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Research Survey

Investigation of Mechanical Properties of Notched Samples Manufactured by Additive Manufacturing Method Under Different Impact Velocities

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Abstract

Fused Filament Fabrication (FFF), which is one of the additive manufacturing methods, has recently found industrial usage areas and has become frequently used. Industries using this production method can be listed as automotive, machine manufacturing, aerospace, etc. While heat and environmental resistance are important factors for parts such as fixtures and apparatus manufactured with this method, mechanical properties are often at forefront. In many studies, the properties of the materials used in FFF under static load have been investigated by tests such as tensile, compression, and bending. However, studies on mechanical properties under impact loading remained at a relatively low level. It is clear that material behavior under impact loading is important, especially for polymer materials.
In this study, the impact resistance of notched Polylactic acid (PLA) samples produced by FFF method under different impact velocities were investigated. For this aim, a Charpy impact testing machine with low capacity (10J) was designed and manufactured, and the hammer was dropped from different heights and different velocity values were obtained. The instantaneous angle of the arm to which the hammer is attached was recorded by a gyro sensor and Arduino. Impact resistance values calculated depending on the impact speed were evaluated comparatively.

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Eklemeli İmalat Yöntemiyle Üretilen Çentikli Numunelerin Farklı Darbe Hızları Altındaki Mekanik Özelliklerinin Araştırılması

Makale Bilgisi

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Öz

Eklemeli imalat metotlarından birisi olan Erimiş Filament Üretimi (EFÜ) son zamanlarda endüstriyel olarak da kendisine yer bulmuş ve sıkça kullanılır hale gelmiştir. Bu imalat metodunu kullanan endüstriler şu şekilde sıralanabilir: otomotiv, makine imalatı, havacılık vd. Bu metot ile üretilen fikstür, aparat gibi parçalar için kimi zaman ısıya ve çevresel etmenlere karşı dayanım önem arz ederken, çoğu zaman mekanik özellikler ön plana çıkmaktadır. Yapılan bir çok çalışmada, çekme, basma eğme gibi testlerle EFÜ'de kullanılan malzemelerin statik yük altındaki özellikleri incelenmiştir. Ancak darbeli yükleme etkisi altındaki mekanik özellikler ile ilgili çalışmalar nispeten düşük seviyede kalmıştır. Ancak, özellikle polimer malzemeler için, darbeli yükleme altındaki malzeme davranışı önem arz etmektedir.
Bu çalışmada, EFÜ metoduyla PLA filament kullanılarak üretilen çentikli numunelerin, farklı çarpma hızları altındaki darbe dayanımı araştırılmıştır. Bu amaçla, düşük kapasiteli (10J) bir Charpy darbe cihazı tasarlanmış ve imalatı yapılmış, çekiç farklı yüksekliklerden düşürülerek farklı hızlar elde edilmiştir. Çekicin bağlı bulunduğu kolun anlık açısı bir gyro sensör ve Arduino kullanılarak kaydedilmiştir. Çarpma hızına bağlı olarak hesaplanan darbe dayanımı değerleri karşılaştırmalı olarak değerlendirilmiştir.

1. INTRODUCTION

Polymer-based additive manufacturing has been increasingly utilized in a wide range of fields for the last several decades. Fused Filament Fabrication (FFF) is the most used method among additive manufacturing methods. The ability to quickly design, alter and print complex geometries produces a cost-effective manufacturing process to reduce the overall number of parts used in space hardware [1–4].

Additive manufacturing technologies are increasingly used in aerospace and missile applications for both military and civil purposes. Many companies in the aviation industry have begun the production trials of different aircraft parts by taking advantage of the 3-D printers. Detailed reviews on aerospace applications were published by various researchers [4–8].

