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Enhancing Strength and Surface Quality of 3D-Printed Metal-Infused Filaments in Fused Deposition Modelling †

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Abstract: Fused deposition modelling (FDM) is a widely used 3D printing technique known for its versatility across industries. However, achieving optimal strength, crucial for applications like the automotive and aerospace industries, remains a challenge. This study demonstrates the efficacy of metal-infused filaments in enhancing FDM's strength and quality. By incorporating metal particles into polymer matrices, their mechanical properties are notably improved. PLA and metal-infill PLA (copper, silver) are tested, with silver PLA showing notably higher tensile strength and hardness. Considerations such as infill density and pattern are discussed for optimizing object strength. This work underscores the potential of metal-infused FDM printing for advancing manufacturing capabilities, especially for intricate, high-strength metal components.

Keywords: 3D printing; fused deposition modelling; metal filament; automotive; aerospace

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1. Introduction

Additive manufacturing (AM), or 3D printing, has rapidly advanced and become a key technology in Industry 4.0 [1]. Unlike traditional subtractive methods, AM builds objects layer by layer from digital models, offering advantages such as cost reduction, waste minimization, shorter lead times, and simplified assembly. AM supports various materials, including metals, polymers, ceramics, and their composites [2], enabling applications in aerospace [3], the medical and dental fields [4,5], machinery [6], electronics [7–9], the automotive industry, food, textiles, construction, and architecture.

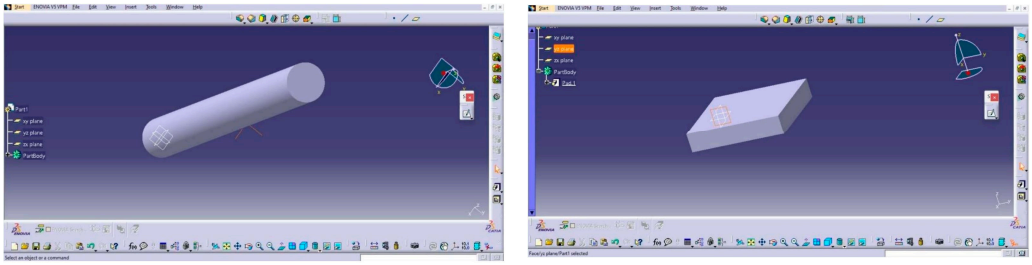
Fused deposition modelling (FDM), a type of additive manufacturing (AM), operates by extruding material through a nozzle [10]. Initially used for visual aids and educational models, FDM is now gaining traction for manufacturing functional parts [11,12]. This shift has led to a focus on designing for FDM, optimizing parts to maximize their benefits while addressing their limitations [13,14].

This research underscores the importance of understanding material properties in metal-infused FDM printing. Characterizing these properties is crucial for optimizing printing parameters and producing reliable, high-strength metal parts for advanced manufacturing.

2. Methodology and Materials

2.1. CAD Model

In additive manufacturing, CAD models are created using software like CATIA V5. For this study, CATIA V5 was used to design a cylindrical bar and a rectangular plate shown in Figure 1.



(**a**) ϕ = 10 mm, L = 300 mm (**b**) 50 × 25 × 10 mm

Figure 1. Mathematical models drafted in Catia V5.

2.2. Materials

PLA, derived from renewable sources like corn starch, is a biodegradable thermoplastic known for its low melting point and ease of extrusion, making it ideal for 3D printing intricate designs with minimal warping and a glossy finish. Metal-infill PLA blends PLA with metal particles, enhancing strength and rigidity to achieve a metallic appearance, suitable for printing on standard 3D printers without specialized equipment or high temperatures.

3. Experimental Setup

Infill density affects the strength of 3D-printed objects, with higher densities leading to greater strength but increased material costs. By adding metals like copper and silver to PLA, its mechanical properties can be enhanced while reducing material usage. This study examines the impact of infusing copper and silver into PLA on tensile and hardness strength. Specimens tested include pure PLA, 30% copper–70% PLA, and 30% silver–70% PLA, shown in Figure 2. Tensile strength and hardness were measured using a Universal Testing Machine and a Rockwell hardness tester, shown in Figure 3.



