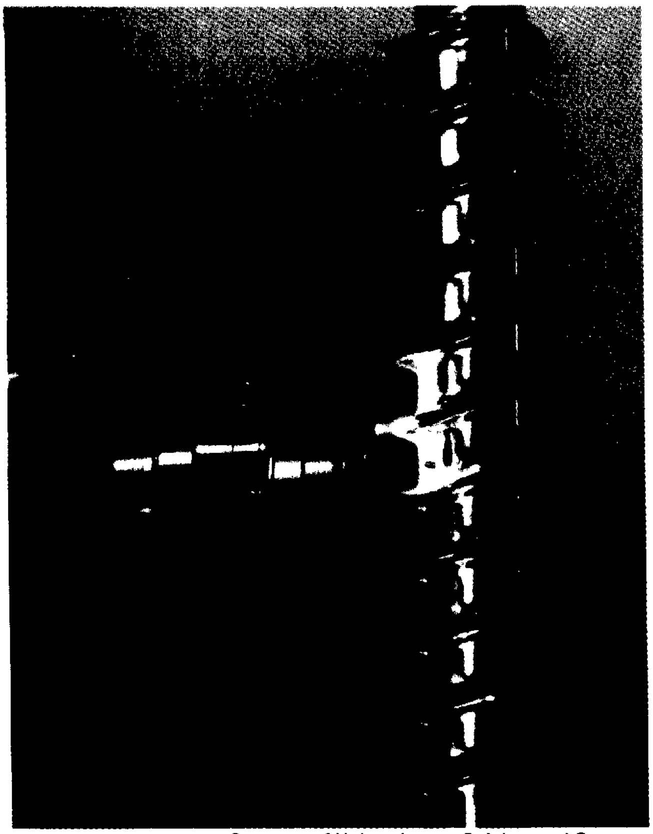
a. This table assumes that only one variable at a time is changed. The table indicates only general trends and does not cover questions of weldability or weld soundness. These factors may make it unwise to change only the indicated variable; the desired change in dilution, deposition rate, or deposit thickness may not be achieved.

perature required to fuse the surfacing material to the base metal. Deposit dilution is, therefore, easily controlled, and heat distortion of the work is held to a minimum. The process is used for overlaying pressure vessels and related components with stainless steel, nickel and cobalt alloys, and various bronzes. Equipment cost is high, but for many applications, considerably lower surfacing costs can result.

OXYFUEL GAS SURFACING

HIGH-QUALITY SURFACING CAN be achieved manually using the oxyfuel gas process.[13] Common practices employ either welding rods or powdered surfacing metal. Semiautomatic surfacing also may be set up using this process.

13. The oxyfuel gas welding (OFW) process is described thoroughly in the *Welding Handbook*, Eighth Edition, Volume 2, Chapter 11.



Courtesy of Hobart Lasers & Advanced Systems

Figure 7.14—Rebuilding of a Feed Screw Using the Automatic Plasma Transferred Arc Process

Manual Surfacing with Welding Rods

THIS METHOD HAS great usefulness for smooth, precise, and extremely high-quality surfacing deposits. The surfacing of flights on a centrifuge scroll, using the manual oxyfuel gas process, is shown in Figure 7.15.

The freedom from high base metal dilution can be very important where surfacing and base metals differ considerably, as with cobalt surfacing alloys applied to steels. Here, the addition of iron is known to be detrimental to the overlay properties.

The oxyfuel welding operation lends itself to very close scrutiny and control by the welder. Tiny areas can be surfaced. Grooves and other recesses may be accurately filled, and very thin layers may be smoothly applied. Rods containing tungsten carbide may be used with minimum melting of the wear-resistant particles and with controlled particle distribution. Preheating and slow cooling tend to minimize cracking with most overlays.

The base metal should be clean because dirt or oxides may interfere with the uniform wetting action desired. A flux is seldom necessary with most alloys. The flame adjustment should be made as recommended by the manufacturer for the specific surfacing metal, to ensure proper melt behavior and intended deposit properties. Most surfacing metals are applied by using a reducing flame that prevents loss of carbon. This may actually add some carbon to the deposit. The effect of the flame on the composition of the deposit is anticipated in the formulation of the welding rod during manufacture. A degree of welding skill is needed for high-quality oxyfuel deposits because improper flame adjustment or manipulation can cause defects. The welding rod used, often a casting, must be of good quality.

