

ABSTRACT

Additive Manufacturing (AM) as an emerging technology has gained more attention in manufacturing industry that promises higher deposition rate, medium complexity, lower material cost, shorter lead times, materials savings and time to market. In this work an emerging technology of Wire Arc Additive Manufacturing (WAAM) process is used to fabricate the 316L stainless steel walls at various heat input conditions. WAAM process enables the higher deposition rate, material usage, moderate complexity and less cost. The WAAM process has the capability to produce the large scale parts at high deposition efficiency and gaining interest from various industrial sectors. Cold Metal Transfer (CMT) is a modified version of Gas Metal Arc Welding (GMAW) process based on the controlled dip transfer mechanism, accurate shape, low heat input, excellent quality and spatter free. In order to optimize the WAAM deposition process under the influences of various process parameters conditions were evaluated. The various process parameters were identified such as: Weld Current (WC), Wire Feed Speed (WFS) and Travel Speed (TS) on weld bead geometry has been also explored. Parameters ranges were identified by based on conducting the trial and error experiments. Primarily, the 316L stainless steel walls were fabricated with various heat input using CMT-WAAM process under the manual mode, According to the results obtained, it suggests that the 316L deposit thin walls cannot be convinced in manual mode with respective to dimension accuracy, control, number of wastages, quality and performances of the part. Initially the bead on plate experiments were conducted to identify the heat input levels, secondly the suitable various heat input condition was selected to fabricate 316L stainless steel thin walls using automatic CMT-WAAM process.

The influence of microstructure characteristics, mechanical, corrosion, wear properties and residual stresses have been explored. The obtained results have revealed that the optimized parameters provide the desirable geometry of single weld beads for the fabrication of WAAM parts. According to the obtained results, the suitable process parameters and levels were identified and selected, the various process parameters value ranges as: WC: 130-150 A, WFS: 4.5-5.5 m/min and TS: 2.5-5 m/min; it has been used for the fabrication of 316L thin walls. The various heat input condition of deposited parts underwent the significant changes in microstructure characteristics and mechanical properties. Heat input is considered as the dominant parameter that leads to increase the temperature, formation of residual stresses and part distortions. The microstructure studies shows the uniform distribution of equiaxed grains and columnar grains with strong aligned columnar crystals followed by epitaxial growth, which grew perpendicular to melt pool boundary. In addition the slow cooling rate provides the sufficient time for the growth of primary dendrites. From the Electron Back Scattered Diffraction (EBSD) analysis, the deposit part shows the large oriented dominant columnar and equiaxed grains, which are influenced by the epitaxial growth with a dominant $\langle 100 \rangle$ texture, which enables the several layers are aligned in the building direction. Micro-hardness studies show the non-uniform distribution of hardness value in various heat input deposit samples, the micro-hardness values are ranging from 170 HV to 210 HV. Micro-hardness value fluctuated due to the complex thermal cycle. Tensile studies exhibit the increases of TS values from 3.7 to 4.1 m/min that provides a significant improvement in tensile properties. The tensile strength of Horizontal Direction (HD) tensile specimen are comparatively higher than the Vertical Direction (VD) tensile specimen, while elongation shows the value of opposite trend. The results have confirmed the formation of anisotropy properties. The samples of HD shows the value as follows as: Yield Strength (YS): 490 MPa, Ultimate Tensile Strength (UTS): 320 MPa & Elongation (EL): 32%) and the samples of VD shows the value as: YS: 460 MPa, UTS: 302 MPa & EL: 36%. The fracture surface as-deposit part exhibited the dimple fracture,

which is due to the formation of micro-void coalescence. Corrosion studies exhibit the poor corrosion resistance as-deposit samples, which is due to the segregation of Chromium (Cr) and Molybdenum (Mo) atoms and formation of Cr-depleted zone in the grain boundaries. The pin on disk results showed that the increase of wear rate from 0.79-2.69 mm³/Nm increase the Co-efficient of friction (COF), plastic deformation and applied load with the increase of TS values. Formation of adhesive wear is due to the formation of severe plastic deformation, occurrence of wear debris and applied load. Residual stress measurement shows the obvious differences in various heat input 316L stainless steel deposit samples. Tensile residual stress were formed in the top region of as-deposit part, which is associated with the significant increase in temperature distribution and higher cooling rates. In this study, the 316L stainless steel walls were fabricated using CMT-WAAM process under various heat input, the microstructure characteristics, mechanical, corrosion and wear properties and residual stress are analyzed. The fabricated CMT-WAAM 316L stainless steel thin walls show a higher mechanical properties than the 316L casting part and wrought parts. This study lays the foundation for the importance of stability of the heat input on the WAAM deposit parts.

Keywords: WAAM-CMT, 316L stainless steel, Heat input, Microstructure, Mechanical properties & Residual stresses