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Material properties

Structural characteristics of fused deposition modeling polycarbonate material

Walter Castro Smith*, Richard W. Dean

Bechtel Marine Propulsion Corporation, PO Box 1072, Schenectady, NY 12301, USA

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ABSTRACT

Rapid prototyping manufacturing techniques provide an avenue for quick and cost effective design assessments leading to shorter design cycles. In addition to providing first-of-a-kind and one-of-a-kind parts, rapid prototyped parts may be used as the actual part. In order for this to occur on a wide-spread basis, material properties of importance to design must be well understood. One pervasive rapid prototyping technique is Fused Deposition Modeling (FDM). A sampling of the basic structural properties of FDM polycarbonate parts as a function of orientation is presented. The results show that repeatable measurements can be made of the ultimate tensile strength and elastic modulus in FDM manufactured polycarbonate parts. The results also show a degradation in strength compared to bulk material properties (30%–53%, depending on orientation) and as manufactured properties as reported by the FDM vendor (36%–63%, depending on orientation).

1. Introduction

Rapid Prototyping (RP) fabrication of parts is becoming more common in industrial as well as hobby and craft settings. As the cost of RP decreases and the quality increases, the use of parts for assembly match-ups, product trials, and real-world applications is increasing. FDM fabrication accounts for a large portion of all RP parts.

Some studies have investigated cost, time to completion and accuracy of RP techniques relative to other manufacturing techniques for investment casting tooling [1], optimization of build orientation for build time minimization [2], as well as the evaluation of parameters critical to the quality production of RP produced parts [3]. What is missing from the current literature is a database of structural properties which can be used to design RP parts for production use. In the case of most RP parts, these data will be anisotropic and highly dependent on production techniques. Despite this anisotropy and dependence on production technique, it is important for design to consider what are limiting values of structural properties, such as ultimate tensile strength (σ_{UTS}), yield strength (σ_y), and Young's modulus (E) when choosing applications appropriate for RP fabrication.

Studies have been undertaken to examine the variability of design properties with manufacturing parameters and environmental exposure [4]. These studies were performed by an FDM machine vendor (Stratasys) and reported on a single orientation (Edge-Up, as defined below). Testing was performed in a climate controlled environment, not representative of normal industrial conditions, and optimized build parameters were used, which may not be used by all FDM operators. The results presented here are representative of parameters for material that was not optimized for structural integrity and so correspond to practical property estimates.

2. Testing

2.1. Production technique

Two series of tensile test specimens were produced. Both series were produced on a Stratasys Vantage SE FDM

* Corresponding author.
E-mail address: wsmith02@hotmail.com (W.C. Smith).

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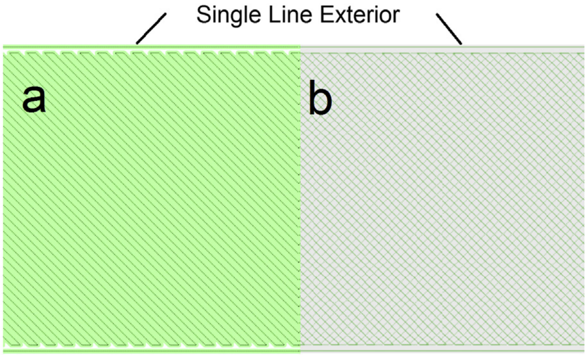

Fig. 1. Representative tool-paths for a single (a) and double (b) layer. This figure is equivalent to looking at a cross section of the structure of a part.

machine with a polycarbonate extrusion thickness of 0.508 mm (0.020 inches) and a slice height 0.254 mm (0.010 inches). The normal build mode was used and T16 tips were used for modeling. A representative build tool-path for a single layer as well as two superimposed adjacent layers is shown in Fig. 1. The layers were laid down in a diagonal pattern with alternating layers rotated by 90°. The edge of each layer was wrapped with a single drawn line, shown by an arrow in Fig. 1.

