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Introducing 3-D Printed Specimens to Mechanical Engineering

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Dr. Jing Zhang's research interests are broadly centered on understanding the processing-structure-property relationships in advanced ceramics and metals for optimal performance in application, and identifying desirable processing routes for its manufacture. To this end, the research group employs a blend of experimental, theoretical, and numerical approaches, focusing on several areas, including:

1. Processing-Microstructure-Property-Performance Relationships: thermal barrier coating, solid oxide fuel cell, hydrogen transport membrane, lithium-ion battery 2. Physics-based Multi-scale Models: ab initio, molecular dynamics (MD), discrete element models (DEM), finite element models (FEM) 3. Coupled Phenomena: diffusion-thermomechanical properties 4. Additve Manufacturing (AM) or 3D Printing: AM materials characterization, AM process (laser metal powder bed fusion, ceramic slurry extrusion) design and modeling

(http://www.engr.iupui.edu/˜jz29/)

Introducing 3D Printed Specimens to Mechanical Engineering Laboratories

Abstract

Tensile testing is a popular laboratory experiment for several engineering disciplines. A recent technique in teaching this lab is to use additively manufactured plastic specimens. As more and more plastic is used in the industry students need to be aware of the specifications of these materials. Following the ASTM 638 standard, 3D printed plastic materials were studied for their potential applications in engineering education. Using the tensile test, the stress-strain curves of the materials have been measured. The Young's modulus, ultimate strength, and fracture toughness of the materials are calculated from the stress-strain curve. Results show that carbon fiber reinforced polymer (CFRP) has the highest stiffness or Young's modulus. Acrylonitrile butadiene styrene plus (ABS*plus*) has the strongest mechanical properties, with highest ultimate strength and fracture toughness. With the measured properties, the 3D printed samples are a viable solution for engineering students to learn mechanical properties of materials. The impacts of using 3D printed specimens on the engineering curriculum for mechanical engineers are also discussed.

Introduction

Fused deposition modeling (FDM) is an additive manufacturing technology commonly used for modeling, prototyping, and production applications. It is one of the techniques used for 3D printing. FDM works on an "additive" principle by laying down material in layers; a plastic filament is unwound from a coil and supplies material to produce a part. Three-D printers that run on FDM Technology build parts layer-by-layer from the bottom up by heating and extruding thermoplastic filament (Chua & Leong, 2003). The process is: (1) Pre-processing: build-preparation software slices and positions a 3D CAD file and calculates a path to extrude thermoplastic and any necessary support material. (2) Production: The 3D printer heats the thermoplastic to a semi-liquid state and deposits it in ultra-fine beads along the extrusion path. Where support or buffering is needed, the 3D printer deposits a removable material that acts as scaffolding. (3) Post-processing: The user breaks away support material or dissolves it in detergent and water, and the part is ready to use ("Dimension® BST/SST 1200es 3D Printers USER GUIDE," 2011).

In this study we used 3D printed ABS, ABS*plus*, and carbon fiber reinforced polymer using an open source 3D printer.

Methodology

Three plastic materials are used in this study: ABS from Stratasys (Eden Prairie, MN), ABS*plus* from the 3D Filament Shop Ltd. (the Swan Centre, Higher Swan Lane, Bolton, UK), and carbon fiber reinforced polymer (CFRP, 20 wt% of carbon fiber) from 3DXTech (Wyoming, MI). At least three samples of each material are used, and only the average mechanical properties are shown.

The specimens used in this study are designed in accordance with the ASTM standard test method for tensile properties of plastics. The printer used is FDM 3D printer developed by 3D Parts Manufacturing LLC (Indianapolis, Indiana).

The tensile testing is done using a MTS Systems universal testing machine according to ASTM standards for tensile properties of plastics. The model number of extensometer used in the test is 634.12E-54.

Before the tensile tests, the width and thickness of the center section of each of the specimens are measured then entered into the testing program. The tensile specimen is loaded into the testing machine by attaching the clamps to both ends and the distance between the clamps is measured and entered into the program. The tensile strain rate applied is 0.2 in/min (0.0847 mm/s). The program records tensile load and elongation, which can be converted to stress – strain curves.

