

## EFFECTS OF SURFACE TREATMENTS ON ABS MECHANICAL PROPERTIES FROM FUSED FILAMENT FABRICATION

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### ABSTRACT

This paper investigates the effect of surface treatments on the material properties of acrylonitrile-butadiene-styrene (ABS) samples printed by fused filament fabrication (FFF). The surface treatments are epoxy coating, abrasive media blasting, and acetone immersion. The measured properties are elastic modulus, tensile strength, yield strength, and fracture strain for ASTM D638 Type-I samples printed on a Stratasys Fortus 250mc printer. Moisture absorption was also studied.

### KEYWORDS

Additive manufacturing (AM), fused filament fabrication (FFF), surface treatment, epoxy coating, abrasive media blasting, acetone immersion

### INTRODUCTION

Although FFF enables the rapid and low-cost development of new designs, parts produced via FFF typically have reduced mechanical properties compared to those made via traditional methods, such as injection or compression molding. Specifically, insufficient bonding at bead-to-bead interfaces can weaken interlayer adhesion [1]. Moreover, the oblong cylindrical geometry of the extruded beads produces voids that serve as stress concentration sites [2]. The layer-by-layer FFF process can give rise to poor surface finish as a consequence of the staircase effect, necessitating post-treatments for as-printed materials [3-4]. Applying surface treatments that reduce this porosity may also enhance the properties of FFF materials.

Prior efforts have applied solvent treatments in order to improve the mechanical properties of FFF components [3,6-7]. While acetone treatment and water sealants have been studied,

epoxy coatings have received less attention in literature. Epoxy coatings can fill resin pores and provide improved mechanical properties over neat ABS [8]. By reducing or creating surface irregularities of parts fabricated through FFF, surface treatments can influence the surface roughness and uniformity of printed parts, impacting their tensile strength and ductility [3]. Mechanical abrasion or acetone treatment may also improve surface finish.



FIGURE 1. Tensile test experimental setup. The ABS specimen is clamped in the universal testing machine.

### EXPERIMENTAL SETUP

To examine the surface treatment effects, the following procedure was used.

1. ASTM D638-14 Type-I “dogbone” test specimens were fabricated using a Stratasys Fortus 250mc printer with a  $\pm 45^\circ$  raster pattern, 0.18 mm layer height, Blue Stratasys P430 ABS<sup>plus</sup> material from new stock, and a solid infill.

2. Samples were subject to: brush coating with epoxy; media blasting; immersion in an acetone solution; or no treatment.
3. Measurements were made of each sample, and surface morphology was observed using optical microscopy and a surface profilometer.
4. Select samples were submerged in water and weighed every hour for 8 hours to measure mass changes due to water absorption.
5. The surface finish was re-observed and surface roughness values were calculated post treatment.
6. Samples were tested using an MTS Criterion Model 45 universal testing machine at a strain rate of 5 mm/min. (Samples used in water immersion tests were not tested.) See Fig. 1.
7. Surface fracture morphology was observed using optical microscopy.
8. From the tensile test data, elastic modulus, yield strength, tensile strength, and fracture strain for all sample types were calculated; see Fig. 2 for all stress-strain data.

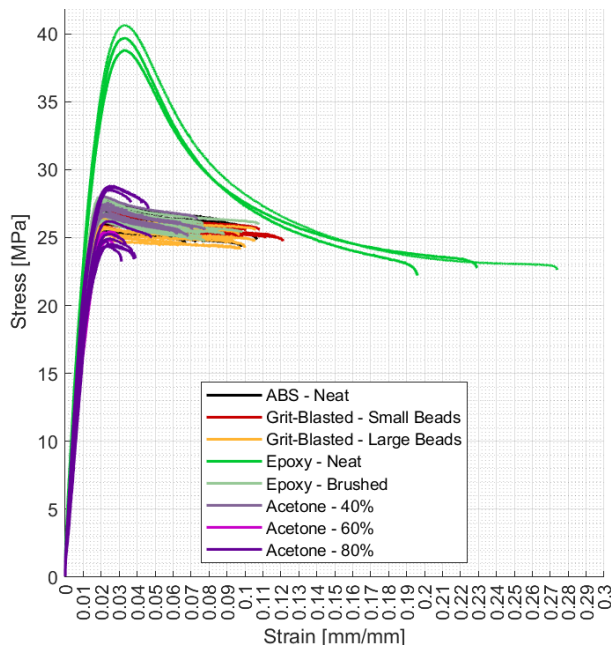


FIGURE 2. Stress-strain curves for all sample types.

