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Fatigue Properties of Inconel 625 Alloy Parts Manufactured by Wire Arc Additive Manufacturing Method

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1. Introduction

Additive manufacturing, also known as 3D printing, is a new computer-controlled method used for the fabrication of the metallic, polymeric and ceramic parts. In this process, the desired part is manufactured by layer-upon-layer depositing of material. In order to make metallic parts, various heat sources such as laser, electron beam, and electric arc are used to melt materials in the powder and wire forms.

In recent years, gas metal arc welding (GMAW) is used as a 3D printing process due to its high deposition rate, and protection of weld metal by an inert gas. This process is known as wire-arc additive manufacturing (WAAM) method. Amongst different alloys, Inconel 625 is a Ni-based alloy used for high-temperature applications in the aerospace and military industries. Previously, the effect of heat treatment on the microstructure and mechanical properties of the Inconel 625 alloy walls manufactured by WAAM process was evaluated. Continuing that research, this study deals with the fatigue and high-temperature tensile properties of the Inconel 625 alloy.

2. Materials and methods

The Ni-Cr-Mo3 welding wire (ESAB) with 0.8 mm in diameter was used for fabrication of Inconel 625 alloy walls on the surface of 304L stainless steel substrate. Deposition of the melt was conducted using a MIG welding apparatus. The welding current of 100A, welding speed of 28 cm/min, and wire feeding rate of 9.5 m/min were selected as the main process parameters. Three different walls with 80 mm in height, 7 mm in thickness, and 400 mm in length were fabricated by 32 overlay welding passes. Then, structure, microstructure, mechanical properties and fatigue strength of the walls were evaluated in both welding and building directions.

3. Results and discussion

Fig. 1(a) and (b) show SEM macrographs of the two first layers deposited on the substrate, and microstructure of the interface between the first layer and the substrate, respectively. The deposited metal is free from weld defects such as cracks and porosity. Higher magnification micrographs of the wall in Figs. 1(c) and 1(d) show the formation of dendritic microstructure along with some inter-dendritic phases. It was illustrated that the dendrites are Ni-based solid-solution phase, while segregation of alloying elements during solidification led to the establishment of delta, Laves and NbC phases in between the dendrites.

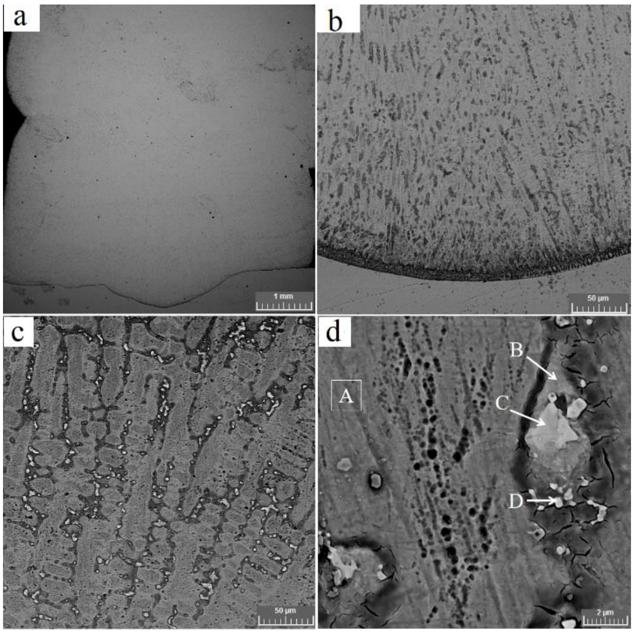

Fig. 1 SEM micrographs showing (a): the two first layers and the substrate, (b): micrograph of the interface between the first layer and the substrate, (c) and (d): Higher magnification micrographs of the wall showing dendritic microstructure and inter dendritic phases

Variation of hardness of the wall in both welding and building directions is shown in Fig. 2.

