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Impact Energy Consumption Capabilities of 3D Printed Specimens

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Abstract – Additive manufacturing which is developed in the last half century is promising manufacturing technology. It uses layer-wise production method for obtaining finished product. In recent years, thousand researches were made but there was still gaps about impact studies. In this study, the effect of fill pattern, filament material and layer thicknesses were investigated on the impact energy consumption capabilities of 3D printed samples via drop weight impact test. The specimens were produced using Fused Deposition Modelling (FDM) Method with various fill patterns, different filament material types and different layer thicknesses. PLA/ PHA, CPE, ABS and PC materials were used for the samples. 0.2, 0.15, 0.1 mm layer thickness were examined for PLA/PHA material products. Concentric, Cubic, Cubic Subdivision, Linear, Triangle and Tetrahedral infill types are used. The effect of room temperature was also investigated during printing of samples. For this aim, the printing area was scanned by thermal camera. As a result of this work, it is concluded that linear fill pattern had a significant difference in energy consumption by comparing other fill patterns. Infill rate and energy consumption capabilities of specimens were directly proportional for linear and cubic subdivision infill type. It was observed that when thickness of layers is increased, the specimen strength was also increased.

Keywords – Drop Weight Impact Test, FDM, Additive Manufacturing, Printing Properties, Energy Consumption

I. Introduction

Additive manufacturing has been developing since 1980's. There are several types of additive manufacturing such as SLS, SLA, FDM. Metal, ceramic and plastic materials are used for production with these methods. FDM is more popular than other additive manufacturing types, because it is more accessible and end user friendly. FDM uses PLA, ABS, PC, CPE, TPU95 and many other special filaments for production material. It has advantages of all other additive manufacturing process. Main advantages of additive manufacturing are easily production of complex parts, less material waste, fast and single main processing.

In last years, we saw huge increase of research about FDM. Several researchers studying about mechanical properties of parts which produced by this technique. As an example, O.S Cornerio et. Al. use polypropylene as a production material for FDM[1], Rai Zou et. al. study isotropic and anisotropic elasticity and yield properties of ABS material which produced by FDM [2]. M. Domingo et. al. study mechanical properties of PC product produced by FDM[3] and J.M. Chacon et. al. examine FDM production parameters for PLA material [4].

When we review literature, we noticed study about drop tower impact test are too few. Tsouknidas et. al. study about bumper type specimens drop weight impact test which PLA type material, produced by FDM and examine effects of layer height, infill density and infill type [5]. In this paper, we study sheet type materials impact resistance which produced by FDM. We examine material type and effect of infill type, layer height and infill density.

II. Materials and Method

Firstly, we developed specimen models for impact test using 3D CAD program. For samples, we use ISO EN 6603 standard. Only the difference is that height of specimens are 10 mm (5 times higher than standard) because we want to see effect of infill type. For shorter specimens, the effect of infill type is not observed very well. Then, these specimen models are exported as .stl format and sent to CURA 3D printing software. Models are sliced into the layers using CURA. Also the printing parameters (material type, infill type, layer height and infill rate) are determined by using CURA. For all type of specimens, 3 different samples are printed. All samples are manufactured using Ultimaker 3D Extended printer. This printer uses FDM method for production.

FDM method working principle is;

1- Filament come to nozzle via feed system.

2- Nozzle moves toward x-y axis and prints material which heated to near of melting temperature.

3- After printing layer, build plate moves one layer height down at z-axis

4- Nozzle starts printing next layer and system repeats itself until all layers printed.

All samples conducted to drop tower impact test using CEAST 9350 test machine in figure 1.

Fig.1 Drop tower impact test system CEAST 9350

The infill types used in this study are concentric, cubic, cubic subdivision, triangle, tetrahedral, linear. They are shown in figure 2.

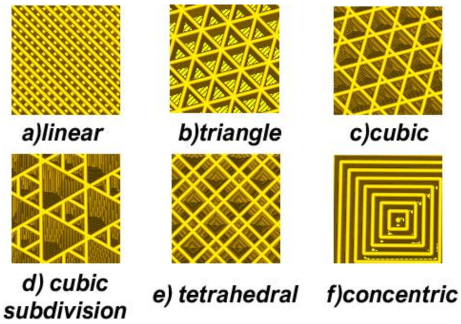

Fig.2 The infill types used in this study.

PLA/ PHA, CPE, ABS and PC materials were used for the specimens. 0.2, 0.15, 0.1 mm layer thickness were examined for PLA/PHA material specimens. Also infill rate examined for 100%, 80%, 60%, 40% and 20% values. Total 66 specimen tested. Unless indicated otherwise, layer thickness 0.2 mm, infill type is cubic subdivision, infill rate is %80 and material type is PLA/PHA. While printing we noticed warping the edge of specimens. Build plate scanned by thermal camera and noticed there is 5^{o} C difference between yellow and orange areas as shown as figure 3. So for solving problem, build plate temperature increased 5^{o}C.

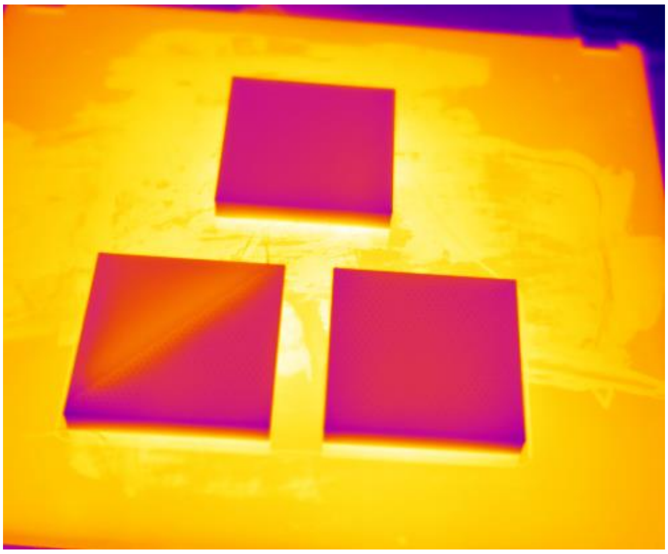

Fig. 3 Thermal scan of build plate while printing

III. Results

According to obtained results, specimen which has 0,2 mm layer thickness absorbed 136 J impact energy, for 0,15 mm layer thickness this value is 8,6 J and for 0,1 mm layer thickness 6,8 J.

