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Bi-metal Structures Fabricated by Extrusion-based Sintering-assisted Additive Manufacturing

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INTRODUCTION

Combining dissimilar metal materials for hybrid structure has gained increasing interest to fill the demand for a variety of industrial applications. The advantages of bi-metal structure include better structural performance, higher mechanical strength, and higher economic efficiency compared with single metal alloy parts. The successful fabrication of such bi-metal structures significantly expands the material selection for specific industrial applications.

EXPERIMENTAL SETUP

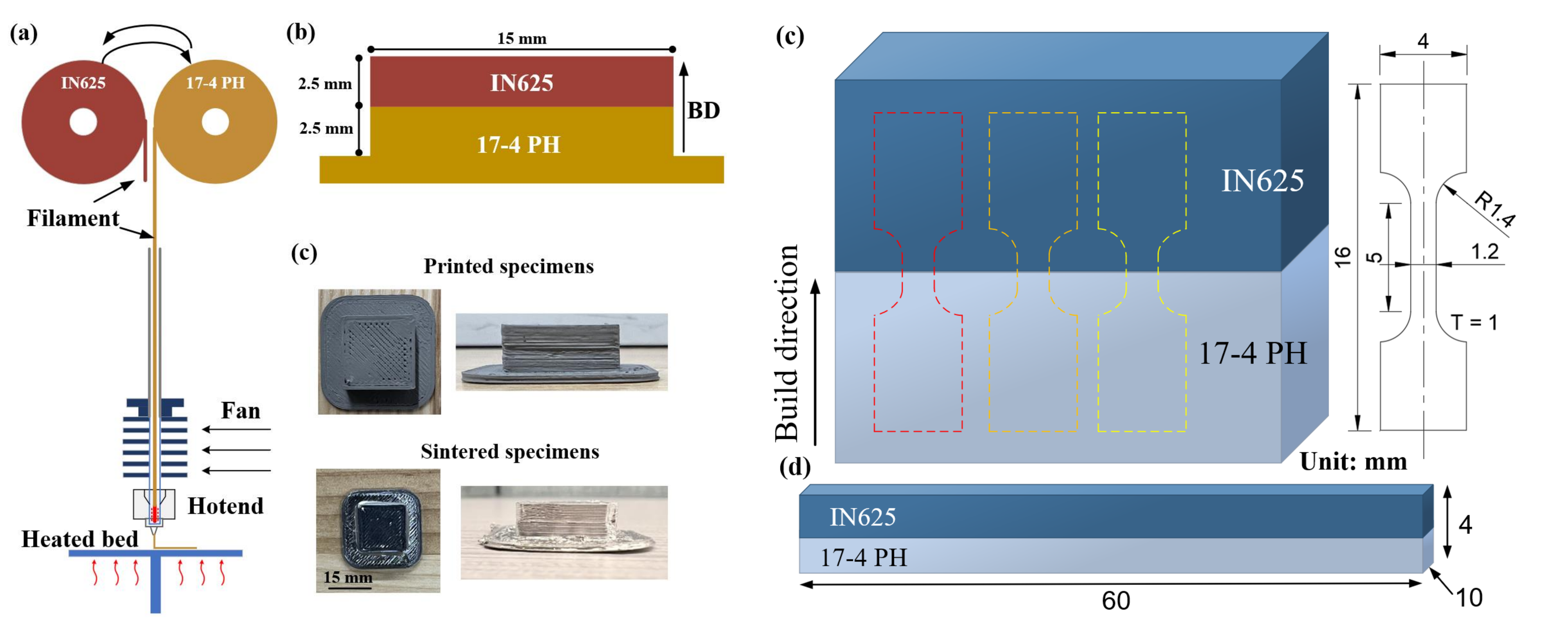

Fig. 1 Experimental setup for (a)-(c): bi-metal fabrication process through material extrusion and sintering and (d)-(e): specimen design for tensile and bending tests, respectively.

