Compatibility of FDM Polymers at Multi-Material Interfaces

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In the rapidly evolving field of additive manufacturing, multi-material printing stands out as a transformative approach that enables the creation of complex structures with varied functionalities, properties, and aesthetics within a single manufacturing process. This technique involves sequentially depositing different materials, where one material is printed followed by another material printed onto it. Such capability not only broadens the scope of design and functional possibilities but also introduces a set of challenges and considerations crucial for successful implementation. Among these, the compatibility of different materials emerges as a paramount concern, with adhesion strength playing a pivotal role in determining the overall integrity, durability, and functionality of the final product.

The seamless integration of multiple materials hinges on a comprehensive understanding of their physical and chemical interactions. Factors such as surface energy, thermal expansion coefficients, and moisture absorption rates must be meticulously evaluated to ensure cohesive bonds that can withstand the intended use conditions.[4] Furthermore, the compatibility extends beyond mere adhesion, encompassing how different materials respond to the printing process itself, including their melt flow behaviors, heat deflection temperatures, and curing mechanisms.[5][1] These aspects are critical in preventing delamination, warping, or other deformations that can compromise the structural integrity and aesthetic quality of the printed object.

Moreover, the adhesion strength between materials is not solely a function of their inherent properties but also of the printing parameters and surface preparation techniques employed. Optimization of print speed, nozzle temperature, and layer thickness, alongside surface treatments such as the application of adhesion promoters, can significantly enhance interfacial bonding.[2][3] Thus, a systematic investigation into these parameters is essential for developing effective strategies to maximize adhesion strength.

Despite the complexity of this issue, encompassing a multitude of factors from material properties to printing parameters, this rudimentary investigation primarily concentrates on a fundamental aspect: a straightforward measurement of the adhesion between materials. It is important to note that due to the vast scope of considerations in this field, this report cannot encompass all the complexities inherent in optimizing material compatibility. Consequently, while we strive to provide valuable insights and methodologies for assessing and improving adhesion strength, it is clear that much further work is required to fully address the challenges presented by multi-material printing. This exploration serves as a stepping stone towards a deeper understanding, highlighting the need for ongoing research and experimentation in this innovative yet demanding area of additive manufacturing.

1 Results

We conducted straightforward testing of the adhesion strength between commonly used FDM material combinations. The materials tested and their print parameters are shown in the table below. The parameters used for printing were the optimized settings for that particular material, but did not consider the effect which these settings would have in a multi material configuration.

Material	Nozzle Temp	Bed Temp	Fan Power
Polylactic Acid (PLA)	220 C°	60 C°	80%
Polyethylene terephthalate glycol (PETG)	250 C°	80 C°	30%
Acrylonitrile Butadiene Styrene (ABS)	250 C°	100 C°	20%
Acrylonitrile styrene acrylate (ASA)	250 C°	100 C°	20%
Thermoplastic polyurethane (TPU)	240 C°	60 C°	20%
PA6 GF Nylon	275 C°	100 C°	20%
Polycarbonate (PC)	290 C°	100 C°	20%

Multi material samples were printed vertically to simulate the weakest possible adhesion scenario, predisposing the samples to delamination. The comparison matrix of which materials worked well with each other is shown in Figure. 1, and the individual data points are shown in Figure. 2.

Several material combinations stood out with poor performance, while a few had extremely strong interfacial bonding. PLA did adhesion was average for TPU and PC, but very weak for PETG, ABS and ASA. Nylon worked well with TPU and even better with itself, but poorly with most other materials. PC had extremely strong adhesion with TPU and itself, but relatively poor adhesion with many of the other materials. Specifically 4 material combinations stood out with delamination forces above $300\ g/mm^3$ (TPU:TPU, PC:PC, TPU:PC, and TPU:PETG).

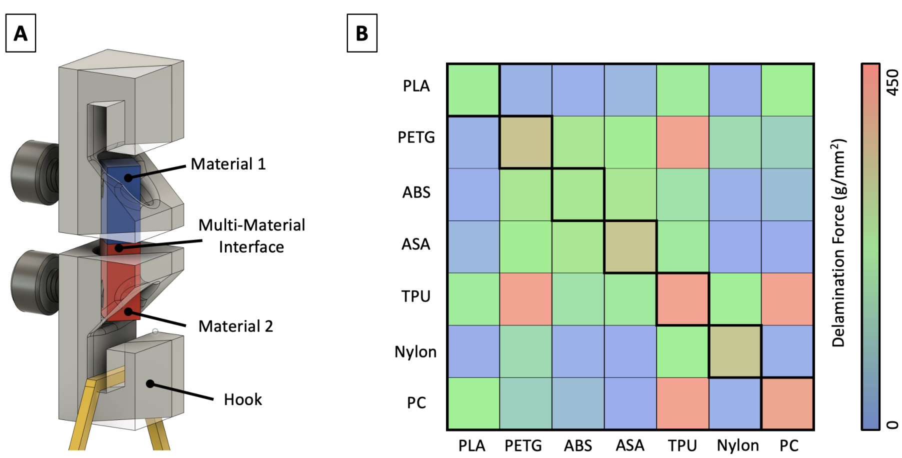

Figure 1: **A)** The test configuration for interfacial bonding testing. The system is placed under increasing load until the interface undergoes failure. **B)** Heat map showing the relative interfacial adhesion of different material pairings. (N=3)