## MATERIALS AND METHODS

According to the manufacturer specifications (Stratasys) for the ABS filament, the tensile strength of the material is 33 MPa, the elastic modulus is 2.2 GPa, and the fracture strain is 6%

[8]. In total, 20 untreated test specimens were printed and tested to use as a baseline for the treated specimens. A Mitutoyo SurfTest SJ-210 stylus profilometer [9] was used to measure the surface roughness. For each dogbone test specimen, four regions over the test surfaces were analyzed to determine average roughness ( $R_a$ ) values, where the ISO 1997 standard was used in conjunction with Gaussian filtering with a 0.25 mm cutoff and  $\lambda_s$  value of 2.5  $\mu\text{m}$  and cutoff number of 9. Optical microscopy was also employed to inspect the topography of both the sample surface and the fracture site (VHX 5000 Keyence digital microscope).

### Mechanical Media Blasting

Mechanical media blasting, also known as grit blasting (GB) or sandblasting, entails the use of an abrasive material to roughen, smooth, or shape a given surface using high pressure, localized impacts. The surfaces of printed specimens were subjected to media blasting with either large glass beads (40 to 60 grit, 254 to 365  $\mu\text{m}$  diameter) or small glass beads (200 grit, 84  $\mu\text{m}$  diameter). A total of six passes per side were completed in a manual sandblasting glove box. The media were propelled by compressed air at a pressure of 80 psi (0.55 MPa) with the nozzle approximately 10 cm from the sample surface.

### Epoxy Coating

As a surface treatment, epoxy can impart numerous benefits to coated surfaces, including improved mechanical properties such as tensile strength and modulus, as well as thermal and chemical resistance [10]. Smooth-On XTC-3D High-Performance epoxy coating was chosen given its commercial availability and intended application for FFF components. The epoxy resin and hardener were combined in a 2:1 volumetric ratio and mixed for one minute. For each of 18 printed dogbone samples, 0.3 mL of the epoxy mixture was loaded into a syringe and deposited on one side and smoothed using a silicone-tipped doctor blade. After two hours of curing at room temperature, samples were flipped over, and the coating procedure was repeated for the other side.

To determine the performance of the epoxy alone, five additional samples were created by pouring neat epoxy into a silicone mold and cutting dogbone samples using a water-jet system. The only material property provided by the epoxy manufacturer was a Shore Hardness of 80D [11].

### Acetone Immersion

Acetone is commonly used for postprocessing AM parts, specifically for polylactic acid (PLA) and ABS. However, prolonged exposure to high concentrations of acetone can affect the part geometry and make parts unsuitable for use [12].

Test specimens were immersed in varying concentrations of liquid acetone. The specimens were fully submerged in either a 40%, 60%, or 80% by volume acetone solution; the balance of the solutions was water. In total, 15 samples were treated for each concentration. In each of three batches, five samples were immersed in the solution for a duration of 10 minutes and the same solution was used for all three batches.

After immersion, the 40% and 60% acetone samples were removed from the solution, patted dry with paper towels, and placed upright along their long edge to dry overnight and evaporate any remaining acetone or water. To prevent the 80% acetone samples from deforming, they were laid horizontally on a silicone mat to dry.