Results and discussion

The fractured tensile samples are shown in Figure 1. In general, the samples show brittle fracture due to relatively small deformation. In order to evaluate the mechanical properties, the stress-strain curves of the three samples are plotted in Figure 2.

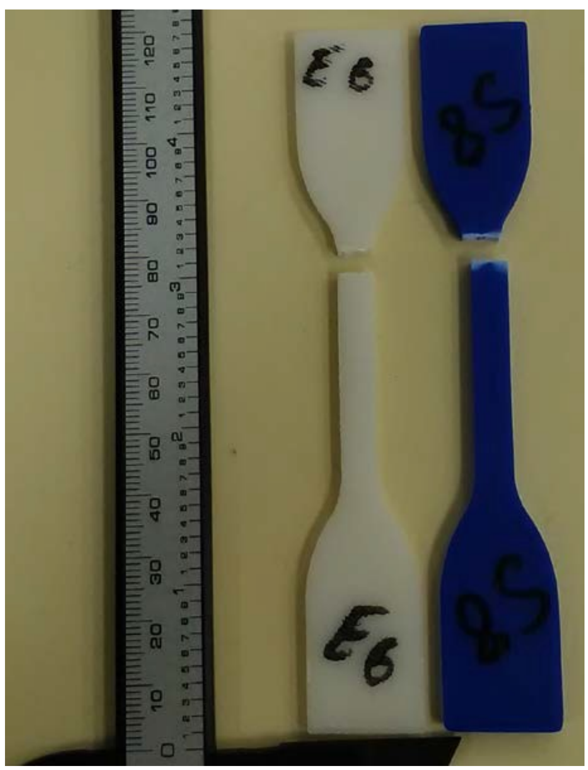

Figure 1: Images of the fracture tensile testing samples (Stratasys ABS (left), Open Source FDM ABS*plus* (right).

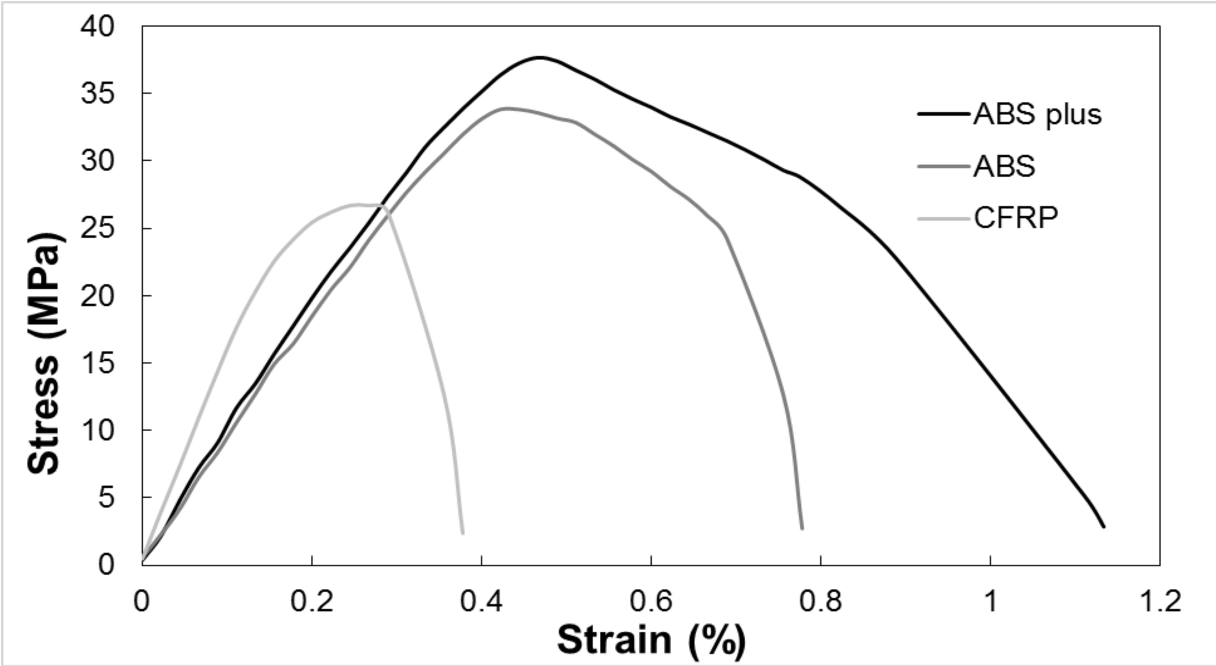

Figure 2: Representative stress-strain curves of tensile tests of three materials

