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Multi-metal printing with affordable material extrusion

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Introduction

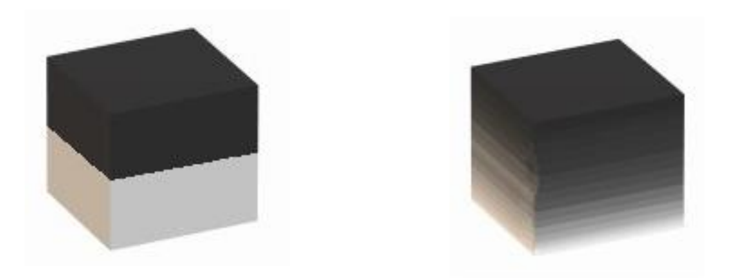
Additive manufacturing (AM) technologies, in the recent decades, have considerably expanded their applications in various fields due to their unique benefits such as producing parts with complex geometries and reducing production time and costs [1-3]. Material extrusion (MEX), which also known as Fused filament fabrication (FFF), is one of AM techniques that produce a 3D part layer by layer using the deposition of melted filaments through a nozzle. The most benefit of using MEX is affordability and availability of this technology using simple home printers. Although a large share of studies has focused on using a single material in AM technologies, a few studies have been conducted on multi material additive manufacturing (MMAM), where it was suggested that joining different metal parts by traditional multi-step welding process could be replaced by functionally graded materials (FGM) in which several metals can be deposited in a single layer [4]. For the first time, this study investigates the possibility of fabricating the coupled and graded parts from two ferrous alloys by Material extrusion based Fused Filament Fabrication (FFF).

Experimental Procedure

- Two metallic filaments used in this study were stainless steel 316L (d_{50}=32.7 µm) and high carbon iron (d_{50}=129 µm) with chemical compositions as follows (Table 1):

Table 1. Chemical composition of two used alloys

Stainless steel 316L - %wt			
C	Cr	Ni	Mo
0.02	16.6	9.86	1.64
Mn	S	P	Fe
0.924	0.0285	0.0617	balance
High carbon iron - %wt			
C	Cr	Ni	Si
1.21	0.246	0.193	0.281
Mn	S	P	Fe
0.107	0.0239	0.0314	balance



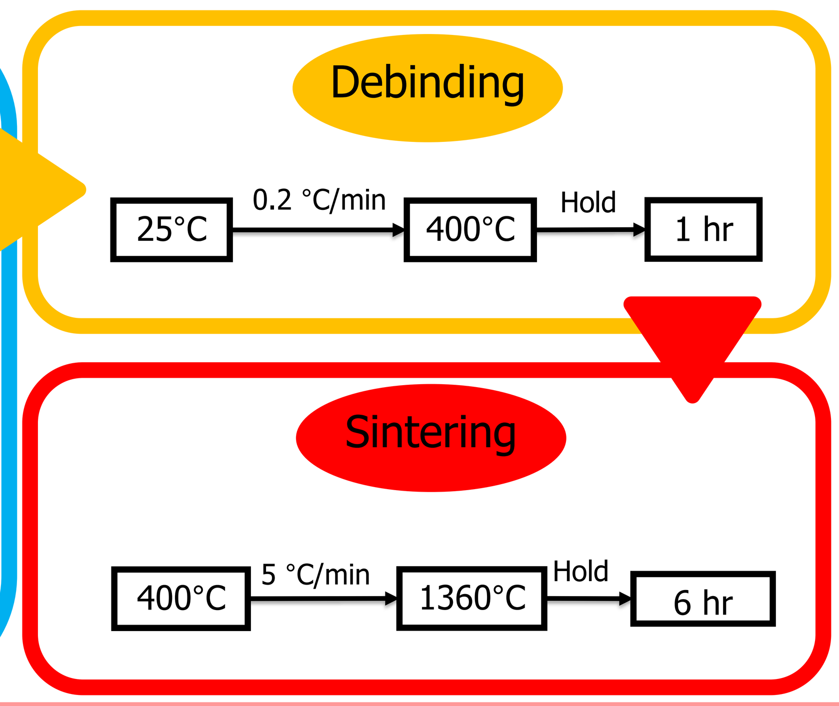
(a) Coupled sample (b) Graded sample

Figure 1. Schematic representations of the printed samples (SS: grey, HCI: black)