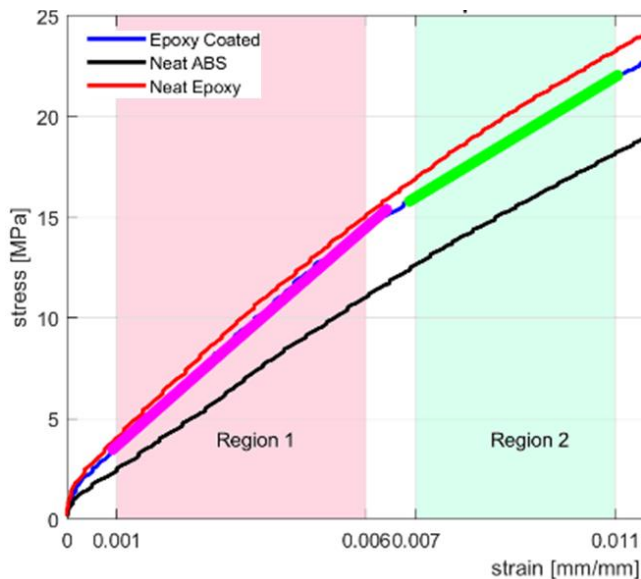


FIGURE 3. Stress-strain curves for neat ABS, neat epoxy, and epoxy-coated samples. Two distinct linear regions are identified for the epoxy-coated samples (magenta and green zones).

### Tensile Testing

To complete the tensile testing of the neat and treated ABS samples, an MTS Criterion Model 45 universal testing machine with a 100 kN load cell was used. Each test specimen was clamped at both ends and pulled at a strain rate of 5 mm/min

until failure. Two pieces of reflective tape were placed at the boundary of the 50 mm gauge length for each specimen, and an MTS laser extensometer [13] was used to record the displacement.

TABLE 1. Values for the mechanical properties of all sample types. Blue highlight indicates a statistically significance difference from neat ABS.

Treatment (% change from neat ABS)	Elastic modulus (MPa)	Tensile strength (MPa)	Fracture strain (%)
Neat ABS (value $\pm$ std. dev.)	2183 $\pm$ 83	26.6 $\pm$ 0.7	8.34 $\pm$ 0.01
GB – Small Beads	2232 (2.2% increase)	26.5 (0.4% decrease)	10.2 (22% increase)
GB Large Beads	2188 (0.2% decrease)	25.9 (2.6% decrease)	8.8 (6.0% increase)
Neat Epoxy	2843 (30.2% increase)	39.7 (49.2% increase)	23.3 (180.7% increase)
Brushed Epoxy	2426 (11.1% increase)	26.9 (1.2% increase)	8.1 (2.4% decrease)
40% Acetone	2224 (1.9% increase)	27.1 (1.9% increase)	6.4 (23.2% decrease)
60% Acetone	2011 (7.9% decrease)	25.3 (4.9% decrease)	2.7 (67.6% decrease)
80% Acetone	2020 (7.5% decrease)	26.1 (1.9% decrease)	3.8% (54.4% decrease)

### Water Absorption and Mass Change

The FFF process can make parts prone to water absorption from the environment and affect both the quality of the surface finish and the dimensional accuracy [4]. The material itself can also become degraded, contributing to a decrease in tensile strength. ABS possesses hygroscopic tendencies, where the polymer can absorb or adsorb water present in the surrounding environment [14].

To assess the hygroscopic tendencies of the treated versus untreated ABS, water absorption tests were conducted. From each treatment group, three samples were immersed in a graduated cylinder filled with water for eight hours. Specimens were removed from the water, their mass was measured, and they were then replaced in the water each hour.

**Data Analysis Methodology**

Engineering stress-strain curves were generated using the force data from the MTS crosshead and displacement data from the laser extensometer. In order to calculate elastic moduli for the samples, points from the initial linear portion of the stress-strain curve were fit using a first-degree polynomial with a zero intercept. The slope was used as the elastic modulus.

yield strength was calculated using the 0.2% offset method. Pooled t-tests and t\*-tests ( $\alpha = 0.05$ ) were used to determine if each treatment type was statistically different from the control group for each material property. The results are displayed in Table 1.

**RESULTS**

Surface profiles for samples from every treatment group are shown in Fig. 4. All  $R_a$  values obtained from stylus profilometry data are provided in Table 2.

TABLE 2. Pre- and post-treatment  $R_a$  values for all sample types.