INTERFACIAL MICROSTRUCTURE

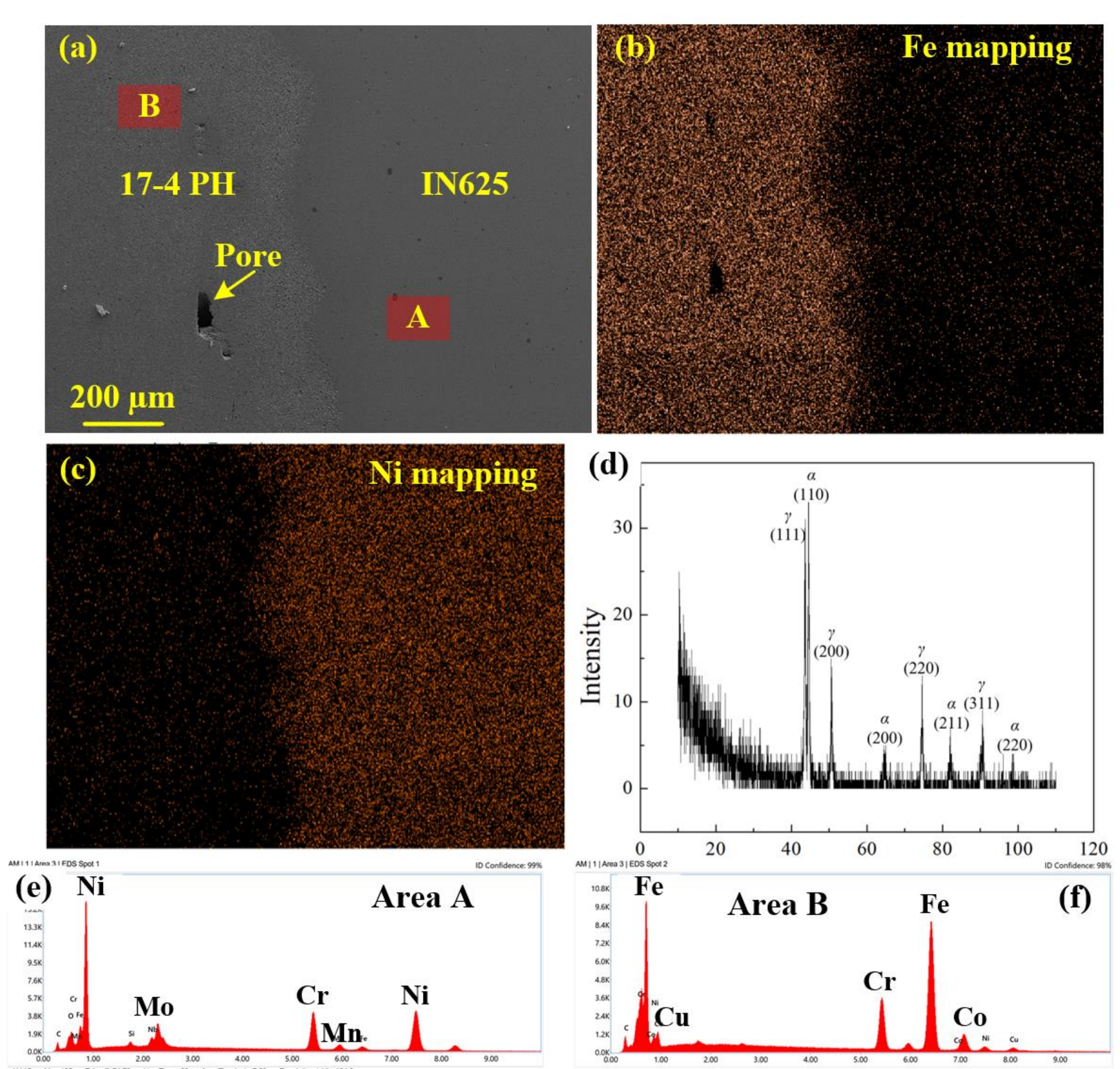

Fig. 2 SEM and XRD results of the 17-4 PH and IN625 bi-metal interface. (a) Polished surface showing pores and interface; (b) Fe mapping by EDS; (c) Ni mapping by EDS; (d) XRD pattern; EDS point scanning results of (e) points A and (f) point B in (a).