Printing

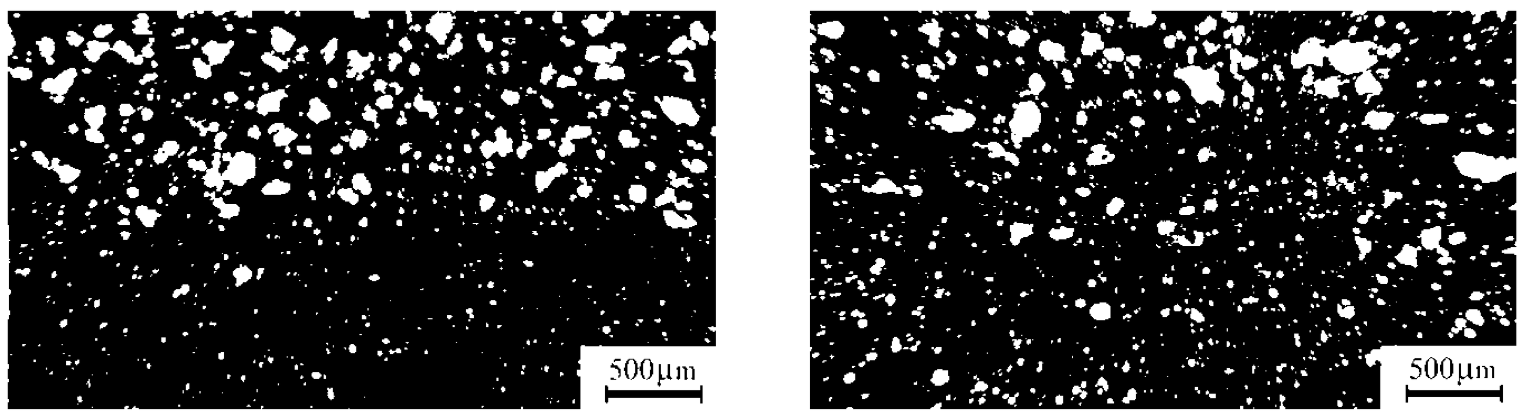
Table 2. Printing settings used for samples

Nozzle temperature	210 °C
Bed temperature	60° C
Infill density	100 %
Printing speed	15 mm/s
Diameter of deposited material	0.8 mm
Line width	0.7 mm
Layer thickness	0.2 mm
First layer thickness	0.53 mm



Results

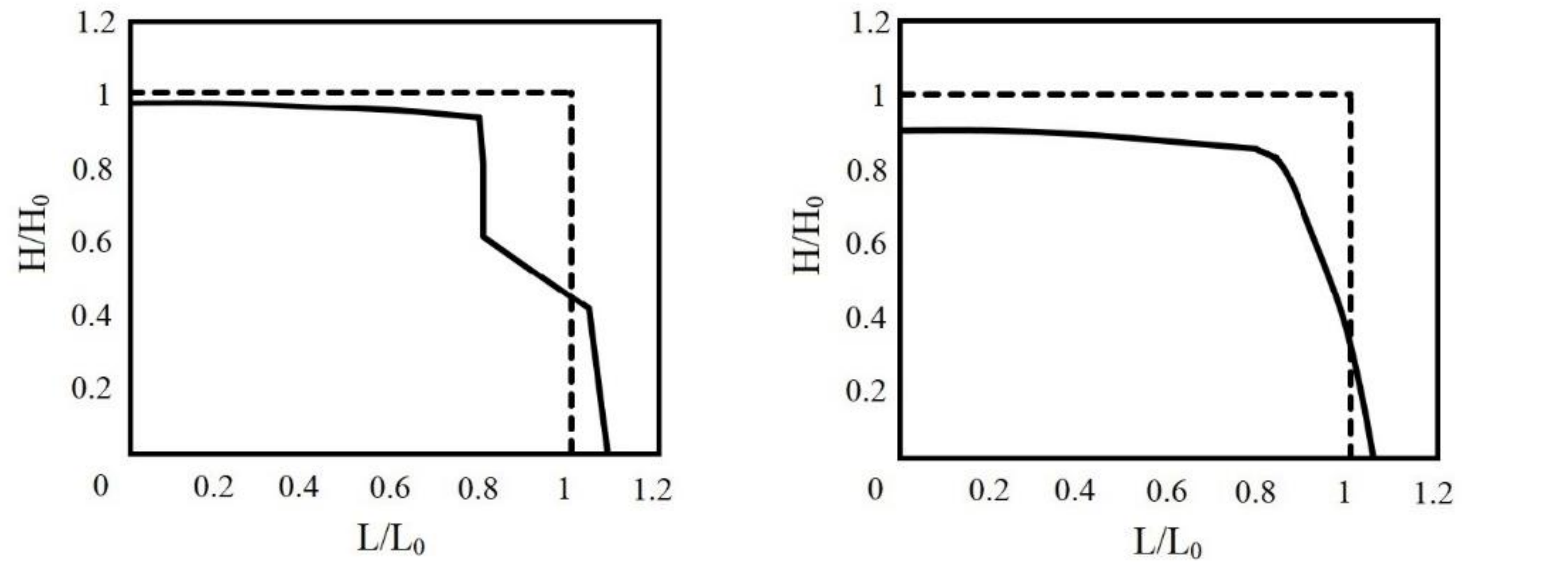
- In the coupled print (Figure 2 a), the difference in particle types of stainless steel 316L and high carbon iron is recognizable. The larger particles belong to high carbon iron (upper zone) and the finer particles represent stainless steel 316L (bottom zone).
- In reality it is not feasible to achieve 0-100% grading. In fact, since the mixing process of filaments occurs in the chamber, a part of filament A is deposited alongside filament B. Due to this, the share of high carbon iron particles (filament B) at the topmost layer of the print would be around 90% instead of 100%.