Treatment	Top $R_a$ [ $\mu\text{m}$ ]		Bottom $R_a$ [ $\mu\text{m}$ ]	
	Pre	Post	Pre	Post
Neat ABS	2.4	-	4.8	-
GB Small	2.6	2.8	5.0	0.03
GB Large	2.2	1.2	5.0	2.1
Neat Epoxy	0.04	-	0.21	-
Brushed Epoxy	2.2	0.04	6.3	1.2
40% Acetone	2.1	2.1	4.0	3.8
60% Acetone	3.6	0.76	5.0	2.2
80% Acetone	3.2	0.01	5.0	0.08

**Mechanical Media Blasting**

Overall, grit blasting the ABS samples with either small or large beads led to the surface textures of both sides of the sample becoming more similar to each other. Media blasting with small beads did not have any significant effect on modulus, although a significant increase in fracture strain was noted. Small beads were visibly embedded in the voids of the sample surface. Meanwhile, media blasting with large beads also did not lead to any significant impacts on modulus or fracture strain; rather, slight decreases in tensile strength were observed. Larger beads did not embed in sample voids but instead tended to discolor the ABS surface with pockmarks.

**Epoxy Coating**

Neat epoxy demonstrated a significantly higher modulus (30.2% increase), tensile strength (39.7% increase), fracture strain (180.7% increase), and a smoother surface morphology

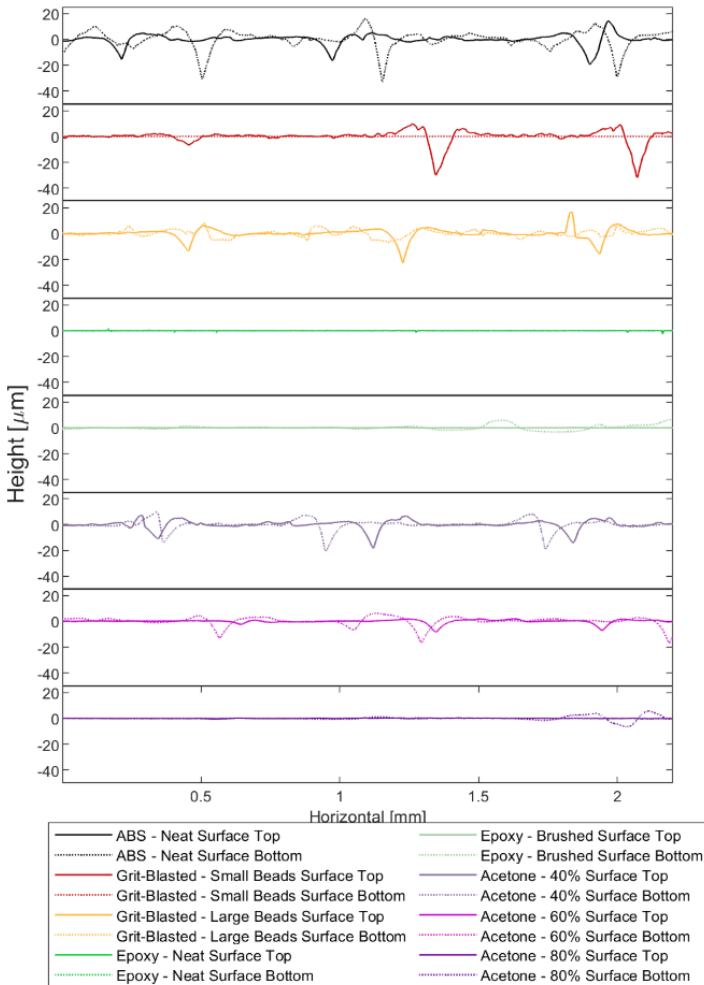


FIGURE 4. Surface profiles for all sample types.

For the epoxy-coated samples, two linear regions were identified; these are visible in Fig. 3. The

compared to neat ABS. The modulus of the epoxy-coated samples, which consisted of ABS coated with epoxy resin, was between that of neat epoxy and neat ABS, confirming expectations for the composite material. Additionally, epoxy-coated samples yielded a higher modulus compared to neat ABS (11.1% increase), together with a smoother surface texture than neat ABS. The superior modulus of the epoxy-coated samples may be a consequence of epoxy infiltration, which has been reported to strengthen interlayer bonding [15]. The epoxy penetration was uneven across the samples.

