Chapter 1

Introductory Chapter: A Brief Introduction to Joining and Welding

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Additional information is available at the end of the chapter

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1. Introduction

Joining is an important process in a number of industries, such as aerospace, automotive, oil, and gas. Many products cannot be fabricated as a single piece, so components are fabricated first and assembled later. Joining technology can be classified as a liquid-solid-state process and mechanical means. Liquid-solid-state joining includes welding, brazing, soldering, and adhesive bonding. Mechanical joining includes fasteners, bolts, nuts, and screws.

Metal joining is a process that uses heat to melt or heat metal just below the melting temperature. Joining metal by fusion is known as fusion welding. Without fusion, the process is known as solid-state welding. Fusion welding includes arc welding and laser welding, Whereas solid-state welding such as friction stir welding (FSW) where process occurred below the melting temperature.

2. Fusion welding (arc welding)

Fusion welding is known as non-pressure welding, in which edge samples to be joined with the filler metal are heated above the melting points to create a weld pool and allow solidification. Gas tungsten arc welding (GTAW) and gas metal arc welding (GMAW) are categorized under fusion welding. GTAW and GMAW are mostly used by the welder to weld both ferrous and non-ferrous metals. In fusion welding, inert gases, such as argon (Ar), helium (He), and carbon dioxide (CO_2), are used for surrounding the electrode and molten metal from the welded metal. These inert gases will eliminate the formation of metal oxides and nitrides, which can lower the ductility and toughness of the welded metal.

3. GMAW

GMAW is also known as metal inert gas (MIG) welding in which an external gas, such as argon, helium, carbon dioxide, argon + oxygen, and other gas mixtures, is used as a shielding gas [1]. Consumable electrode wire, having the same or approximate chemical composition to that of parent metal, is continuously fed from a spool to the arc zone. The arc from the welding parameters (voltage and current) heats and melts the samples' edges and the filler wire. The fused filler metal is supplied to the surface of the workpiece, fills the weld pools, and forms the joint between the workpieces similarly or dissimilarly. The overall process in GMAW is described as a semi-automatic method because of the automatic feeding of the filler rod while the welder controls only the position and speed of the torch. GMAW can weld almost all metals and alloys, aluminum alloys, and stainless steel [2].

4. GTAW

GTAW is also known as tungsten inert gas (TIG) welding, in which heat from an electric arc is used. The arc sparks between a tungsten non-consumable electrode and the workpiece [1]. The molten pool is shielded by an inert gas such as argon, helium, and nitrogen. The shielding gas prevents the molten pool from atmospheric contamination. The heat produced by the arc melts the samples' edges. The filler rod can be used if required, especially in welding aluminum. GTAW produces a high quality weld of most metals because it does not use flux. An externally supplied shielding gas is necessary because of high temperatures involved to prevent metal from oxidation. Direct current is typically used, and its polarity is important as this welding method still uses current and voltage as critical parameters. Given that the tungsten electrode is not consumed during welding, a stable and constant arc is preserved at a constant current level. The filler metals used are usually similar to the parent metals to be welded, without using flux. The shielding gas used is normally argon or helium (or a mixture of gases). GTAW is used for a wide variety of metals and applications. Metals that usually can be welded by GTAW are aluminum, magnesium, titanium, and copper and its alloy. The tungsten electrode is usually in contact with a water-cooled copper tube (contact tube), which is connected to the welding cable from the terminals. Both the weld current and electrode must be cooled to avoid overheating during welding.

5. Laser welding

Laser welding has shown remarkable progress as a high-efficiency welding technique through the years. The process of Laser welding for metal is based on melting metal under a highly concentrated beam of radiation that is focused on the surface metal to join two parts. Radiation is partially absorbed by the upper layer of the metal, causing it to heat to the melting point. The important processing parameters involved in laser welding include laser properties (average and peak power, beam quality, beam diameter, wavelength, and focal length), weld setting (focus position toward the material surface, weld type, and shielding gas), and physical properties of the parent metal. There are two types of welding area, namely conduction or keyhole mode. The obvious width and depth difference in this welding area is due to the energy *E* and peak power density *PPD* applied.

Laser welding has many advantages over the conventional joining method, such as deep penetration, low heat input, small heat-affected zone (HAZ), and high speed. In terms of production, some of the advantages of laser welding are high speed, high process productivity, flexibility in control, and automation. Three common types of laser machines, namely CO_2, Nd:YAG, and fiber lasers, are widely used in the industry for welding purposes. CO_2 is known as a gas laser with a wider wavelength compared with solid-state lasers Nd:YAG and fiber lasers. Unlike solid-state lasers, the wide wavelength of the CO_2 laser results in poor absorption by a wide range of materials. Meanwhile, the fiber laser presents several advantages over the Nd:YAG laser because of the former's compact design, good beam quality, and low cost of ownership and maintenance.

