

Welding Handbook

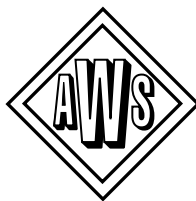
Ninth Edition

Volume 1

WELDING SCIENCE AND TECHNOLOGY

Prepared under the direction of the
Welding Handbook Committee

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ISO9001
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Welding Handbook, Ninth Edition

Volume 1 *Welding Science and Technology*

Volume 2 *Welding Processes—Part 1*

Volume 3 *Welding Processes—Part 2*

Volume 4 *Materials and Applications—Part 1*

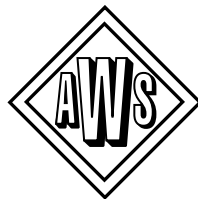
Volume 5 *Materials and Applications—Part 2*

Welding Handbook

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Volume 1

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CHAPTER 1

SURVEY OF JOINING, CUTTING, AND ALLIED PROCESSES



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CHAPTER 1

SURVEY OF JOINING, CUTTING, AND ALLIED PROCESSES

INTRODUCTION

This chapter introduces the conventional and more widely known joining, cutting, and thermal spraying processes. The distinguishing features of the various processes are summarized and compared to one another. Among the joining processes reviewed are the arc, resistance, and solid-state welding processes as well as brazing, soldering, and adhesive bonding. The cutting processes examined include thermal and non-thermal methods. The thermal spraying processes considered include flame and plasma arc spraying as well as arc and detonation flame spraying.

With respect to process selection, as several processes may be applicable for a particular job, the challenge lies in selecting the process that is most suitable in terms of fitness for service and cost. However, these factors may not be compatible, thus forcing a compromise. The selection of a process ultimately depends on several criteria. These include the number of components to be fabricated, capital equipment costs, joint location, structural mass, and the desired performance of the product. The adaptability of the process to the location of the operation, the type of shop, and the experience and skill levels of the employees may also have an impact on the final selection. These criteria are examined as they relate to the various joining, cutting, and thermal spraying processes.

As this chapter is intended to serve merely as a survey of the most common joining, cutting, and thermal

spraying processes,¹ the reader is encouraged to conduct a thorough investigation of the processes that appear to have the best potential for the intended applications. This investigation should take into account safety and health considerations such as those presented in the American National Standard *Safety in Welding, Cutting, and Allied Processes*, ANSI Z49.1,^{2, 3} and the information provided in the manufacturers' material safety data sheets (MSDSs). Additional sources of information about the joining, cutting, and allied processes are listed in the Bibliography and Supplementary Reading List at the end of this chapter. In particular, *Welding Processes*,⁴ Volume 2 of the American Welding Society's *Welding Handbook*, 8th edition, presents in-

1. For further information on the categorization of the welding, joining, cutting, and allied processes, see Appendix A.

2. At the time of the preparation of this chapter, the referenced codes and other standards were valid. If a code or other standard is cited without a date of publication, it is understood that the latest edition of the document referred to applies. If a code or other standard is cited with the date of publication, the citation refers to that edition only, and it is understood that any future revisions or amendments to the code or standard are not included; however, as codes and standards undergo frequent revision, the reader is encouraged to consult the most recent edition.

3. American National Standards Institute (ANSI) Committee Z49 on Safety in Welding and Cutting, *Safety in Welding, Cutting, and Allied Processes*, ANSI Z49.1, Miami: American Welding Society.

4. O'Brien, R. L., ed., 1991, *Welding Processes*, Vol. 2 of *Welding Handbook*, 8th ed., Miami: American Welding Society.

depth coverage of each of the welding, cutting, and allied processes.

JOINING PROCESSES

The goal of the joining processes is to cause diverse pieces of material to become a unified whole. In the case of two pieces of metal, when the atoms at the edge of one piece come close enough to the atoms at the edge of another piece for interatomic attraction to develop, the two pieces become one. Although this concept is easy to describe, it is not simple to effect. Surface roughness, impurities, fitting imperfections, and the varied properties of the materials being joined complicate the joining process. Welding processes and procedures have been developed to overcome these difficulties by incorporating the use of heat or pressure, or both. Though portions of this description do not apply to brazing, soldering, and adhesive bonding, an explanation will be given when these processes are described later in the chapter.

Barring a few exceptions, most welding processes apply significant heat to the base material. This heat is only a means to bring the atoms at the edge of one piece of material close enough to the atoms of another piece for interatomic attraction. However, this heat is detrimental to the microstructure of the materials being joined. As hot metal tends to oxidize, sufficient protection from oxidation must be provided by the welding process to prevent this detrimental reaction with ambient oxygen. Some metals are far more sensitive than others, in which case protection from oxidation becomes more demanding. Thus, while examining each welding process, the reader should consider whether heat is produced by the process and, if so, the manner in which it is produced. The means by which sufficient protection against oxidation is provided by the process should then be identified.

The selection of an appropriate joining and cutting process for a given task involves a number of considerations. These include the following:

1. Availability and fitness for service;
2. Skill requirements;
3. Weldability of the base metal alloy with respect to type and thickness;
4. Availability of suitable welding consumables;
5. Weld joint design;
6. Heat input requirements;
7. Demands of the welding position;
8. Cost of the process, including capital expenditures, materials, and labor;
9. Number of components being fabricated;

10. Applicable code requirements; and
11. Safety concerns.

The overview of the joining processes featured in Table 1.1 presents an initial reference guide to the capabilities of various joining processes with respect to a variety of ferrous and nonferrous metals. This table indicates the processes, materials, and material thickness combinations that are usually compatible. The columns on the left list various engineering materials and four arbitrary thickness ranges. The processes most commonly used in industry are listed across the top.

