3D printing of bimetallic materials: characteristics and performance

Impression 3d des matériaux bimétalliques : caractéristiques et performances

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ABSTRACT. Bimetals 3D printing is a state-of-the-art technology, in which process parameters and heat treatments play key roles on the mechanical, thermal and structural properties of components. Our research goal is to investigate the potential of 3D printing bimetallic materials for different component parts according to each need. The procedures used in evaluating the results are based on the laser power, scanning speed, layer thickness, and materials of both additive manufacturing and heat treatments. The materials which were studied encompass Inconel 718, GH4169, 316L chrome steel, Inconel 625 and Ti6Al4V-W7Ni3Fe. It also shows the scanning speed has a large effect on the mechanical properties of Inconel 718, the laser power value when the porosity of GH4169 is at the minimum. Suitable functional materials produced by WAAM and wire-arc additive manufacturing assembly with robust, defect-free interface Indeed one of the other key observations from this study was that thermal conductivity and mechanical properties change significantly with the processing of the material, this then also strengthens the rationale for optimizing manufacturing parameters. This research highlights the potential of researching on materials with gradient properties and numerical simulation in future development of additive manufacturing of bimetallic and related alloys.

RÉSUMÉ. L'impression 3D de bi métaux est une technologie de pointe, dans laquelle les paramètres du processus et les traitements thermiques jouent un rôle clé sur les propriétés mécaniques, thermiques et structurelles des composants. L'objectif de notre recherche est d'étudier le potentiel de l'impression 3D de matériaux bimétalliques pour différents composants en fonction de chaque besoin. Les procédures utilisées pour évaluer les résultats sont basées sur la puissance du laser, la vitesse de balayage, l'épaisseur de la couche et les matériaux de la fabrication additive et des traitements thermiques. Les matériaux étudiés sont l'Inconel 718, le GH4169, l'acier chromé 316L, l'Inconel 625 et le Ti6Al4V-W7Ni3Fe. L'étude montre également que la vitesse de balayage a un effet important sur les propriétés mécaniques de l'Inconel 718, la valeur de la puissance du laser lorsque la porosité du GH4169 est au minimum. En effet, l'une des autres observations clés de cette étude est que la conductivité thermique et les propriétés mécaniques changent de manière significative avec le traitement du matériau, ce qui renforce la justification de l'optimisation des paramètres de fabrication. Cette étude met en évidence le potentiel de la recherche sur les matériaux à gradient de propriétés et de la simulation numérique dans le développement futur de la fabrication additive d'alliages bimétalliques et apparentés.

KEYWORDS. Additive manufacturing, materials, bimetallic, characteristics.
MOTS-CLÉS. Fabrication additive, matériaux, bimétallique, caractéristiques.

1. Introduction

3D printing of bimetallic materials opens up new possibilities in additive manufacturing [LKA 22] [LKA 24]. By combining two metals with different properties, this technology enables components with properties optimized for specific needs. Precise control of manufacturing parameters and heat treatment is necessary to influence the mechanical, thermal and structural properties of parts, resulting in improved performance and reliability. For example, a scanning speed of 1300 mm/s optimizes the mechanical properties of Inconel 718 alloys [WAN 21]. GH4169 samples show that 600 W is the optimal laser power to minimize porosity and maximize mechanical strength [SHA 19]. Functional materials of 316L stainless steel produced by WAAM and Inconel 625 show that straight interfaces offer better properties than smooth interfaces [ROD 22] [AMI 24]. Gradient gluing in the production of wire arch inserts shows a strong and flawless bond between different materials. Selective laser melting (SLM) requires precise optimization of parameters to achieve optimal microstructures and mechanical properties. The critical energy density [LAR 20] of 44.4 J/mm^3 affects the porosity and thermal conductivity of 316L stainless steel [SIM 20]. Bimetallic Ti6Al4V-W7Ni3Fe [ZHA 23] structures fabricated by directed energy deposition show excellent thermal and mechanical properties.

2. Materials and methods

The properties of bimetallic materials vary depending on the additive manufacturing process and heat treatment parameters. Below is a diagram outlining the various additive manufacturing methods for bimetallic parts, highlighting the alloys used and the most common techniques.