The mechanical properties of additively manufactured parts made of PLA have been extensively investigated in the literature, especially focusing on the printing parameters' effects on the mechanical behavior. A number of studies have been reported regarding the modification of the processing parameters such as infill properties, layer thickness, layer orientation, bed, and nozzle temperature to improve the properties of the final product [9–12]. Additionally, for the characterization of mechanical properties, different tests such as uniaxial tensile, compression, bending, and compression tests were used [11–15]. It is thought that there are not enough studies in the literature on impact resistance among these loading types. Moreover, the effect of impact velocity on impact strength were more seldom investigated. One study that included impact velocity parameter was published by Vidakis et al. [13]. In this study, ABS and ABS Plus notched and unnotched samples were subjected to impact under different strike velocities to observe the critical impact resistance

In this study, a low capacity Charpy impact testing machine is designed and manufactured. Then, V-notched PLA samples were manufactured using FFF method for impact test. Impact tests were carried out with different hammer heights which supply different impact velocities. The test results reported in the present study will not only enrich the literature, but also provide a perspective for engineers who design and manufacture with FFF method.

2. EXPERIMENTAL DETAILS

PLA filaments are mostly preferred by users due to their affordable price, environmental product and easy printing. Therefore, in this study, CCTREE branded PLA filament with a thickness of 1.75 mm and a tolerance of ±0.03mm was used as the sample material.

Test samples were produced using Creality Ender 3 Pro branded FFF machine which has 220 × 220 × 250 mm print volume and equipped with an automatic bed leveling unit. STL files of the test sample were generated using SolidWorks CAD software and further sliced for printing using Ultimaker Cura software version 4.8.0.

The V-notched test sample was designed to have a height and width of 10 mm and a ligament length under the notch of 8 mm. Radius and angle of the notch were 0.25 mm and 45o, respectively. Samples were manufactured with 100% filled with longitudinal lines. The sliced sample is given in Fig. 1. Used production parameters were given in Table 1.

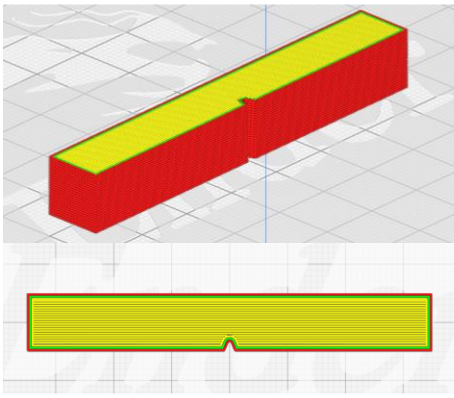

Figure 1. V-notched Charpy test sample.

Table 1. Used production parameters.

Parameter	Value
Nozzle Diameter	0.4 mm
Layer Height	0.4 mm
Printing Temperature	200 °C
Build Plate Temperature	50 °C
Print Speed	50 mm/s

For testing the produced samples, a low capacity (10J) Charpy impact testing machine is designed and manufactured in accordance with ASTM E23 (Fig. 2.) Designed machine has a hammer with a weight of 3080 g and a distance from center of gravity of 197.69 mm.

The hammer is carried by a shaft that is attached to the bearings on both sides and moves together with the hammer. The angle of the hammer is measured via GY521/MPU6050 gyro sensor bolted to carrier shaft. Then, measured data is sent to Arduino UNO microcontroller via jump wires. The data read by Arduino UNO is transferred to PC over USB channel and a program is developed using Labview software to calculate impact strength and impact velocity. The flowchart of data acquisition system and the user interface of the developed program are given in Fig. 3 and Fig. 4, respectively. Data logging rate was 100 Hz. Potential energy values were calculated using

Equation 1 in the background. For the initial state, the maximum angle at the falling side and for the last state (after cracking the sample) maximum angle at the rising side is taken in to account. Fracture energy is calculated as the difference of these two values. Impact strength value is calculated by dividing fracture energy to cross-sectional area under the notch. Additionally, impact velocity is calculated using Equation 2. and changing h value.

$$E=mgh \qquad (1)$$

Where E is potential energy, m is mass of hammer, g is the acceleration of gravity and h is initial or last height of hammer.

$$V = \sqrt{2gh} \qquad (2)$$

Where V is impact velocity, g is the acceleration of gravity and h is the initial height of hammer.