Table 1. Max Absorbed Energy Values Of Different Infill Types

Infill Type	Max Absorbed Energy
Concentric	125,22 J
Cubic	138,76 J
Cubic Subdivision	136,73 J
Tetrahedral	137,8 J
Triangle	139,3 J
Linear	3,55 J

As shown as table 1, the specimen which has a linear infill type has lowest energy absorption capability. For material types; ABS specimens absorbed 18.55 J, PLA/PHA specimens absorbed 136 J, CPE specimen absorbed 48.46 J and PC specimen absorbed 29,13 J energy. The specimen which has 80% infill rate absorbed 136,73 J energy, respectively this value change to 27 J for 60% infill rate. For infill rate 40%, max absorbed energy value is 6,33 J and for 20% infill rate, value is 5,7 J. Also the specimen which producted from ABS material with various infill rate in linear infill type tested and results are given table 2.

Table 2. Max absorbed energy values of different infill rates

Infill rate	Max absorbed energy
100	9.17
80	7.51
60	4.46
40	3.2
20	1.59

IV. Discussion

When we examine results of different infill types, we noticed there is not much difference in infill types except linear as shown as figure 3.

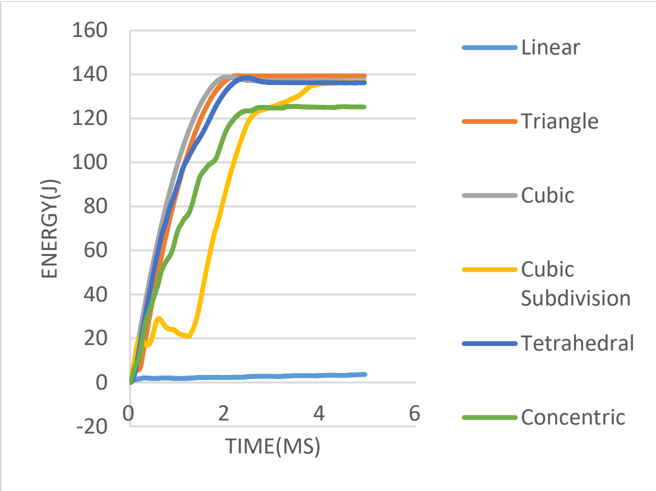

Fig. 3 Effect of infill types

The reason of this much difference between linear and other infill types is the other infill types scatter impact effect to more wide area while linear infill can't. So crack of other infill types is wider than linear as shown as figure 5.

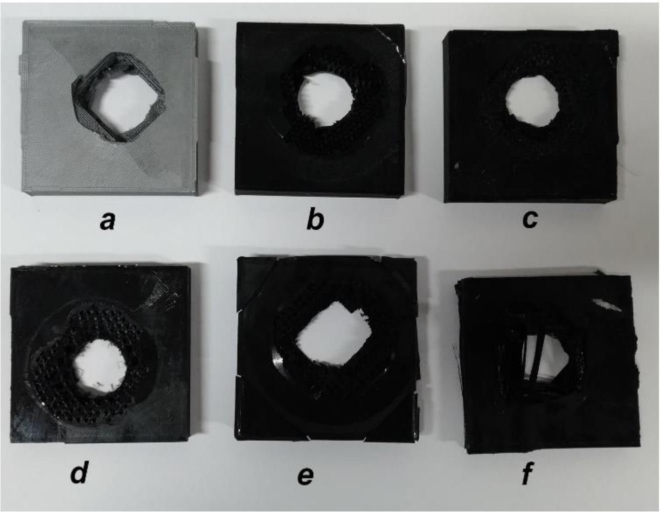

Fig. 5 Tested specimens; a) linear b) triangle c) cubic d) cubic subdivision e) tetrahedral f) concentric

Also we noticed better strength with increase the layer thickness. The reason of this is increasing layer thickness it causes decreases number of layer so it decrease the amount of porosity between layers and increase rigidity. Also increasing infill rate, cause more rigid materials and increase energy absorbing capability of specimens.

V. CONCLUSION

The impact energy consumption rates of 3D printed samples are investigated for various fill patterns, filament materials and layer thicknesses. The tests are carried out by following ISO EN 6603 standard.

All test specimens are produced in Ultimaker 3 extended FDM machine. It is noticed that the environment temperature causes temperature differences in manufactured specimens and it causes warping faults especially for ABS filaments. Thermal camera views show that there are 5 °C temperature differences in the top surface of produced specimens when environment temperature is around 20 °C. All faults are removed by increasing the built plate temperature by 5 °C.

It is observed that only linear fill pattern has an important effect in impact energy consumption. It has very low consumption capability by compared all others. Cubic fill pattern consume 125 joul energy during drop impact test, while all other pattern types consume around 137 joul.

Various filament materials are investigated for the same test. It is shown that PLA/PHA has best performance for the energy consumption by comparing ABS, PC and CPE filaments. ABS has the lowest energy consumption capability.

The effects of infill rates of specimens are also investigated. It is found that when we increase the amount of infill rates, the amount of consumed energy also increases during impact.

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