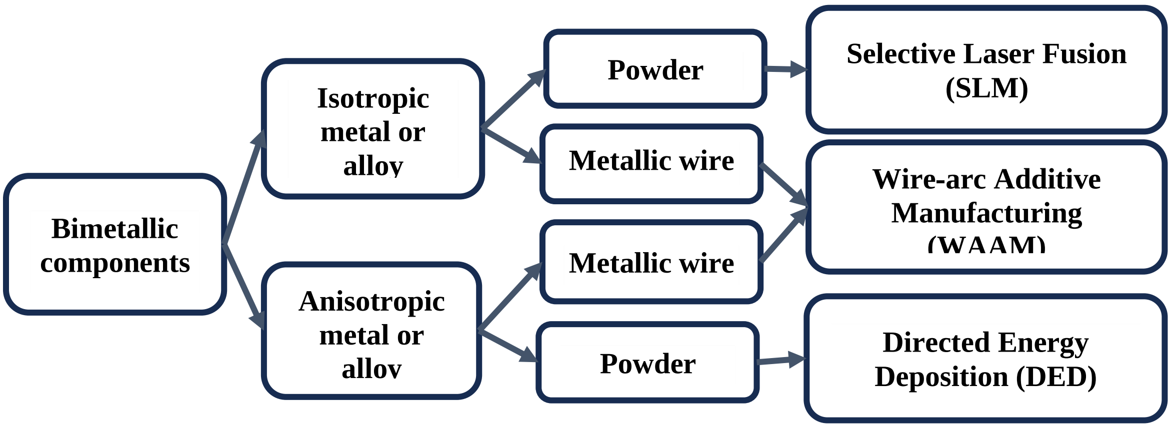

Figure 1. *Alloy types and current technologies for bimetallic parts*

2.1. Characteristics of bimetallic materials

The materials used were metal powders and threads of various compositions, including alloys often used in industrial applications. The table below lists the most common bimetals, their composition and mechanical properties.

Bimetallic materials	Composition	Density (g/cm^3)	Tensile strength (MPa)	Yield strength (MPa)	Modulus of elasticity (GPa)	Hardness (HV/ HRC)
W7Ni3Fe	90% W, 7% Ni, 3% Fe	17.0 to 18.5	700 to 1000	700 to 1000	360 to 400	250 to 350
Ti6Al4V	90% Ti, 6% Al, 4% V	4.43	895 to 965	825	110	340
Inconel 718	Ni, Cr,Fe, Nb, Mb et Ti	8.19	1034 to 1276	689 to 1034	200	30 to 40
316L stainless steel	Fer, Cr17%, Ni 12%, Mb 3%	8.00	485	170	200	171 to 178
Inconel 625	Ni58%,Cr22%, Mb9%, Nb4%, Fe5%	8.44	760	345	200	194 to 257
Mild steel	Iron and Carbon	7.85	300 to 600	200 to 400	200	159 to 170
GH4169	Ni55%,Cr20%, Nb5%,Mb3% , Ti 1.15%	8.19	1034 to 1276	689 to 1034	200	30 to 40

Table 1. *The compositions and mechanical properties of the commonly used bimetals.*

2.2. Process parameters for additive manufacturing of bimetallic materials

We will investigate the effects of additive manufacturing [ELJ 23] [AIT 23] process parameters for bimetallic materials, including laser power, scanning speed, layer thickness and powder and wire composition, on microstructure and mechanical properties. The histogram below shows the average values of these parameters for each bimetallic material.

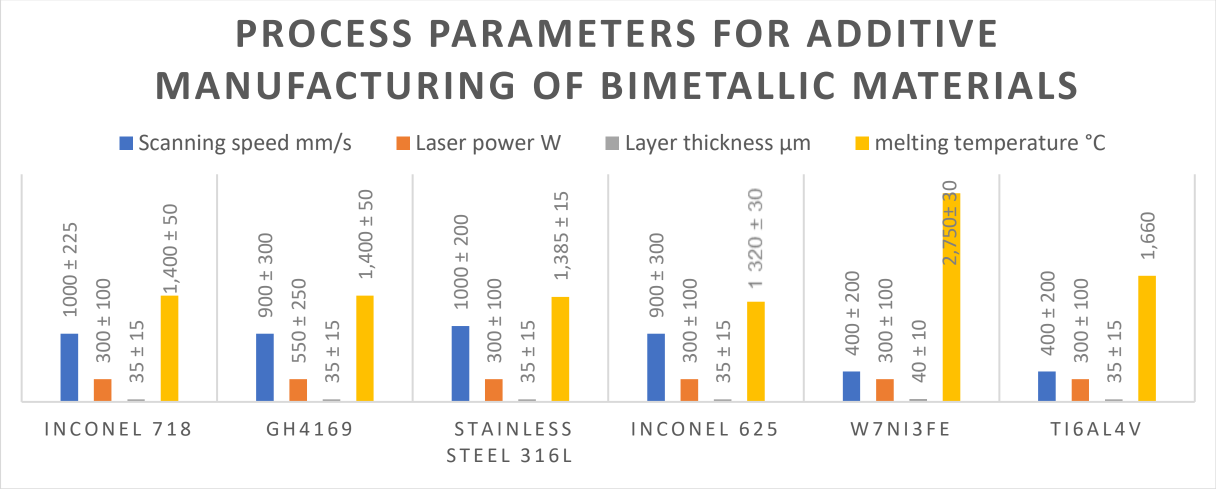

Figure 2. *Process parameters for additive manufacturing of bimetallic materials*

