Chapter 17
Mastering Friction Stir Welding (FSW) With Machine Learning (ML): A Comprehensive Guide to Algorithms and Applications

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ABSTRACT

This chapter introduces machine learning (ML) in friction stir welding (FSW), a solid-state welding process that has gained significant attention in research and application. The chapter discusses five primary ML methods: artificial neural networks (ANNs), support vector machines (SVM), random forests (RF), particle swarm optimisation (PSO), and convolutional neural networks (CNNs). The chapter emphasizes the successful application of ANNs in optimizing FSW process parameters and predicting tool wear, tensile failure, and fracture positions. CNNs are shown to be effective for microstructure studies and image detection, while SVM is a good tool for FSW process monitoring and temperature control. RF is demonstrated to have good abilities in investigating welding defects and tool monitoring, while PSO is frequently used in FSW welding bead studies. The chapter provides a straightforward methodology for those interested in utilising ML in welding studies, particularly for FSW.

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INTRODUCTION

Welding combines two metal pieces to create a strong and durable connection. Its origins can be traced back to the Bronze Age, when heat was used to join metals(Miller Welds, 2016). Since then, the manufacturing, construction, and engineering industries have widely adopted welding techniques. Throughout history, industries, including World War I, have relied on welding to create weapons and military equipment. Gas welding was essential for repairing and modifying vehicles in the automotive industry. The advent of new materials, such as aluminum and titanium, presented challenges, and new techniques were developed to overcome them. Today, aerospace uses welding extensively to create aircraft and spacecraft.

Early forms of welding were blacksmiths used forge welding to create swords and armour. Forge welding involves heating two pieces of metal to a high temperature and hammering them together. The electric arc welding process, which involves passing an electric current through two pieces of metal to create a strong bond, is a breakthrough in welding technology. It played a critical role in World War I in manufacturing weapons and military equipment, and it is still widely used today with various advancements made over the years. Welders were in high demand, and the process was used extensively to create tanks, ships, and aircraft. Gas welding was widely used in the automotive industry and was essential for repairing and modifying vehicles. In the 1950s and 1960s, new materials, such as aluminium and titanium, presented new challenges for welders (Olabode et al., 2013). These materials were difficult to weld, and new techniques were developed to overcome these challenges. Today, welding is used extensively in aerospace to create aircraft and spacecraft.

The importance of welding in the manufacturing industry cannot be overstated, as it creates everything from bridges and buildings to cars and airplanes. Welding has also played a critical role in developing new technologies, such as parts for nuclear reactors and components for renewable energy technologies like wind turbines and solar panels. The welding industry continues evolving, constantly developing new technologies like laser welding to enhance the process.

Welding has also played a critical role in the development of new technologies. For example, welding is used to create parts for nuclear reactors (Jeyaganesh et al., 2014), and new welding techniques are being developed to create components for renewable energy technologies such as wind turbines (Stavridou et al., 2015) and solar panels (Karalis et al., 2005). The welding industry continues to evolve, and new technologies are being developed to improve the process. Laser welding, for example, uses a high-energy beam of light to create a bond between two pieces of metal. This technique is more precise and efficient than traditional welding methods and is being used in increasing applications. Today, new techniques are being developed to improve the process continually. The importance of welding cannot be overstated, and it will undoubtedly continue to play a critical role in developing new technologies and creating new products for years to come.

Friction Stir Welding (FSW) is a solid-state joining method for welding metals that cannot be welded through conventional fusion welding techniques(R. K. Al-Sabur & Jassim, 2018). FSW has several advantages over traditional welding techniques, such as welding materials with low melting points, welding dissimilar metals, and producing high-quality welds with minimal distortion. FSW involves joining two pieces of metal without melting the material. Instead, FSW uses a rotating tool to apply friction and pressure to the material, causing it to soften and bond. The process was first invented in 1991 by The Welding Institute in the UK and has since become a popular alternative to traditional welding techniques(Belalia et al., 2024; Serier et al., 2024).