The first series of specimens tested were created by the FDM machine using a STereo Lithography (STL) file of the dimensions for specimen Types I, II, and III from ASTM D638, and shown in sketch form in Fig. 2. As the machine does not match the tolerances defined in the ASTM D638 specification, some variability is expected in edge and face linearity in this series of specimens. This type of specimen is representative of small parts where "edge effects" might be significant.

The second series of specimens were machined using conventional methods from large blocks of FDM deposited material. For this series, only ASTM D638 Type I specimens were manufactured. The results from this series are representative of the properties of the interior of large parts. In this case, specimen dimensions meet the requirements of ASTM D638 since the specimens were accurately machined from FDM materials.

In all cases, layers of polycarbonate material were deposited as shown in Fig. 1. To assess the orientation dependence of the properties of this material, three distinct orientations were used for specimens, Fig. 3. For Series 1 testing, two orientations (FU and UR) were used. For Series 2 testing, all three specimen orientations were used.

3. Results

3.1. Series 1

Series 1 was a pilot study to examine the optimal testing techniques for use in Series 2. Series 1 comprised only two

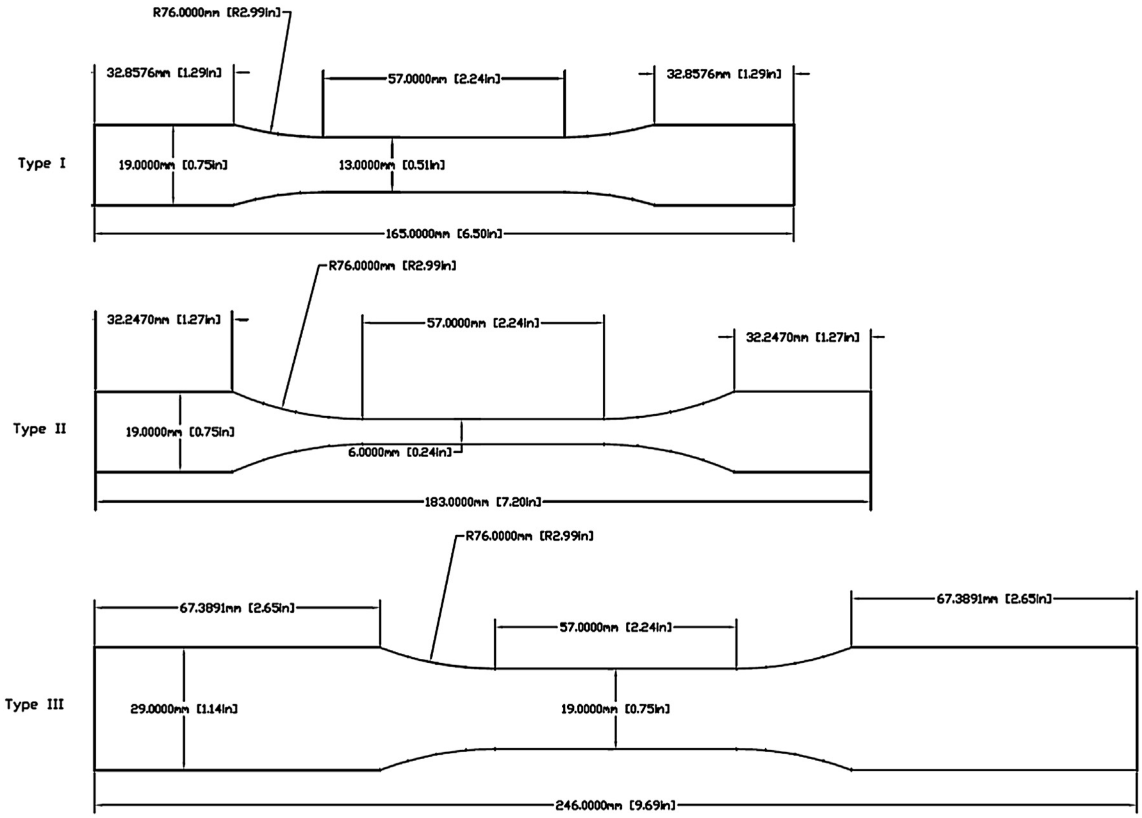

Fig. 2. Sketch of ASTM D638 specimen Types I, II, and III.