In a typical application, a low melting point high-carbon surfacing metal, such as a high-carbon chromium iron or a chromium-cobalt-tungsten alloy, is deposited on a low- or medium-carbon steel that has a high melting point. By using a reducing flame, the base metal is preheated uniformly over a small area. The reducing flame carburizes the surface, lowers its melting point, and finally, melts a film on the surface. This melted film appears as a "sweat" or glistening surface. The tip of the surfacing rod, which should be preheating on the fringe of the flame, is now moved into the hot center of the flame and melted. It should wet the surface as it melts and spread smoothly over the heated area. As the flame is moved to the edge of the surfaced area, the welding rod tip is moved before it, progressively melting the rod as needed. This method of application is known as the *forehand method.* It minimizes the dilution of the base metal that occurs when the backhand method is used. Many welders use a weaving motion of the flame and the rod to maintain the balance between surface heating and rod melting.

Special preparation of the base metal may be helpful. Grooves or recesses can be ground or machined where surfacing is needed and filled with the molten deposit. This not only aids in precise positioning but also tends to protect the edge of the deposit from chipping under impact.

Surfacing deposits that have a wide plastic temperature range, such as the nickel-chromium-boron alloys and austenitic high-carbon chromium irons, can be wiped or "struck off" to shape with a steel straight edge while the weld is still only partially solidified.

Because of preheating requirements and the nature of the flame and the process, oxyfuel surfacing does not have the capability for high deposition rates offered by most of the arc welding processes. However, for many applications, it is clearly the most satisfactory process. Well-established uses include the surfacing of steam valves, automotive diesel engine valves, chain saw bars, plowshares, and other agricultural implements. Although ductility may be decreased, the pickup of

Figure 7.15—Using the Manual Oxyfuel Gas Process to Rebuild the Scrolls of a Centrifuge with a High-Chromium Surfacing Material

carbon from a reducing flame is generally beneficial for those alloys that rely on carbides for abrasion resistance.

Manual Surfacing with Powdered Surfacing Metal

THIS VARIATION OF the gas welding process utilizes an oxyfuel torch fitted with a powder hopper and a powder feed control device. The surfacing powder is aspirated into the gas stream and exits with the gas from the torch tip, sometimes resulting in a sprayed deposit that is only mechanically bonded to the surface. However, by using the proper technique, a fusion bond may be obtained by sweating the base metal using the technique described in the preceding section and applying the surfacing alloy. The application and fusion of the surfacing alloy with the base metal occur in one operation.

The equipment is inexpensive, and excellent results can be obtained by even an inexperienced operator. One advantage of this method is that many alloys not readily obtainable in rod or wire form are available as suitable powders. Smooth, thin, porosity-free deposits can be made in one pass. Deposition rates will vary with torch size. Large torches with tips producing bulbous flames are able to deposit up to 10 lb (4.5 kg) of metal per hour. The thickness is controlled by the rate of powder flow and movement of the torch.

Semiautomatic Surfacing

WHERE THE NUMBER or symmetry of parts is such that an orderly sequence of preheating, deposition, and postheating can be arranged, it may be economical and efficient to set up a semiautomatic installation. For this installation, specially designed burners and mechanized part handling are used. The operator, using a welding rod 6 ft (1.8 m) or more long, intermittently feeds the hardfacing surfacing metal as it is required. Good judgment is needed for deposition control, but manual skill is less important, productivity is higher, and a more uniform product results than with manual gas welding.

This method has been well developed in some plants where repetitive production of many small parts is involved. The facing of truck and engine valves is an example. The burner arrangement ensures directional solidification. Deposit quality is held at a high level. Cast welding rods, made by continuous casting, are commercially available for the important alloys used for valve facing. A somewhat different application utilizes long, tungsten carbide filled welding rods for the hardfacing of feed mill hammers; the narrow hammers are fixtured in a series to provide a large flat surface for welding.