It should be noted that additional information such as the considerations listed above must be taken into account before process selections are finalized. Nonetheless, Table 1.1 serves as a useful tool in providing general guidelines for the screening and selection process.

ARC WELDING

The term *arc welding* applies to a large, diversified group of welding processes that use an electric arc as the source of heat. The creation of a weld between metals using these processes does not usually involve pressure but may utilize a filler metal. The arc is struck between the workpiece and the tip of the electrode. The intense heat produced by the arc quickly melts a portion of the base metal, resulting in the formation of a weld. The arc welding processes may be moved along the joint to produce the weld or held stationary while the workpiece is moved under the process.

Arc welding operations are performed by conducting the welding current through consumable electrodes, which take the form of a wire or rod, or nonconsumable electrodes, consisting of carbon or tungsten rods. Metal arc processes utilize consumable electrodes that combine electrode filler metal with the molten base metal to create the weld. They may also produce a slag covering to protect the molten metal from oxidation. The nonconsumable arc processes can generate a weld by melting the base metal only, resulting in what is termed an *autogenous weld*. If filler metal is required in a nonconsumable process, it may be fed either manually or mechanically into the molten weld pool. In this case, the nonconsumable electrode serves only to sustain the arc.

Shielded Metal Arc Welding

Illustrated in Figure 1.1, shielded metal arc welding (SMAW) is a basic, versatile process used to weld ferrous and some nonferrous metals. The most widely known of the arc welding processes, shielded metal arc welding is sometimes referred to colloquially as *stick*

Table 1.1
Capabilities of the Commonly Used Joining Processes

		Processes*																						
		S M A W	S A W	G M A W	F C A W	G T A W	P A W	E S W	E G W	R W	F W	O F W	D F W	F R W	E B W	L B W	T B	F B	R B	I B	D B	I R B	D F B	S
Material	Thickness†																							
Carbon steel	S	x‡	x	x		x				x	x	x			x	x	x	x	x	x	x	x	x	x
	I	x	x	x	x	x				x	x	x		x	x	x	x	x	x	x	x	x	x	x
	M	x	x	x	x					x	x	x		x	x	x	x	x	x				x	x
	T	x	x	x	x			x	x		x	x		x	x	x	x	x					x	
Low-alloy steel	S	x	x	x		x				x	x	x	x		x	x	x	x	x	x	x	x	x	x
	I	x	x	x	x	x				x	x		x	x	x	x	x	x	x	x	x		x	x
	M	x	x	x	x					x	x		x	x	x	x	x	x	x				x	x
	T	x	x	x	x			x			x		x	x	x		x					x		
Stainless steel	S	x	x	x		x	x			x	x	x	x		x	x	x	x	x	x	x	x	x	x
	I	x	x	x	x	x	x			x	x		x	x	x	x	x	x	x				x	x
	M	x	x	x	x		x				x		x	x	x	x	x	x	x				x	
	T	x	x	x	x			x			x		x	x	x			x					x	
Cast iron	I	x										x					x	x	x				x	x
	M	x	x	x	x							x					x	x	x				x	x
		x										x						x					x	
	T	x	x	x	x							x						x					x	
Nickel and alloys	S	x		x		x	x			x	x	x			x	x	x	x	x	x	x	x	x	x
	I	x	x	x		x	x			x	x			x	x	x	x	x	x				x	x
	M	x	x	x			x				x			x	x	x	x	x					x	
	T	x		x				x			x			x	x			x					x	
Aluminum and alloys	S	x		x		x	x			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	I	x		x		x				x	x		x	x	x	x	x	x			x		x	x
	M	x		x		x					x			x	x		x	x			x		x	
	T	x		x				x	x		x				x			x					x	
Titanium and alloys	S			x		x	x			x	x		x		x	x		x	x				x	x
	I			x		x	x				x		x	x		x		x					x	
	M			x		x	x				x		x	x		x		x					x	
	T			x			x				x		x		x			x					x	
Copper and alloys	S			x		x	x			x§	x				x		x	x	x	x	x		x	x
	I			x						x				x				x					x	x
	M			x						x				x				x					x	
	T			x						x				x				x					x	
Magnesium and alloys	S			x		x				x					x	x	x	x			x		x	
	I			x		x				x				x	x	x	x	x			x		x	
	M			x										x	x	x		x					x	
	T			x											x			x						
Refractory alloys	S			x		x	x			x	x				x		x	x	x	x		x	x	
	I			x			x			x	x				x		x	x					x	
	M										x													
	T										x													

* SMAW = shielded metal arc welding; SAW = submerged arc welding; GMAW = gas metal arc welding; FCAW = flux cored arc welding; GTAW = gas tungsten arc welding; PAW = plasma arc welding; ESW = electroslag welding; EGW = electrogas welding; RW = resistance welding; FW = flash welding; OFW = oxyfuel gas welding; DFW = diffusion welding; FRW = friction welding; EBW = electron beam welding; LBW = laser beam welding; TB = torch brazing; FB = furnace brazing; RB = resistance brazing; IB = induction brazing; DB = dip brazing; IRB = infrared brazing; DB = diffusion brazing; and S = soldering.

† S = sheet (up to 1/8 in. [in.] 3 millimeters [mm]); I = intermediate (1/8 in. to 1/4 in. [3 mm to 6 mm]); M = medium (1/4 in. to 3/4 in. [6 mm to 19 mm]); T = thick (3/4 in. [19 mm] and up).

‡ Commercial process.

§ Copper requires molybdenum-coated tips.