3. Results and discussion

Inconel 718 alloys were produced by selective laser melting at different scanning speeds [WAN 21]. Increasing the scanning speed from 1000 to 1450 mm/s increased the melt depth/width ratio and favored the transition from cellular dendritic structures to columnar dendrites, reducing dendrite spacing and columnar grain size. Tensile properties showed a non-monotonic transition, with a maximum tensile strength of 1014 MPa and an elongation of 19.04% at 1300 mm/s [WAN 21]. Porosity and mechanical properties of GH4169 samples, fabricated with varying laser powers [2], were analyzed. Porosity first decreased, then increased slightly with increasing laser power from 300 to 800 W, reaching a minimum of 0.28%. At 600 W, the samples showed an average yield strength of 587 MPa, an ultimate tensile strength of 903 MPa and an elongation at break of 13.6%, with a fatigue limit of 173.7 MPa [SHA 19]. An FGM functional material in 316L stainless steel and Inconel 625 was fabricated by WAAM, using direct and smooth interfaces [ROD 22]. Direct interfaces showed superior mechanical properties with higher strengths and elongations. Secondary phases and lower residual stresses were observed in the direct interface FGM, improving overall performance. Carbon steel, 316L stainless steel and Inconel 625 were joined by wire-arc additive manufacturing [AMI 24]. The materials showed a strong, flawless metallurgical bond. Microstructure and mechanical properties were analyzed [RAN 22], revealing high hardness and tensile strength values. Samples failed on the carbon steel side, indicating high interface strength. The thermal conductivity of 316L stainless steel manufactured by SLM varies according to processing conditions and porosity. A critical energy density of 44.4 J/mm³ has been identified [LAR 20], above which porosity increases and thermal conductivity decreases [SIM 20]. The amorphous regions identified also reduce thermal conductivity at faster scanning speeds. Bimetallic Ti6Al4V and W7Ni3Fe structures fabricated by DED exhibit thermal conductivities three times higher than those of Ti6Al4V at 300°C [ZHA 23]. Fracture strain and hardness vary according to element diffusion and intermetallic phase formation. Interfaces are free of cracks and elemental gradients. WAAM is an additive manufacturing process using arc welding, offering advantages in terms of cost and deposition rate. Mild steel, austenitic stainless steel and a bimetallic sample were successfully fabricated. The interfaces are free of weld defects, with a variation in hardness due to chromium migration. The samples show isotropy in terms of toughness and mechanical properties above standard values.

The results show that additive manufacturing parameters have a significant influence on the properties of alloys and composites. In the case of Inconel 718, an increased scanning speed improves the dendritic structure and mechanical properties, achieving a tensile strength of 1014 MPa [WAN 21]. GH4169, treated at 600 W [SHA 19], has a minimum porosity of 0.28% and excellent mechanical strength. Functional materials in 316L and Inconel 625 manufactured by WAAM show that direct interfaces offer better mechanical properties [ROD 22] [AMI 24]. Wire-arc additive manufacturing reveals robust, defect-free joints. Thermal conductivity [SIM 20] of 316L stainless steel varies with energy density and porosity, with a critical density of 44.4 J/mm³. Bimetallic Ti6Al4V-W7Ni3Fe structures fabricated by DED show a thermal conductivity three times higher than that of Ti6Al4V [ZHA 23]. Finally, gradient joining with wire-arc additive manufacturing shows a strong bond between the different materials, with mechanical properties suitable for advanced industrial applications. A promising line of research would be the optimization of parameters to produce materials with gradient properties, including systematic studies, composite development and numerical simulations, is identified as a promising avenue for the future of additive materials manufacturing.

4. Conclusion

The development of bimetallic 3D printing emphasizes the importance of process parameters and heat treatment in defining component properties. Research on metal alloys highlights the important impact of optimizing these parameters. The direct interfaces of the functional materials show excellent performance, while the gradient bond provides a strong bond between the materials. Parameter optimization, including system studies, component development and numerical simulations, opens promising perspectives for the future of additive manufacturing, focusing on the manufacturing of advanced bimetallic components.

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