Fabrication of Stainless-Steel Alloy Using Wire Arc Additive Manufacturing

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ABSTRACT

Wire Arc Additive Manufacturing (WAAM) is an efficient process for producing large metallic parts with high deposition rates and less cost. This study investigates the influence of different shielding gas mixtures (SG-1: 100%Ar, SG-2: 95%Ar+5%CO_2, SG-3: 90%Ar+10%CO_2, and SG-4: 80%Ar+20%CO_2) on CMT-WAAM fabricated 316L stainless steel. The microstructure exhibited columnar dendritic grains with epitaxial growth. Microhardness values ranged from 185 HV–220 HV, the horizontal specimens showed higher tensile strength than vertical specimens and indicating anisotropy properties. The SG-3 produced superior mechanical properties and a finer grain structure, demonstrating its suitability for advanced engineering applications.

KEYWORDS: WAAM; stainless steel; shielding gas mixtures; mechanical characteristics

1. INTRODUCTION

Stainless steel 316L is widely used in automotive, shipbuilding, oil & gas, chemical and cryogenic industries because of its excellent corrosion resistance, and mechanical properties [1]. Wire Arc Additive Manufacturing (WAAM) enables cost-effective fabrication of large and complex components with high deposition rates and material utilization. Cold Metal Transfer (CMT)-based WAAM improves process stability by reducing heat input and less spatter [2]. Shielding gases play a vital role in determining arc stability, bead quality, penetration and geometrical accuracy. Argon (Ar) - Carbon-di-oxide (CO_2) mixtures are commonly employed because they provide better arc stability and wettability than pure gases [3]. CO_2 content significantly influences heat transfer, penetration, residual stress, and mechanical performance [4]. However, limited research has investigated the effect of different Ar–CO_2 shielding gas mixtures on CMT-WAAM. Therefore, this study examines the influence of various shielding gas combinations on the microstructure and mechanical properties of WAAM 316L and provide an improved part quality and engineering performance.

2. MATERIALS AND METHODS

Thick-walled 316L stainless steel were fabricated using a Fronius CMT-based WAAM system integrated with an ABB IRB 4600 robot arm and ER316L filler wire at 1.2 mm diameter. The samples (150 × 40 × 20 mm) were deposited on AISI 316L substrate using optimized process parameters. Total four samples were processed under varying shielding gas mixtures, while all other welding parameters, including a gas flow rate of 16 L/min and a contact tip-to-work distance of 10 mm were kept constant. The mechanical test specimens were extracted from the surface area through deposition direction. Tensile samples were taken from the horizontal and vertical directions of the thick-wall.

3. RESULTS

The optical micrographs of the 316L stainless steel revealed sound metallurgical bonding between the deposited layers and substrate, with visible fusion lines and defect-free layer deposition. The microstructure consisted predominantly of columnar γ-austenite grains with δ-ferrite distributed along

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the dendrite boundaries. Fine columnar dendrites formed through epitaxial growth at the layer interfaces due to directional solidification. The grain morphology gradually changed from fine columnar grains near the fusion line to coarse columnar grains in the middle region and back to finer columnar grains near the top of each deposited layer as shown in Figure 1. The average hardness of the various deposit was 186 HV, 214 HV, 220 HV and 210 HV. The micro-hardness increases in bottom region which is due to higher cooling rates and rapid solidification. The variations in hardness of the deposit wall are attributed to the columnar and coarse structure [5]. Moreover, the hardness was higher in SG-3 due to variation in cooling rates and thermal cycles. The tensile properties exhibit the specimens in horizontal directions UTS: 454.82 MPa, YS: 305.24 MPa & EL: 38.4% were higher than the vertical directions UTS: 446.24 MPa, YS: 298.45 MPa & EL: 40.3% and confirm the formation of anisotropic properties. The mechanical properties of as-deposit 316L stainless steel thick-wall as shown in Table 1.

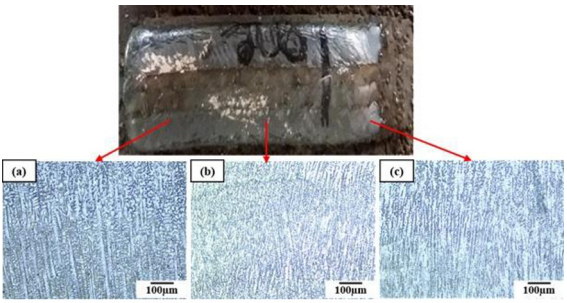

Figure 1. Microstructure of 316L stainless steel thick-wall (a) top, (b) middle and (c) bottom region

Table 1. Mechanical properties of CMT-WAAM 316L thick-wall deposit

Designation	UTS (MPa)	YS (MPa)	Hardness (HV)
SG-1	453.4	319.4	186
SG-2	459.3	297.8	214
SG-3	460.1	325.1	220
SG-4	446.4	298.5	210

4. CONCLUSION

The effect of various shielding gas mixtures on WAAM 316L stainless steel parts was successfully explored. Microstructure revealed large number of γ columnar grains with epitaxial growth of dendrites. Micro-hardness value shows non-uniform distribution from bottom to top region along the deposition direction. Tensile results exhibit the variations in UTS and YS values between the horizontal and vertical samples due to variation in microstructural inhomogeneity and thermal gradients.

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