Abstract

This thesis aims to systematically investigate the microstructural and mechanical properties, assess weld quality, and optimize the weld attributes of 3-mm-thick sheets of Ti-6Al-4V, a highly reactive alloy that presents challenges during welding; and HY 282, a superalloy prone to crack formation at elevated temperatures, separately, using electron beam (EB). Thus, the goal of this research is to achieve welding that is free from defects, cracks, and of high strength with promising quality, after minimizing the lead time and material waste. In order to achieve this, the following studies were performed in the thesis work. First, an experimental study was conducted to investigate the microstructure and mechanical properties of as-welded and post-weld heat-treated (PWHT) conditions for EB-welded Ti-6Al-4V and HY 282 alloys, separately. Further, PWHT was incorporated to enhance the mechanical properties. The results were compared for the as-received base metal, weld metal, and post-weld heat-treated materials to identify property improvements. As a result, from the microstructural study, α' martensite, widmanstatten α, and acicular α structures were found in the fusion zone (FZ) of Ti-6Al-4V alloy. The formation of martensite can promote high tensile strength after welding. Similarly, fine columnar dendritic structures were predominantly observed in the FZ of HY 282 alloy, accompanied by MC carbides in the grains and grain boundaries, which further enhances mechanical strength and microhardness. After welding, the mechanical properties, including tensile stress and microhardness values, significantly increased for both alloys. After employing PWHT, the tensile strength and microhardness properties of the HY 282 alloy weld were further enhanced. Second, we assessed post-weld defects to evaluate weld quality for both alloys. Various defects, including cracks, porosity, and lack of fusion, were examined using scanning electron microscopy, non-destructive testing, micro-Raman spectroscopy (for hydrogen detection), and elemental mapping (to trace oxygen). The resultant weldments are free from oxygen, hydrogen, cracks, porosity, and lack of fusion. This result demonstrated substantial progress in the welding of HY 282 alloy using EBW, compared to the reported literature on laser beam and gas tungsten arc welding. Third, modeling and optimization were done on the weld parameters for EBW of Ti-6Al-4V and HY 282 alloys to minimize the lead time, cost, and material waste. For Ti-6Al-4V alloy, regression analysis and metaheuristic techniques were employed, while for HY 282 alloy, an Artificial Neural Network (ANN) and various metaheuristic techniques were incorporated to model and optimize the process parameters of EBW. Consequently, NSGA-II produced the best Pareto-optimal front, with the highest hypervolume indicator and lowest spacing metric, implying greater diversity and uniformity in optimizing the bead width and depth of penetration of Ti-6Al-4V weld. On the other hand, using ANN-Grey Wolf Optimizer (GWO) provided the best prediction performance for input-output modeling, and particle swarm optimization (PSO) yielded the highest optimization results for ultimate tensile strength in EBW of HY 282 alloy. Finally, this study recommended EBW for Ti-6Al-4V and HY 282 alloys to achieve crack- and porosity-free welds with superior strength.

Keywords: Electron beam welding, HY 282 alloy, Ti-6Al-4V alloy, Mechanical properties, Weld quality, Weld optimization, Artificial neural network, Metaheuristic Techniques.