(**a**) PLA (**b**) 30% copper–70% PLA (**c**) 30% silver–70% PLA

Figure 2. 3D-printed specimens after testing.



(**a**) (**b**)

Figure 3. (**a**) Universal Testing Machine. (**b**) Rockwell hardness tester.

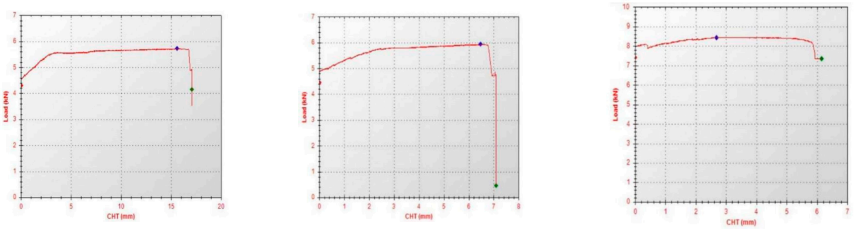
4. Results and Discussion

4.1. Tensile Test

Tensile tests were conducted using a Universal Testing Machine (UTM) on ASTM D-638-compliant specimens at room temperature. For each material (PLA, PLA with copper, and PLA with silver) three sample specimens were prepared, with the results outlined in Table 1. The graphs in Figure 4a–c show load versus cross-head travel for PLA, 30% copper–70% PLA, and 30% silver–70% PLA specimens, respectively.

Table 1. Tensile test values of different samples.

S.No	Material	Peak Load (kN)	Break Load (kN)	Elongation (mm)	Yield Stress (N/mm^2)	Tensile Strength (N/mm^2)
1	PLA	5.72	4.14	17.05	54.749	72.829
2	PLA WITH COPPER	5.94	0.46	7.09	56.787	75.630
3	PLA WITH SILVER	8.44	7.36	6.14	94.474	107.462



(**a**) PLA (**b**) 30% copper–70% PLA (**c**) 30% silver–70% PLA

Figure 4. Load vs. CHT.

In Figure 4a, PLA exhibits peak and break loads of 5.72 kN and 4.14 kN, respectively, at 17.05 mm elongation. Its tensile strength is 72.829 N/mm^2, with a yield stress of 54.749 N/mm^2. In Figure 4b, the 30% copper–70% PLA blend shows peak and break loads of 5.94 kN and 0.46 kN, respectively, at 7.09 mm elongation. Its tensile strength is 75.630 N/mm^2, with a yield stress of 56.787 N/mm^2. Figure 4c demonstrates that the 30% silver–70% PLA composite yields peak and break loads of 8.44 kN and 7.36 kN, respectively, at 6.14 mm elongation. Its tensile strength is 107.462 N/mm^2, with a yield stress of 94.474 N/mm^2.

4.2. Rockwell Hardness Test

Rockwell hardness testing used a 1/4 ball indenter and a 60 kN load. Readings were taken at three positions on the upper surfaces of rectangular plate-shaped specimens, and the averages were tabulated (Table 2).

Table 2. Hardness test values of different samples.

S.No	Material	RHN Value			
		T1	T2	T3	Avg.
1	PLA	42	44	45	43.67
2	PLA WITH COPPER	80	94	82	85.33
3	PLA WITH SILVER	78	75	79	77.33

5. Conclusions

This study investigates the enhancement of strength and surface quality in fused deposition modelling (FDM) using metal-based filaments, particularly copper and silver blended with a polymer matrix. Tensile and Rockwell hardness tests were conducted on PLA, copper-infused PLA, and silver-infused PLA. The results demonstrate that silver PLA exhibits superior tensile strength (107.46 N/mm^2) and Rockwell hardness (77.67) compared to both copper-based PLA and standard PLA, highlighting the potential of metal-infused FDM for high-strength-component production. The present work emphasizes the impact of infill density and pattern on object strength, recommending their optimization for specific applications. Overall, metal-infused FDM has led to significant advancements in additive manufacturing, enabling the production of robust metal parts suitable for critical industries like automotive and aerospace.

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