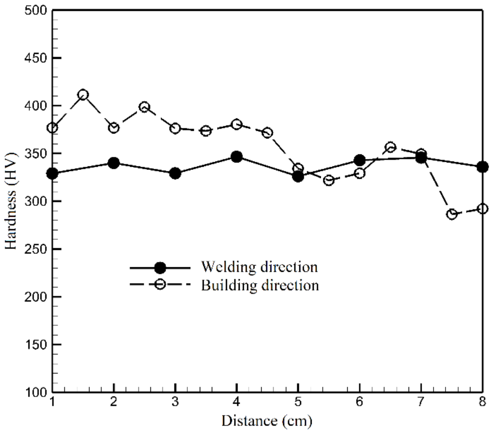

Fig. 2 variations of hardness of the wall in both welding and building directions

The hardness is almost uniform along the welding direction due to the development of the uniform microstructure. In contrast, the hardness decreased with increasing the wall height due to increase in the grain size,

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and also segregation of alloying elements into the inter-dendritic region.

Stress-strain curves of the samples extracted in welding and building directions are shown in Fig. 3. It is observed that yield and tensile strengths in the welding direction are respectively 6.7 and 8.6% higher than the building direction. With increasing the test temperature to 700 °C, the yield and tensile strengths decreased to 275 and 521 MPa, separately.

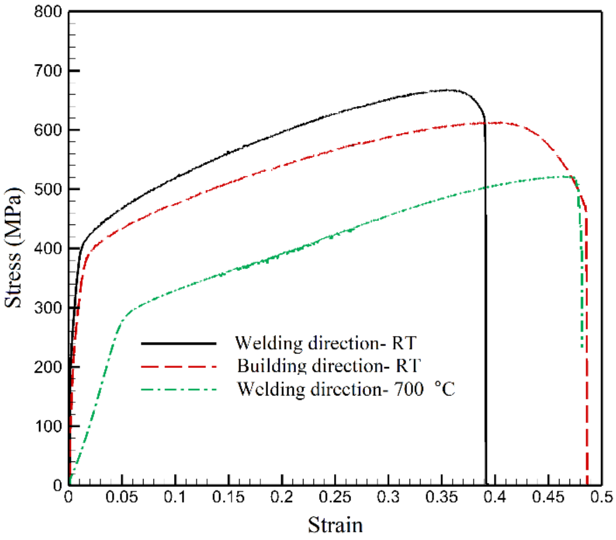

Fig. 3 Stress-strain curves of the samples extracted from welding and building directions at room temperature (RT) and 700 °C.

The S-N curves of the alloy tested in the welding and building directions are illustrated in Fig. 4. In the selected range of stress amplitude, both directions showed similar fatigue properties at high stresses. However, the number of cycles to failure was higher for the welding direction than the building direction at low stress amplitudes. Fractography of samples confirmed that all fatigue cracks initiated from the samples' surface.

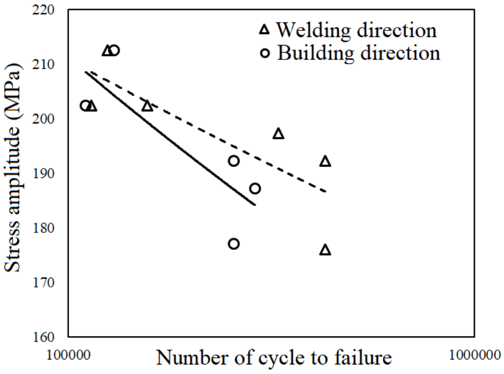

Fig. 4 Stress-strain curves of the samples tested in both welding and building directions

4. Conclusion

The microstructure of the Inconel 625 alloy wall manufactured by WAAM method contained Ni-based solid solution dendrites along with Laves, delta and NbC inter-dendritic phases. Mechanical properties of the manufactured wall were slightly different in the welding and building directions. Moreover, high-cycle fatigue strength of the alloy in the welding direction was better than the building direction, especially at low stress amplitudes. Fractography of the samples illustrated that all fatigue cracks initiated from the surface. This confirmed the high quality of the walls manufactured by this method.