coatings

Editorial

Fabrication of Multi-Material Components by Wire Arc Additive Manufacturing

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Citation: Zhang, C.; Yu, H.; Sun, D.; Liu, W. Fabrication of Multi-Material Components by Wire Arc Additive Manufacturing. *Coatings* **2022**, *12*, 1683. https://doi.org/10.3390/coatings12111683

Received: 2 November 2022
Accepted: 4 November 2022
Published: 5 November 2022

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Complex and harsh service environments in the aerospace industry, power industry, automotive industry, injection molding industry and medical industry require components to have spatially tailored properties [1]. For example, a number of aerospace components, including rocket nozzles, are applied in extreme environments. The heat flow and working temperature are very different in the upper and lower regions of the rocket nozzle, and thus, the preferred material properties may vary for each region.

The requirement of spatially tailored properties for one component has led to an increasing demand to apply different materials to different areas of the same part [1]. Multi-material additive manufacturing technologies are helping this requirement become a reality [1]. Out of all the additive manufacturing technologies [2], wire arc additive manufacturing (WAAM) technology stands out due to its ability to produce large metallic structures with high deposition rates and low costs [3]. The WAAM technique, which employs an electric arc as the heat source and has a building capacity that can be expanded to tens of meters, has the ability to fabricate fully dense and large dimensional parts [4]. In general, the cost of metal wire is only ten percent of the cost for the same weight of metal powder [5]. Moreover, WAAM machines can be easily adapted from arc welding machines, which are usually much cheaper than other types of AM machines, such as laser powder bed fusion machines and laser directed-energy deposition machines [3].

Many researchers have used WAAM to build multi-material metallic components. Various bimetal components, such as steel–bronze, steel–FeAl, steel–nickel, Al–5Mg alloy–AA6061 alloy, Inconel 740H superalloy–P91 steel, steel–copper, and mild steel–stainless steel, have been successfully fabricated via WAAM [6–12].

For example, in 2013, Liu et al. [7] utilized the WAAM technique to fabricate mild steel–silicon bronze bimetal parts based on the single-pass multi-layer model. By using suitable deposition parameters, metallurgical bonding with a non-defect interface occurred with an intermixing zone consisting of the mixture of α-Fe and ε-Cu. Liu et al. found that Cu was not observed on the steel side, but Fe entered the bronze region in the shape of particles and big chunks. Meanwhile, it was found that the silicon element was concentrated in the interfacial region and on the bronze side where Fe existed. The steel–bronze interface showed good adhesion without cracks or pores. The tensile strength of the bimetal samples reached 305 MPa. The fracture location was near the middle of the bronze side, indicating that a strong bonding between steel and bronze was obtained [7].

In 2016, a functionally gradient Fe–Al thin wall structure with an aluminum composition gradient from 0% to over 50% was fabricated using a WAAM system by researchers from the University of Wollongong [8]. The researchers successfully demonstrated that the designed chemical composition in the buildup wall can be accurately obtained by adjusting the ratio of the wire feed from the Fe and Al wires. The WAAM wall contains a continuous composition gradient in the vertical direction from 100% steel substrate to over 50% Al content. In the transverse direction, the chemical composition is generally homogeneous, but is less consistent in both the dilution-affected region at the root of the wall and in the top layers of the upper surface. Spatially tailored materials and properties in one part were demonstrated in this study, where the hardness values from the wall's bottom to upper surface increased from around 150 Hv to 650 Hv [8].

In 2020, the WAAM process was used to fabricate a steel–nickel bimetal structural component [12]. Interestingly, it was found that the average tensile strength of the WAAM steel–nickel bimetal structure was 634 MPa, which significantly exceeded that of feedstock materials (steel, 537 MPa; nickel, 455 MPa). Due to the use of an interweaving deposition strategy, the as-fabricated sample exhibited hierarchically structural heterogeneity. The improved mechanical response during the tensile test was attributed to the interlocking microstructure, which forms a strong bond at the interface, and to the solid solutions that were strengthened from the intermixing of the Fe and Ni in the interfacial region.

In 2021, to achieve better corrosion properties, an Al–5Mg alloy (AA5083) block with good corrosion resistance was WAAMed over an AA6061 substrate, whose corrosion resistance is not as good as that of the Al–5Mg alloy [6].

In 2022, to guide the manufacturing of a dissimilar alloy applied in advanced ultra-supercritical fossil fuel power plants, bimetallic structures of Inconel 740H superalloy and P91 steel were fabricated using WAAM [9]. It was found that the microhardness of the gradient zone was the least hard in comparison with the P91 and 740H regions. Intergranular cracks were observed in the gradient zone. The causes for the formation of cracks in the gradient region were the sudden change in the volumetric coefficient of thermal expansion due to the formation of MC carbides, together with the development of local strains that generated the thermal residual stresses. Therefore, Sridar et al. [9] suggested that changing the deposition sequence and introducing gradient layers with a mixed chemical composition of P91 and 740H will be favorable for obtaining defect-free builds.

Very recently, it was reported that the fabrication of a steel and copper bimetallic structure was realized by cold metal transfer-based wire arc additive manufacturing (CMT-WAAM), which is better than other contemporary WAAM techniques due to its low heat input and production of less spatter at higher deposition rates [11]. Alfredo Suárez et al. [10] fabricated mild steel–stainless steel bimetallic structures by using WAAM. Two different deposition strategies, the superimposed strategy and overlapping strategy, were used. There was not a lack of fusion, pores, and microcracks in the built samples. It was found that the wall built by the overlapping strategy had a higher UTS and YS than the one made using the sandwich strategy, and it was less ductile. In terms of hardness, the samples had similar hardness values in both strategies, with values around 380 HV in the ER70 mild steel region and 190 HV in the SS316L stainless steel region [10].

In summary, WAAM has the advantages of fabricating large multi-material metallic structures with high deposition rates and low costs compared with other AM technologies. It has been demonstrated that many different types of bimetal components can be successfully fabricated through WAAM, including steel–bronze, steel–FeAl, steel–nickel, Al–5Mg alloy–AA6061 alloy, Inconel 740H superalloy–P91 steel, steel–copper, and mild steel–stainless steel. The deposition strategy is very important for spatially tailoring properties and for achieving excellent interfacial bonding. To establish other future industry applications, large-size multi-material WAAM, more material combinations, deformation and defect control, numerical modeling of multi-material WAAM, and advanced deposition strategies should be further investigated.

Author Contributions: Writing—original draft, review and editing, and funding acquisition, C.Z.; review and editing and funding acquisition, H.Y. and D.S.; review and editing, W.L. All authors have read and agreed to the published version of the manuscript.

Funding: The authors are grateful for the finance support from the Innovation Group Project of Southern Marine Science and Engineering Guangdong Laboratory (Zhuhai) (No. 311021013). This work was also supported by the funding of the State Key Laboratory of Long-Life High Temperature Materials (DTCC28EE190933).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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