Educational Method for Mechanical and Surface Properties Measurements of Additively Manufactured Samples

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Educational Method for Measuring of the Mechanical and Surface Properties of Additively Manufactured Materials

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Abstract

Additive manufacturing methods are being taught widely in many universities and schools. Students learn how to use 3D printers to make their designed parts, but they usually do not measure the mechanical and surface properties of their additively manufactured parts to compare the new materials with the conventional materials such as steels, aluminums, and injected polymers. This article summarizes some of the standard applicable testing methods for testing the mechanical and surface properties of additively manufactured test samples in universities. In the presented model, students use polymer or metal 3D printers to manufacture their test samples for tensile, impact and hardness test equipment to measure the mechanical properties of the printed materials. They also measure and compare the surface properties such as surface roughness, metallography and microstructure, and resistance against wear, abrasion, and corrosion. The presented model is intended to provide students with a general idea about the usefulness of AM materials and the probable differences between them and conventional materials. The model can be developed as a new course or be added to the additive manufacturing or material science courses in sophomore or junior levels.

Keywords: 3D printing, Additive manufacturing, Mechanical properties, Surface properties

Introduction

Low-cost 3D printers have made it possible for schools across the nation to have additive manufacturing implemented in their labs and curriculum. AM machines are used widely by students [1]. The ease of prototype manufacturing in 3D printing encourages students to prefer AM machines to conventional manufacturing machines in building their projects. One major question remaining unanswered is that how well the AM manufactured parts will perform under load and pressure in an industrial application. Providing the students with hands-on experiences in measuring the mechanical and surface properties of AM manufactured parts and comparing them with those of well-known conventional materials seems essential. Although the properties of the most common AM materials are available in the literature, the practical experience of pulling, impacting, or breaking the printed parts will make much more sense for the students. Because of the porosities and imperfections inherent in AM materials [2], the surface properties of the printed parts are different from conventionally manufactured parts. These surface properties affect the suitability and durability of the AM materials for various applications. It is worthwhile to have students measure, notify and present the differences in the surface properties. The introduced tests can be developed as a new course or be added to the additive manufacturing or material science courses in sophomore or junior levels.

Mechanical properties

Although standard organizations such as ASTM and ASME released additional new standards such as ASTM F3122, or ASME Y14.46 specifically designated for testing AM materials, the conventional standard methods of testing, been used by various research groups [3], are still applicable [4, 5] and recommended for students to compare the mechanical properties of the new materials with those of conventional materials. The combination of destructive tests listed here reveals the differences in major mechanical properties for students. Compression, Bending, Shear, and Torsion tests are other mechanical tests to add to the list in case of the machine availability in the lab.

Tensile Test

Tensile test with a tensile machine conforms to ASTM E4 standard is used to draw the Load/Extension or Stress/Strain curve. Ultimate tensile strength, yield strength, yield point, Modulus of elasticity, stress at rupture, and maximum elongation is calculated from the curve. The specimens are prepared based on ASTM E8 standard for metallic parts and ASTM D638 for plastic parts. For AM samples, the students can draw the 3D model of the test specimen based on the standards or acquire the STL file from online CAD libraries. An example of tensile test performed on additively manufactured stainless steel 304L can be found in [6]. A review on tensile test as well as other mechanical tests on AM polymers is also reported in [3].

Impact Test

Charpy and Izod impact tests based on ASTM E23 for metallic parts and ASTM D256 for plastic parts is performed to measure and compare the toughness of materials. For AM samples, the students can draw the 3D model of the sample based on the standards or acquire the STL file from online CAD libraries. AM samples of Ti-6A1-4V, AISI 316L (X2CrNiMo18-14-3) and maraging steel 300 (X3CoMoTi18-9-5) manufactured by Selective Laser Melting (SLM) method were subjected to Charpy impact test, and the results were reported in [7]. Charpy impact test also was used in [8-10]. Izod impact test results for AM polymer specimens are reported in [11].

Hardness Test

Indentation hardness tests such as Brinell conform to ASTM E10, or Rockwell tests conform to ASTM E18 are used to test the resistance of the metallic samples to surface deformation. Durometer hardness test conforms to ASTM D2240 is used for plastic parts. Students can use their destroyed test samples from tensile or impact test for measuring and comparing the surface hardness.

Fatigue Test

Defective AM materials show a difference in dynamic loading and fatigue life due to increased porosities and fusion defects which accelerate crack initiation and propagation inside the material [12, 13]. Although there is ongoing research on the fatigue life of AM materials, it is not practical for the students to do the fatigue test and compare to the fatigue life of AM materials to that of conventional materials in a semester time. It is recommended to dedicate a lecture class to the fatigue life of AM materials.

Surface properties

Visual Inspection

The unpolished surface of an AM part is not good enough for lots of the application, and post-processing of the samples is required. Students can compare the surfaces of their AM samples to the conventional materials and discuss the post-processing processes as are necessary for AM parts in different industrial applications.

Surface Preparation and Metallography

The porosities are inherited with current AM manufacturing methods. The defects are visible through a standard metallography test. The test samples are prepared based on ASTM E3 standard. It is a good practice for students to look at the microstructure of an AM specimen and compare the metallographic pictures to those of conventional materials.

Wear, Abrasion and Corrosion Resistance

A pin on disk wear test conform to ASTM G99, a Taber abrasion test conform to ASTM D4060, and a corrosion test conforms to ASTM B117 also can be added to the tests in case of the equipment availability.

Permeability Test for Plastic Parts

For AM plastic parts, due to porosities and imperfections inside the material, the permeability of the material increases. Besides the importance of permeability for AM objects intended to contact with gases and liquids [14], a permeability test conforms to ASTM D1434 can show the extent of the porosities.

Conclusions

Additive manufacturing methods were initially introduced as quick and flexible methods to build prototypes of new products. However, because of some unique features and benefits, they are replacing some well-known conventional manufacturing methods in some application. The new improved commercialized AM machines are used in mass production. Despite the extent of ongoing research and development on AM methods, they are associated with some drawbacks and quality related issues. While students look at the new AM methods as advanced manufacturing methods, it is essential to present them a full picture of the new technology with all of its benefits and problems, and provide them with the opportunity of testing and comparing the mechanical and surface properties of new materials. A model consisting of several standard test methods was presented in this paper. The equipment is used to perform the presented tests are the same as that used for conventional materials and usually available in material science labs of universities.

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