


# Chapter 11

## Quantitative Analysis of 3D-Printed Bimetallic Component: Wire-Arc Additive Manufacturing and Metal Forming

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### **ABSTRACT**

*The book chapter reports on hybrid manufacturing (wire-arc additive manufacturing and metal forming) of 3D-printed bimetallic structure parts. After 3D printing, the metal flow behaviour of the printed material was studied using a Gleeble 3500 thermal-mechanical simulator. The test conditions were temperature range 850-1000°C and strain rate of 1s<sup>-1</sup> and 10s<sup>-1</sup> to strain of 0.6. The results show that the initial microstructure of the bimetallic structure had excellent bonding properties. The flow stress-strain curves increased with a decrease in deformation temperature and vice versa at a given strain rate. The study developed a constitutive equation that predicts the metal flow behaviour of the material studied. From the analysis, the material constants were a stress exponent of 4.76 and an activation energy of 213.7 kJmol<sup>-1</sup>. The study indicates that this method (hybrid manufacturing) is possible in the industrial production process.*

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## **INTRODUCTION**

Bimetallic materials offer better performance and numerous advantages than a single material (Sridar, Klecka and Xiong, 2022). For example, heat-resistant 9-12 wt% Cr steel with superior creep strength and excellent corrosion resistance at high temperatures is widely applicable in aerospace, automotive, and fossil power plant applications (Ennis and Czyska-Filemonowicz, 2003; Czyska-filemonowicz, Zielińska-lipiec and Ennis, 2006). However, this steel lacks suitability for structure components operating at temperatures higher than 700°C for advanced boiler systems. To achieve high thermal efficiency, hence reducing CO<sub>2</sub> emissions, an increase in operating conditions (temperature of up to 700°C and 35 MPa pressure) for modern power plants is paramount. Therefore, joining different steels by welding for the boiler piping system will achieve higher power plant performance. Joining dissimilar materials will take advantage of individual material properties. However, DWJ has associated challenges such as porosity, inclusion and residual stress, thus requiring urgent attention. These structures can be joined using additive manufacturing AM (3D printed) parts to avoid metallurgical challenges associated with dissimilar weld joints.

Additive Manufacturing (AM) has gained popularity as a potential method for reducing production time, cost and material wastage (Balashanmugam, 2021; Krishna, Manjaiah and Mohan, 2021; Srivastava and Rathee, 2022). This method builds a component from computer-readable 3D model data through layer-by-layer deposition. AM saves 50% of production costs compared to conventional manufacturing (Ivanova, Williams and Campbell, 2013; Gibson, Rosen and Stucker, 2015). AM has wide applications in aerospace, construction, manufacturing, automotive, biomedical, oil and gas industries (Ford, 2016; Najmon, Raesi and Tovar, 2019; Yusuf, Cutler and Gao, 2019; Behera, 2020). The potential of AM as an alternative manufacturing process is growing steadily among the industry players for different applications, hence shaping the future of the manufacturing industry (Gornet, 2017). AM improves sustainability in manufacturing by enabling resource-efficient production and closed-loop material flows, thus improving production through product and process redesign (Ford, 2016). The wide application of AM provides a platform for manufacturing complex geometry components (Mhapsekar, McConaha and Anand, 2018).

AM techniques are mainly classified into powder bed fusion (PBF), sheet lamination, and directed energy deposition (DED) (Friel, 2015; Dinovitzer *et al.*, 2019). Figure 1 summarises the main AM processes and corresponding heat sources. For example, Wire-arc additive manufacturing WAAM is a DED technique employed as an AM process (Vora *et al.*, 2022). This technique uses a wire feedstock as an energy source. In DED, a concentrated energy source melts metallic feedstock and is deposited onto a substrate to print the component (Ahn, 2021). DED is renowned for its rapid deposition speeds, versatility in materials, and ability to change and repair existing structures (Ahn, 2021). This technique is extensively reported in the literature using wire or powder and heat source such as an electron beam (Sames *et al.*, 2016; Negi *et al.*, 2020; Singh, Kapil and Das, 2020; Svetlizky *et al.*, 2021), plasma arc (Alberti, Bueno and D'Oliveira, 2016; Ivántabernero *et al.*, 2018; Dass and Moridi, 2019; Artaza *et al.*, 2020), laser (Ding *et al.*, 2015; Rumman *et al.*, 2019; Lorenz *et al.*, 2020; Yoo, Lee and Kim, 2023), and electric arc (Sames *et al.*, 2016; Li *et al.*, 2017; Singh, Kapil and Das, 2020; Rosli *et al.*, 2021; Svetlizky *et al.*, 2021). WAAM process uses different heat sources such as gas metal arc welding (GMAW), tungsten arc welding (GTAW), plasma arc welding (PAW) and cold metal transfer (CMT) (Marinelli *et al.*, 2019; Ríos, Colegrove and Williams, 2019). The WAAM basic principle is, as in Figure 2.

The main challenge for all wire-feed AM processes is defect formation, such as residual stresses and distortion generated during the AM process. These phenomena occur due to excessive energy input, high

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