Figure 2. Charpy impact testing machine.

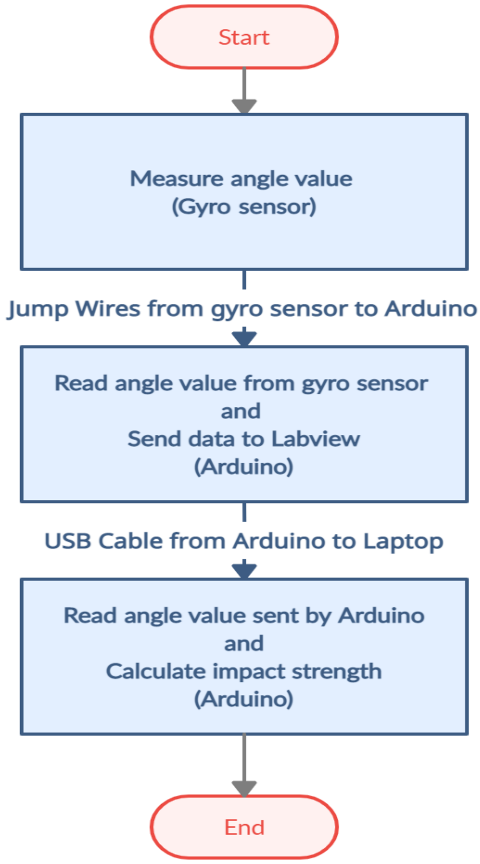

Figure 3. The flowchart of data acquisition system.

Figure 4. The user interface of the developed program.

3. RESULTS AND DISCUSSION

Produced V-notched samples were tested using developed Charpy impact testing machine. The samples were tested at five different impact velocities: 1, 1.5, 2, 2.5 and 3 m/s. Obtained impact resistance values of tested samples were given in Fig. 5. Photographs of the fractured samples were given in Fig. 6. Minimum impact resistance is obtained as 6.20 kJ/m^2 at the lowest impact speed (1 m/s). The samples could not be fractured under this value. This value is determined as critical impact resistance. Impact resistance values increased linearly up to 2 m/s and then increased slightly up to 3 m/s.

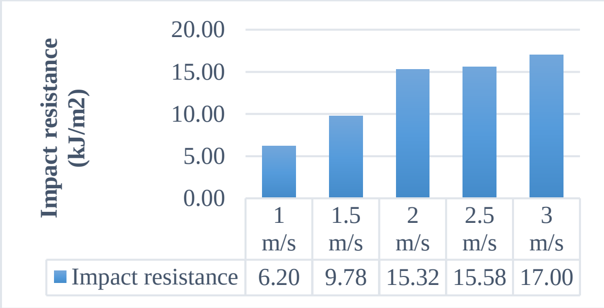

Figure 5. Impact resistance of tested samples.

The trend of observed results is in accordance with Vidakis et al. [13]. As observed in this study, the impact resistance values showed a rapid increase from critical impact resistance to a certain value and then the increase rate decreased.

Tanveer et al. (2019) studied the effect of variable infill density along cross section of the samples on mechanical properties. The authors concluded that the infill density is directly proportional to the impact strength, which results in the weight of raw material. The findings of the authors are in agreement with the results obtained in this study [16].

Figure 6. The fractured samples.

4. CONCLUSION

In this study, V-notched samples manufactured using FFF method were subjected to Charpy impact testing. For this purpose, developed and manufactured a low capacity testing machine was used. Test samples were tested under five different impact velocities.

- The lowest impact resistance value obtained was 6.20 kJ/m^2 at 1 m/s impact velocity.
- The highest impact resistance value obtained was 17.00 kJ/m^2 at 3 m/s impact velocity.
- The higher impact velocity resulted in higher fracture energy.

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VITAE

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