ABSTRACT: The manufacturing of bi-metal structure has received much interest because it provides compensated properties for a single metal alloy, meeting the harsh requirements for components used in key industries like aerospace, defense, energy, etc. Additive manufacturing (AM) has been extensively applied in building multi-material structures because of its ability to vary material type and composition in a layer-by-layer mode. However, fusion-based AM technologies usually induce interfacial cracks and delamination resulted from the large mismatch of coefficient of thermal expansion (CTE) between dissimilar materials, while the solid-state AM methods generate a large number of pores at the interface, requiring post-fabrication heat treatment. In this study, we aim to build high-quality 17-4 PH stainless steel and nickel alloy bi-metal structure with material extrusion AM method, followed by debinding and sintering processes. The microstructure and mechanical properties of the bi-metal structure were thoroughly investigated. It was revealed that small pores were distributed in the whole part, and no brittle intermetallic phase but slightly larger pores were formed at the interface. The material transition zone was relatively small in thickness, exhibiting low bonding strength and low hardness but a ductile deformation behavior. The completion of this study provides a pioneering analysis of bi-metal structures built by extrusion-based sintering-assisted AM, and shows a great promise for further adoption of this technology in a variety of industrial applications.

INTERFACIAL MICROSTRUCTURE

- The SEM image in Fig. 2(a) exhibits the polished surface of the 17-4 PH and IN625 bi-metal structure and a winding interface.
- Large pores can be observed at the 17-4 PH region due to the lack of sintering, whereas smaller pores are found at IN625 region.
- The EDS mapping indicates a low level of atomic diffusion of Fe into the nickel matrix.
- The XRD spectrum in Fig. 4(d) indicates that no additional phases are formed other than the Ferrite (*α, BCC*) from 17-4 PH and nickel matrix (*γ, FCC*) from IN625.
- The grain morphology depicted below also shows the porosity difference of 17-4 PH and IN625 and indicates an interfacial thickness at around 10 µm.