The mechanical properties of the three materials, derived from the stress-strain curves in Figure 2, are summarized in Table 1. CFRP has the highest Young's modulus, due to its inclusion of high stiffness carbon fibers. However, its ultimate strength and fracture toughness are lower than those of ABS and ABS*plus*. So 3D printed CFRP is suitable for rigid applications. ABS and ABS*plus* have similar Young's modulus, but ABS*plus* has much higher ultimate strength and fracture toughness. Therefore, ABS*plus* is suitable for large deformation applications, but more expensive than ABS. The order of cost of the three materials is: ABS < ABS*plus* < CFRP.

Table 1: Averaged mechanical properties of 3D printed ABS, ABS*plus*, and CFRP

	Young's modulus (GPa)	Ultimate strength (MPa)	Fracture toughness (MPa)
ABS*plus*	9.8	37.7	0.286
ABS	9.2	33.9	0.179
CFRP	17.1	26.7	0.073

Educational Impact

The goal was to give students more samples to test. Because the measured materials properties were consistent we proceeded to use them in a classroom laboratory experiment. Previously our school acquired metal specimens at a cost of $10 each. Our department did take the time to manufacture our own samples using a CNC mill, however that only reduced the cost in half. The low cost of the 3D printed plastic samples allows student groups to test multiple samples. Plastic specimens costs about 20 cents for the least expensive ABS. So with reduction in price, we could afford to give students multiple specimens to complete the lab experiment. In the future ABS and ABS*plus* can be ground up and be locally reused to make additional specimens.

The students could test five specimens and be able to calculate the standard deviation using the built-in software or use other computer programs. Previously with steel, brass or aluminum the costs are too high to get enough samples to do a standard deviation per student lab group. Using the ASTM 638 standard at least five specimens are required to do a standard deviation.

This paper focuses in on the utilization of flat-bar specimens. Obviously, for low-cost round cylinder specimens, bolts can be used with a little modification. Bolts are great for testing steel because they extremely low cost and are available in different grades, so students can acquire direct feedback on the grade properties. Despite this, bolts in aluminum, brass, and nylon are not cheap, and more difficult to find with an unthreaded section. Additionally, thin filament wire is available in various materials. Both of these materials are not necessarily the ideal “dog-bone” material.

Two other nuisances in a material acquisition are manufacturing samples and the testing machines used. Manufactured specimens cost upwards of $10 each. However, more and more options are available nowadays. If making rubber or weak plastic samples a die can be used to cut out the flat dog-bone. Also, there are router tables that can trim the metal pieces as well.

Lastly, the universal testing machines can be expensive. We desire that students use the machines themselves. And the Teaching Assistant merely watches the experiment. A fully featured universal testing machine price depends on the load cell size. Many more competitors are making machines that can do testing to the ASTM standard. While some schools have the budget for expensive machines, and while others have experimented with making their own machines there is a middle ground. Affordable 5KN can be acquired for less than $4,000. At that price point allowing students to have a better lab experience is possible, even with more sub-standard specimens (bolts and wire).

Once, our teaching laboratory has several low-cost tensile testing machines the lab can many more teaching possibilities. We hope to explore those soon, and share those results.

Summary

Three 3D printed plastic materials were investigated: ABS, ABS*plus*, and CFRP. Here are the results: (1) CFRP has the highest stiffness or Young’s modulus, (2) ABS*plus* has strongest mechanical properties, with highest ultimate strength and fracture toughness, and (3) 3D printed samples are a viable solution for engineering students to learn mechanical properties of materials. We reduced the cost of the specimens drastically, and gave students more hands-on experience in the lab. Future work includes using multiple tensile testing machines and determining if the use of metal specimens are needed for student learning outcomes.

References

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