Even though the brushed epoxy samples had a higher modulus, tensile strength was not significantly different. It is likely that the epoxy began to delaminate from the ABS at a relatively low strain, leading the samples to behave more like neat ABS samples in terms of yield strength and tensile strength. Figure 3 shows a visible change in modulus (slope) for region 2 (relative to region 1) that is within 0.05% of the neat ABS modulus at approximately 0.6% strain, suggesting the epoxy and ABS delaminated.

#### Acetone Immersion

The change in materials properties of the acetone-treated samples depended on the acetone concentration. Treatment with 40% acetone did not have any significant effect on modulus, yield strength, or surface morphology, but a decrease in fracture strain was observed. On the other hand, immersion in 60% acetone contributed to a smoother surface texture, decrease in modulus, and a significant reduction in fracture strain. Finally, submersion in 80% acetone led to the most prominent smoothing of the sample surface, a decreased fracture strain (brittle fracture), as well as a warping of the sample into a curved geometry; see Fig. 5. This latter observation may be a result of the permeation of the strongly concentrated acetone into the pores of the sample.

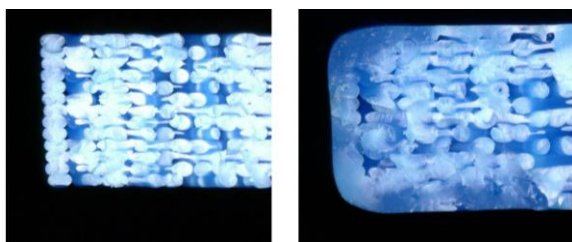


FIGURE 5. Optical fractographs of an untreated sample (left) and a sample treated with 80% acetone solution (right).

#### Moisture Absorption

The average percent mass change for water-immersed samples from each treatment group is conveyed in Fig. 6, which includes standard error bars showing 95% confidence intervals and red stars denoting which treatments held statistical significance in comparison to neat ABS. In general, all surface treatments, except for grit blasting with small beads, were able to significantly ( $\alpha = 0.05$ ) reduce percent mass change due to hygroscopic absorption, relative to neat ABS.

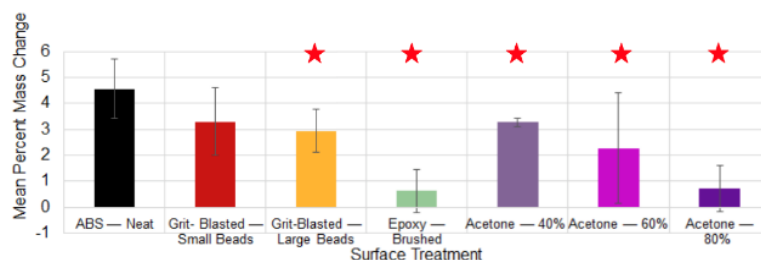


FIGURE 6. Mean percent mass change due to surface treatment and water absorption. The 95% confidence intervals are included.

#### CONCLUSIONS

Currently, additive manufacturing, and fused filament fabrication in particular, have led to a diverse array of applications spanning mechanical, biomedical, and aerospace engineering, in addition to products in electrical sensing and renewable energy. The continued exploration of surface treatments has the potential to advance the understanding of 3D printed materials and their applications in engineering, medicine, and beyond.

The surface treatments examined in this study, excluding grit blasting with large beads and immersion in 60% acetone, did not exhibit significant effects on the tensile strength of ABS. However, grit blasting with small beads was observed to increase fracture strain compared to neat ABS; acetone immersion in either 40%, 60%, or 80% solution, however, led to more brittle fracture modes. Importantly, epoxy brush coating contributed to notable increases in elastic modulus, together with reduced moisture uptake by the ABS. Overall, considering the insignificant impacts of most of the surface treatments studied on the tensile strength of ABS, this study concludes that these surface modifications can be customized to tune the desired properties.

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