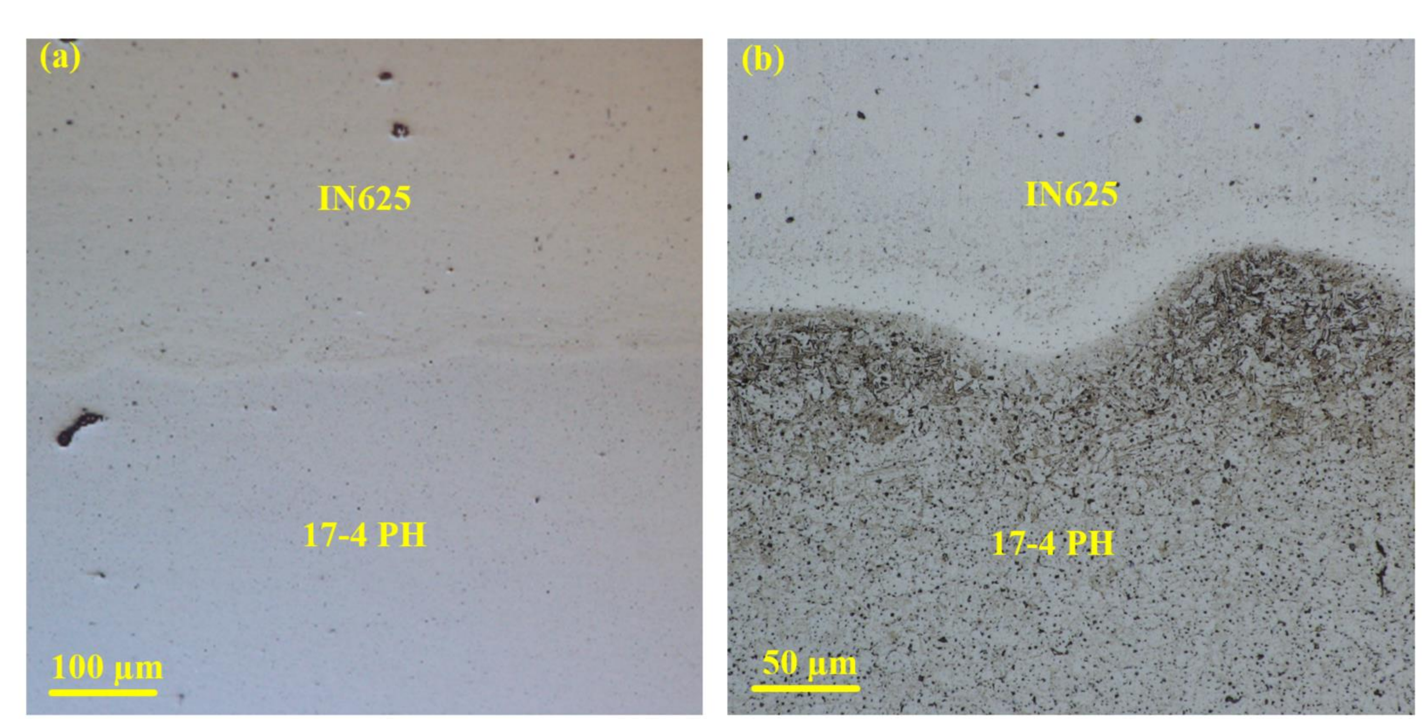

Fig. 3 Microstructure of the 17-4 PH and IN625 bi-metal interface showing (a) pore distribution and (b) grain morphology.