(a) Coupled sample (b) Graded sample

Figure 2. Optical microscope images taken from the cross section of two types of prints.

- To study the apparent shape evolution and shrinkage level, the dimensions of the samples were measured and plotted after sintering in optimum conditions. The dotted line introduces the dimensions of the print (green sample), while the solid line belongs to the sintered sample.



(a) Coupled sample (b) Graded sample

Figure 3. The dimensional profile of samples. L/L0 and H/H0 are the sintered/green ratios (H0 = 9.82 mm and L0 = 5.28 mm).

- The dimensional change behavior is not similar at the upper and bottom zones in the couple sample. This difference is induced by the type of materials in each zone, as the HCI particles are located in the upper section and SS 316L at the bottom. The higher shrinkage in the upper half can be explained by the fact that HCI has a higher densification parameter than SS 316L in the same sintering conditions.
- A similar phenomenon was recorded in the graded sample, with the difference that the shrinkage level decreases gradually but uniformly from top to bottom. Due to this difference in shrinkage at the two zones, "stair-shaped" and "A-shaped" distortion was observed in coupled and graded samples, respectively.

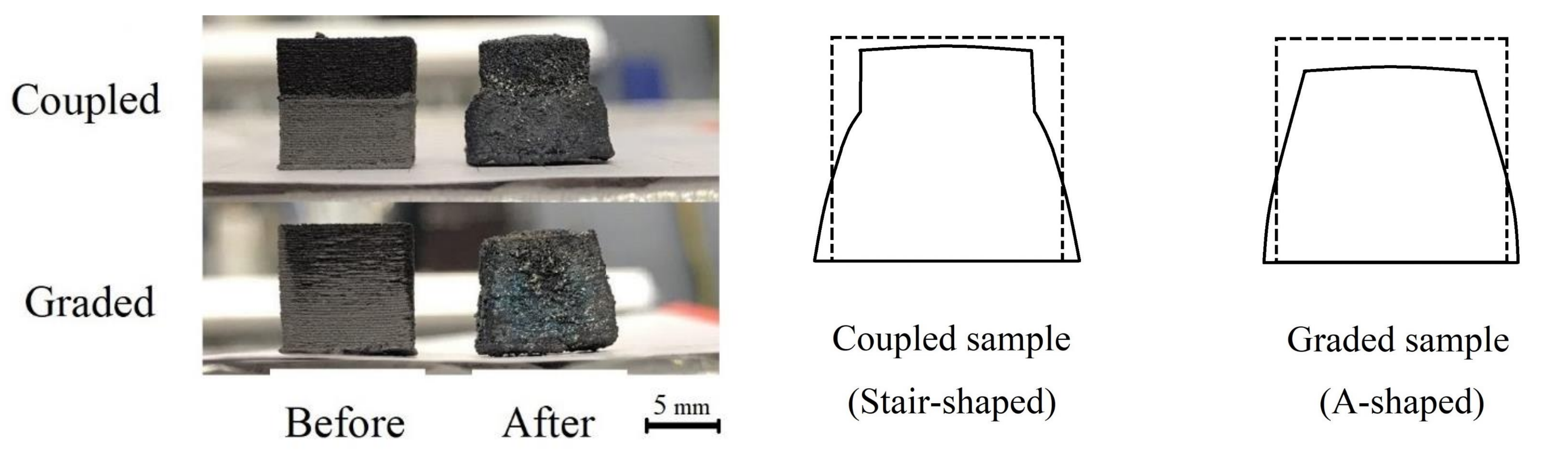


Figure 4. Images of green (before) and sintered (after), and distortion mode of samples.

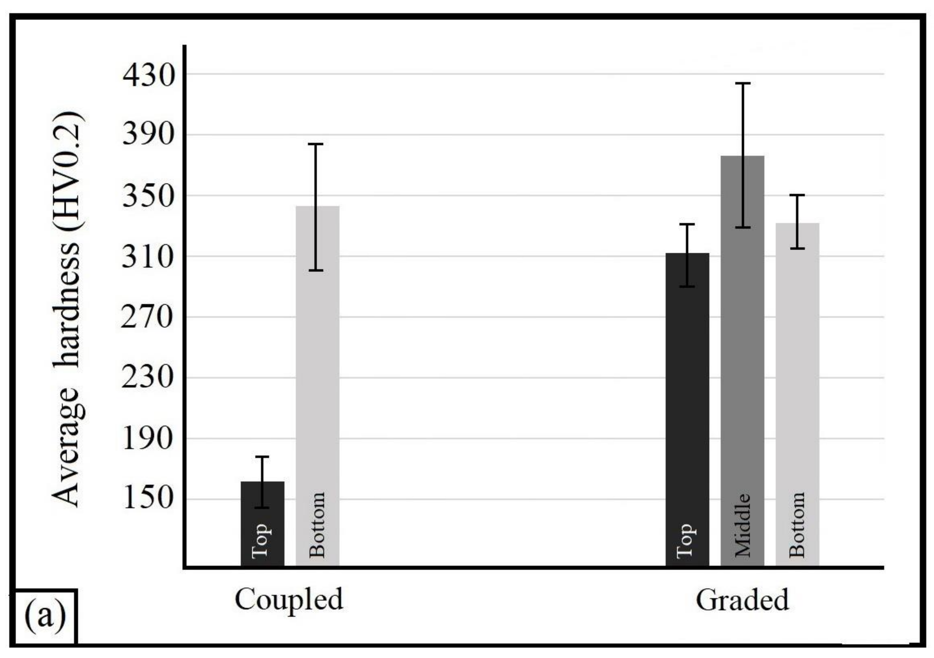


Figure 5. The average micro-hardness in different zones of 2 types of samples.

- The hardness measurement was conducted at 6 points in each zone so that top and bottom zones in the couple sample (in total 12 points); and top, middle and bottom zones in the graded sample (18 points) were measured.
- In the couple sample, which top and bottom zone represent fully HCI and SS 316L, the average hardness is 161.3 HV0.2 and 343.21 HV0.2, respectively. This value considerably increased at the top of the graded sample to 312.35 HV0.2, where adding a small amount of SS 316L particles resulted in a huge increment in the average hardness. On the other side, in the middle zone of the graded sample, an improvement in hardness is visible (373.39 ± 2.69 HV0.2).

Conclusions

1. A feasibility study on fabrication of multi-metal parts by material extrusion technique was conducted.
2. Two types of multi-metal, including the couple and graded samples, were successfully printed from high carbon iron and stainless steel 316L filaments.
3. A different shrinkage behavior was discovered, where "stair-shaped" and "A-shaped" distortions observed in the couple and graded samples, respectively.
4. The affordable FFF technology can be used as an alternative for conventional joining methods to produce coupled or graded parts with more complex geometries and lower production costs at least for small batches.

References

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