Because specialized burners and fixtures are needed for mechanized hardfacing by gas welding, it is advisable to consult equipment manufacturers when planning a system of this type.

THERMAL SPRAY SURFACING

THERMAL SPRAYING IS a process in which a metallic or nonmetallic material is heated and then propelled in atomized form onto a substrate.[14] The material may be initially in the form of wire, rod, or powder. It is heated to the plastic or molten state by an oxyfuel gas flame, by an electric or plasma arc, or by detonation of an explosive gas mixture. The hot material is propelled from the spray gun to the substrate by a gas jet. Most metals, cermets, oxides, and hard metallic compounds can be deposited by one or more of the process variations. The process also can be used to produce free-standing objects using a disposable substrate. It is sometimes called *metallizing* or *metal spraying*.

When the molten particles strike a substrate, they flatten and form thin platelets that conform to the surface. These platelets rapidly solidify and cool. Successive layers are built up to the desired thickness. The bond between the spray deposit and substrate may be mechanical, metallurgical, chemical, or a combination of these. In some cases, a thermal treatment of the composite structure is used to increase the bond strength by diffusion or chemical reaction between the spray deposit and the substrate.

The density of the deposit will depend upon material type, method of deposition, spraying procedures, and subsequent processing. The properties of the deposit may depend upon its density, the cohesion between the deposited particles, and its adhesion to the substrate.

Thermal spraying is widely used for surfacing applications to attain or restore desired dimensions; to improve resistance to abrasion wear, corrosion, oxidation, or a combination of these; and to provide specific electrical or thermal properties. Frequently, thermal sprayed deposits are applied to new machine elements to provide surfaces with desired characteristics for the application.

14. Thermal spray processes are described thoroughly in the *Welding Handbook*, Eighth Edition, Volume 2, Chapter 28.

There are five major thermal spraying methods:

(1) Flame spraying (FLSP)
(2) Plasma spraying (PSP)
(3) Arc spraying (ASP)[15]
(4) Detonation flame spraying
(5) High-velocity oxyfuel spraying (HVOF)

These variations are based on the method of heating the spray material to the molten or plastic state and the technique for propelling the atomized material to the substrate.

In flame spraying, the surfacing material is continuously fed into and melted by any oxyfuel gas flame. The material may be initially in the form of wire, rod, or powder. Molten particles are projected onto a substrate by either an air jet or the combustion gases.

The resurfacing of boiler tubes, using the manual flame spray process, is illustrated in Figure 7.16.

In plasma spraying, the heat for melting the surfacing material is provided by a nontransferred plasma arc.[16]

15. This method is commonly called *electric arc spraying*.
16. For information on plasma arc systems, refer to Chapter 10, "Plasma Arc Welding," *Welding Handbook*, Vol. 2, 8th Ed.

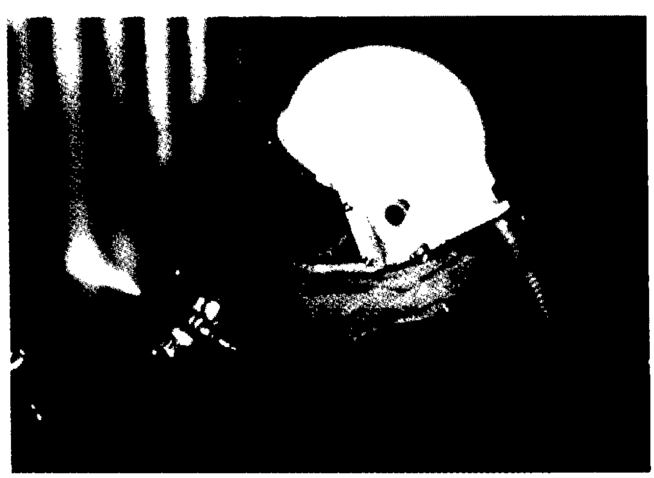


Figure 7.16—Using the Flame Spray Process to Resurface Boiler Tubes Subject to Erosion and Corrosion from High-Sulfur Fuels