MECHANICAL PERFORMANCE

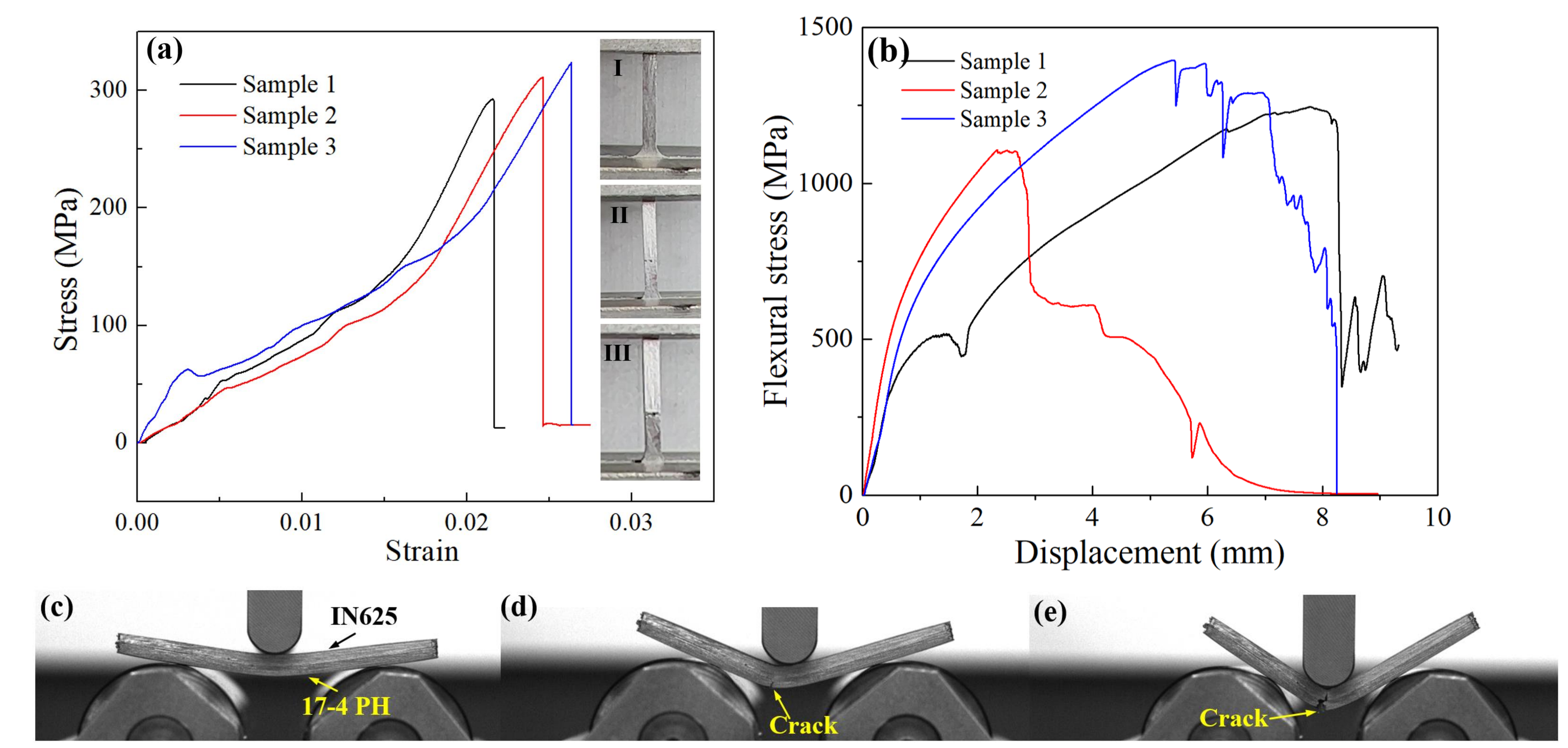

Fig. 4 Mechanical performance of 17-4 PH and IN625 bi-metal specimen through (a) Tensile tests and (b)–(e) bending tests.

- Three tensile specimens exhibit a gradual increase in stress at the beginning, which is followed by an abrupt fractural failure at the material interface. The average UTS is around 300MPa.
- Unlike the tensile fractural behavior, specimens under bending deformation exhibit ductile behavior and the highest bending strength is higher than 1000 MPa.
- Cracks are formed and propagates at the bottom surface of the bending specimen, suggesting no delamination occurs during the test.
- The hardness tests indicate a reduction of hardness at the interface, and determine the thickness of transition zone at 20 µm.

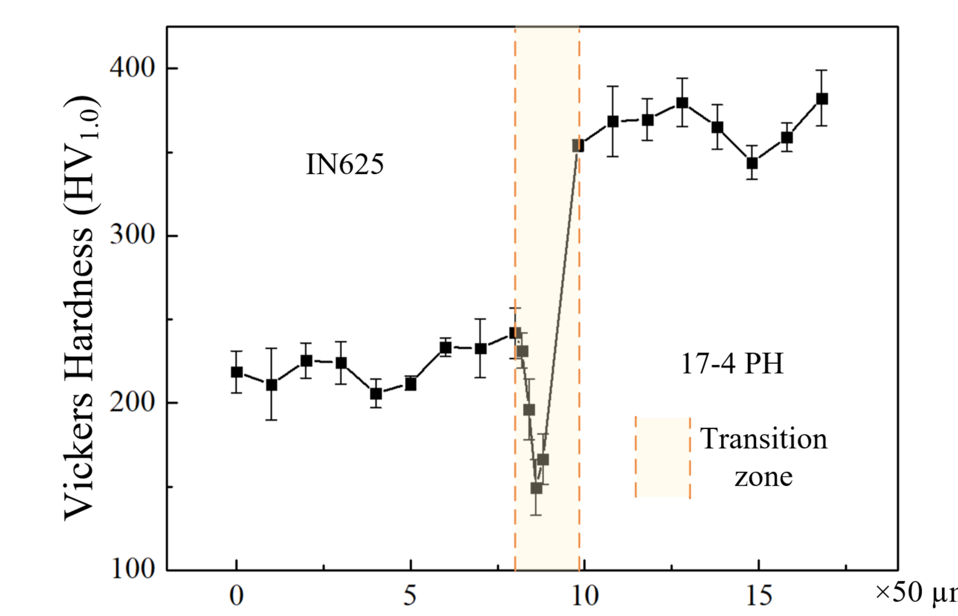

Fig. 5 Vickers hardness of the 17-4 PH and IN625 bi-metal structure.

CONCLUSIONS

- The 17-4 PH and IN625 bi-metal structure was well-bonded after sintering without delamination.
- A composition gradient of iron was measured at the bi-metal interface and the nickel element exhibited a much sharper transition at the interface.
- The bi-metal interface built by material extrusion AM exhibited a bonding strength below 300 MPa and shows small elongation under the tensile force. However, no delamination is detected for the flexural bi-metal specimen, suggesting a ductile bending behavior.

ACKNOWLEDGEMENTS

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