6. FSW

FSW is a welding process that involves solid-state joining; this process has expanded rapidly since its development in 1991 by The Welding Institute, UK [3–6]. FSW is a solid-state welding technique that does not involve melting and occurs below the melting point. It uses a rotating tool to generate necessary heat for welding. This tool consists of three parts: the shank, shoulder, and pin. The shank is the part where the tool is attached to the FSW machine, whereas the shoulder and pin are attached to the workpiece. The shoulder and pin provide additional frictional treatment and prevent the plasticized material from escaping from the weld region. During FSW, the rotating tool moves along the joint of two plates that generate heat. This tool then recirculates flow of the plasticized material near the tool surface. The size of the tool shoulder is larger than that of the pin tool. The FSW tool serves two main functions, namely workpiece heating and material movement to produce a joint [4]. Heating is produced by friction of the pin and workpiece and plastic deformation of the workpiece. The heat that is produced will soften the material around the pin, and tool rotation will move the material from the front of the pin to the back of the pin. The result of this process is a joint produced in solid state.

FSW can be utilized in a wide variety of industries, such as automotive, aerospace, maritime, and railway [3, 4, 7–11]. FSW has been considered the most substantial joining process in the past decade because it offers many advantages such as energy efficiency, environmental friendliness, and versatility [4]. Compared with arc welding, FSW uses less energy and does not require a shielding gas and flux, thereby making this process an eco-friendly one. This joining process does not need any filler, so it is suitable to join many types of dissimilar metals. FSW is a technique that can avoid drawbacks from common fusion welding because FSW can be conducted under solid state. Several problems (e.g., spatter, hot cracking, and distortion) in other types of welding are eliminated by using FSW [12]. Defects such as voids, lack of penetration, and broken surface can be minimized by using this welding technique.

7. Overview of the chapters

Chapter 2: “New approaches to the Friction Stir Welding of aluminum alloys” written by Marcello Cabibbo, Archimede Forcellese, and Michela Simoncini. The main contribution of this chapter is the presentation of two new methods to weld aluminum alloys sheets by using FSW.

Chapter 3: “A mesh-free solid mechanics approach for simulating the friction stir welding process” written by K. Fraser, L. St-Georges, and L. I. Kiss. The main contribution of this chapter is the introduction of a new approach to simulate FSW by smoothed particle hydrodynamics (SPH). This approach can determine elastic and plastic deformation, residual stresses, temperature, and material flow in the same model.

Chapter 4: “Gas Tungsten Arc Welding with Synchronized Magnetic Oscillation” written by Thiago Resende Larquer and Ruham Pablo Reis. This chapter describes a method of controlling arc motion using the magnetic oscillation method of GTAW. The good coordination of magnetic oscillation and the welding process can influence the delivery of arc energy to the welded metal, thereby controlling the formation of weld bead.

Chapter 5: “A Comprehensive mode of the transport phenomena in Gas Metal Arc Welding” written by J. Hu, Z.H. Rao, and H.L. Tsai. This chapter explains the development of a comprehensive two-dimensional GMAW model, which considers the effect of arc plasma, electrode condition, droplet formation, detachment transfer, impingement onto the workpiece and the weld pool, and weld formation. This model uses volume of fluid approaches to track the free surface, which can eliminate the requirement of boundary condition at the interface.

Chapter 6: “The analysis of temporary temperature field and phase transformation in one-side butt welded of steels flats” written by Jerzy Winczek. This chapter describes model approaches for temperature field and phase transformation analysis of butt welding. This model is verified by metallographic observation of the butt weld workpiece, which was welded using an arc welding machine.

Chapter 7: “Laser and Hybrid laser-arc welding” written by G.A. Turichin. This chapter explains the technology of laser and hybrid laser-arc welding. It discusses the uniqueness of laser and hybrid laser-arc welding on metals and its potential application in the industry.

Chapter 8: “Current issues and problems in the joining of ceramic to metal” written by Uday M.B., Alias Mohd Noor, and Srithar Rajoo. This chapter describes the challenges of joining between ceramics and metals. These two metals have significantly different properties, so joining of these materials is difficult. This chapter explains various studies that have been conducted on joining between ceramic and metals.

Chapter 9: “Diffusion Bonding: Influence of Process Parameters and Material Microstructure” written by Thomas Gietzelt, Volker Toth, and Andreas Huell. This chapter deals with the technology of diffusion for welding application. The parameters that influence mechanical properties and the microstructure, as well as those involved in diffusion welding, are discussed.

Chapter 10: “Applying Heat for Joining Textile Materials” written by Simona Jevšnik, Senem Kurson Bahadir, Dragana Grujić, and Zoran Stjepanovič. This chapter explains the application of joining technology in the textile industry. It explores methods such as fusion, hot air, and hot wedge welding for joining textile. The basic knowledge and working principle of these technologies, as well as application opportunities, are presented in this chapter.

Chapter 11: “Magnetic Pulse Welding: An Innovative Joining Technology for Similar and Dissimilar Metal Pairs” written by T. Sapanathan, R.N. Raoelison, N. Buiron, and M. Rachik. This chapter focuses on magnetic pulse welding process, its potential requirements, interfacial kinematics of the welding, weld features as well as interfacial behaviors, and multi-physics numerical simulations. The magnetic pulse welding is recognized as one of the promising joining method to weld similar and dissimilar metal, which provides many attractive advantages.

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