Some materials were barely compatible, and challenging to print onto each other at all. ABS and ASA both struggled severely to adhere to PLA, and multiple rounds of printing were required to achieve enough samples to test. Other materials such as the nylon may have performed better with a different material composition. The particular nylon used was a glass fiber reinforced PA6 nylon intended for structural rigidity and wear resistance. However, the glass reinforcement may have impacted the ability of other materials to adhere to the surface during the second phase of deposition.

There are considerations which were not explored here, the speed, temperature, cooling, and ambient heat all contribute to the strength of the multi-material interface. Specifically the order of deposition is likely important and was not considered here. Printing PC onto PLA vs printing PLA onto PC would likely have very different adhesion strenghts due to the vast difference in melting points between the two (290 for PC and 220 for PLA). When PC is printed onto PLA it will very slightly remelt the surface and allow for diffusion to improve the bonding. However, when PLA is printed onto PC, its temperature might not be sufficient to induce the same level of diffusion. This same principle applies for all the pairings shown here with different extrusion temperatures.

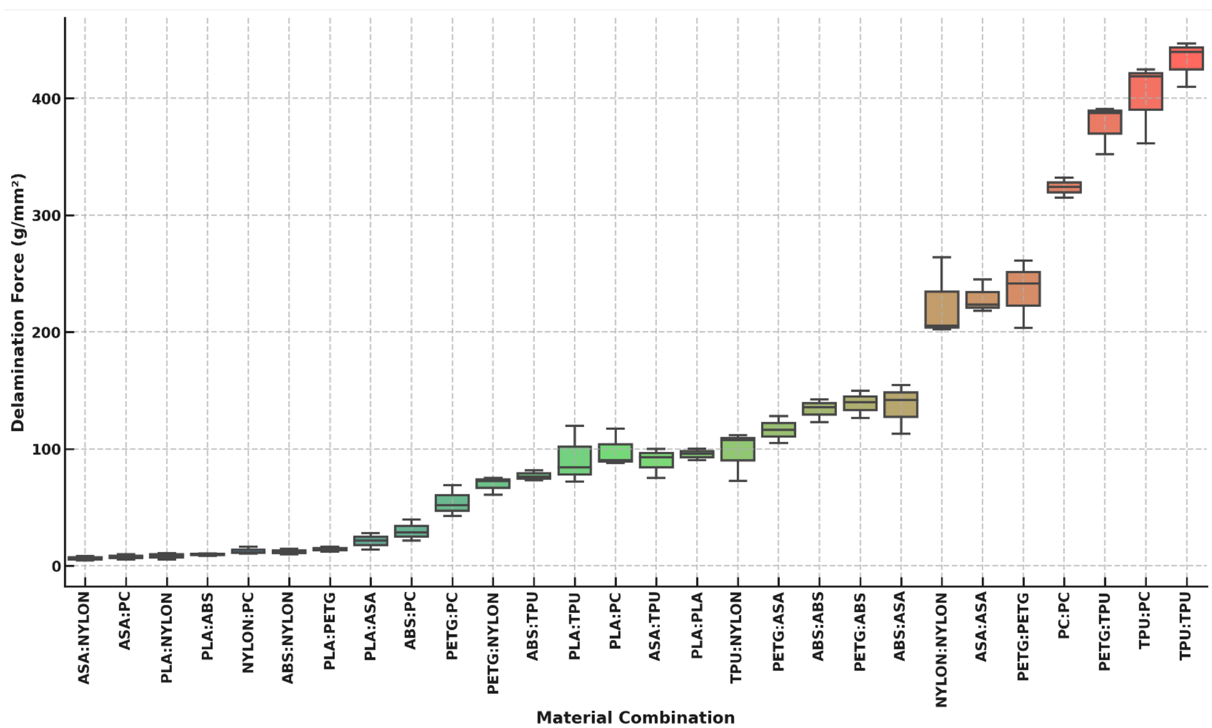

Figure 2: Delamination force of the individual multi-material combinations. (N=3)

Much further testing is required to understand the interplay of all these variables and allow for the fabrication of devices which utilize multi-material interfaces to their full potential.

2 Methods

The following test samples were printed on a Voron 0.1 FDM 3D printer in a fully enclosed chamber to maintain ambient temperature. The hotend utilized was a Dragon HF (Phaetus), paired with the mini afterburner extruder and toolhead. Prints were executed at 50 mm/s print speeds with 5,000 mm^2/s acceleration. The hotend was primed with 50 mm of extrusion prior to printing at the multi-material interface to ensure full contact throughout the interface.

The testing was conducted with the device shown in figure.1, wherein the sample was attached to two hooks and underwent increasing tension until delamination occurred.

References

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