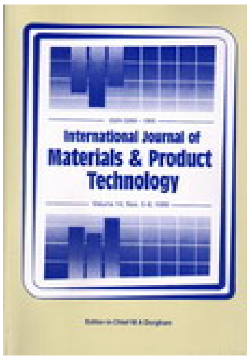

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Effect of process parameters on impact strength and hardness of FDM printed ABS parts

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Abstract: Fused deposition modelling, an additive manufacturing (AM) process, helps in manufacturing complex components that are influenced by the various process parameters. The main objective is to experimentally evaluate the Shore D hardness and Izod impact of 3D-printed test specimens. Using a 3D printer, the test specimens are manufactured. The test specimens were manufactured taking into account various printing factors such as printing orientation, printing pattern, and infill density. The specimens were produced with three printing orientations (edge, vertical, and flat), four infill patterns (grid, rectilinear, honeycomb, and cubic), and an infill density range of 20% to 100%. For 60% infill density, cubic infill structure, and edge printing orientation, the highest impact strength is obtained (2,024 J/m) and a Shore D hardness of 45.7, and for 40% infill density, honeycomb infill structure, and edge printing orientation, the lowest impact strength is obtained (203 J/m), with a hardness of 42.8 on the Shore D scale. The study shows that the Izod impact strength and Shore D hardness of FDM-printed ABS items are affected by process parameters.

Keywords: Shore D hardness; additive manufacturing; Izod impact strength; process parameters; fused deposition modelling.

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1 Introduction

Rapid prototyping (RP) objects have been created using additive manufacturing (AM), which primarily creates visual models for design verification and the creation of functional testing goods throughout product development. Components can be immediately manufactured from computer-aided design models. It aids in reducing the amount of time needed to finish the product development cycle.

A cutting-edge and superior manufacturing technique called additive manufacturing (AM) is used to create items from data files generated by computer-aided design software. A 3D model is built in AM layer by layer. The parts manufactured by an AM process require less time, cost less to fabricate, and can produce more complicated parts compared to traditional manufacturing methods (Mohamed et al., 2015). Several engineering sectors, including aerospace, biomedicine, supply chain and logistics, automotive products, and custom parts, use AM technology extensively. For engineering applications, these technologies can be utilised to create conceptual models, functional models, and customised models (Mohamed et al., 2016; Chen et al., 2016).

AM is categorised by ASTM F2792-12a (2012) under stereolithography (SLA), fused deposition modelling (FDM), selective laser sintering (SLS), electron beam melting (EBM), laminated object manufacturing (LOM) and solid ground curing (SGC). A wide variety of machines are used, depending on the AM process. FDM is used because of its affordable equipment cost, readily available materials, material changeability, simplicity of operation, and most significant additive manufacturing technology. The build quality of components using FDM technology is influenced by a number of variables, including mechanical strength, dimensional accuracy, and surface finish (Tontowi et al., 2017). To determine the effect on the FDM process parameter, significant research efforts are undertaken. In the AM process, it's crucial to choose the right process parameters (Popescu et al., 2018). For an FDM process, it is important to take into account the infill density, layer thickness, infill pattern, and caster angle. The right parameter selection can lead to optimal performance (Raut and Kolekar, 2023).

According to the review of the literature, build quality is a significant factor impacting impact strength. The features of acrylonitrile butadiene styrene (ABS) filaments, which are suited for technical applications, include temperature resistance, mechanical strength, flexibility, and machinability. Tsouknidas et al. (2016) studied the effect of energy dissipation on commercially available PLA filament by varying the layer height, infill patterns, and infill density. The results show that porous specimens are more prone to changes in process parameters, which decrease with higher density. Al Khawaja et al. (2020) studied FDM-based additive manufacturing to understand the mechanical behaviour of printed parts. The compression properties of PLA filament are checked based on the application. In order to investigate the three-point bending strength, impact strength, and tensile strength of 3D-printed components utilising FDM, recycled polylactic acid (Re-PLA) and polylactic acid (PLA) were utilised. The chosen process parameters include infill structure, infill density, and layer thickness. The optimum parameters were 0.25 mm layer thickness and 70% infill density using PLA filament (Atakok et al., 2022). In order to determine the Izod impact strength and hardness, the author examined optimised conditions for producing effective lightweight components from carbon fibre PLA filament. The experimental analysis followed the Taguchi design of the experiment's L9 array. Infill pattern, printing speed, infill density, and nozzle temperature are taken into account as process variables. The parameters used to produce lightweight parts with optimum impact strength and hardness were observed at a nozzle temperature of 240°C, a print speed of 120 mm/s, and an infill density of 50% with a grid-type infill pattern (Ansari and Kamil, 2022). Izod impact testing of test specimens of polylactic acid (PLA) and polyethylene terephthalate glycol (PETG) was fabricated using a Prusa MK3 printer. The test sample has a 100% infill density, a raster angle of ±45° and layer thickness 0.15 mm are the fixed parameters and four thicknesses of 4 mm, 6 mm, 8 mm and 10 mm. The PLA specimens provide a stronger impact force, while the PETG specimens allow for a higher deflection. Comparable results are shown by the Izod impact strength ratings for both materials (Popa et al., 2022).

According to reports, most of the current research focuses on studying the tensile characteristics of ABS parts. The effects of infill density, infill pattern, and printing orientation on impact strength and hardness have not been thoroughly studied. Additionally, there are comparatively few documented works using ABS as printed material. Because ABS is a printing material, it is crucial to investigate the manner in which infill density, infill pattern, and printing orientation affect the final product. The main objective of the current study is to determine the effects of infill density, infill pattern, and printing orientation on the impact strength of FDM-printed ABS parts.

2 Material and method

2.1 Material

ABS filament material with a 1.75 mm diameter was used to build the items using the FDM machine. Butadiene, an elastomer, is spread during the process across a styrene and acrylonitrile copolymer particle matrix to create ABS, a thermoplastic. Around 90–100% of its makeup is made up of the resins acrylonitrile, butadiene, and styrene. Wax, tallow, and mineral oil (each in the range of 0–2%) may also be present in trace levels. Styrene improves the stiffness of the ABS copolymer, butadiene increases impact resistance, and acrylonitrile enhances its heat resistance. Furthermore, ABS is less expensive. Due to its excellent process stability, chemical resistance, strength, precision, and repeatability (Osama et al., 2019), it is a good option for FDM. The constant parameters used for ABS filament in a 3D printer are shown in Table 1.

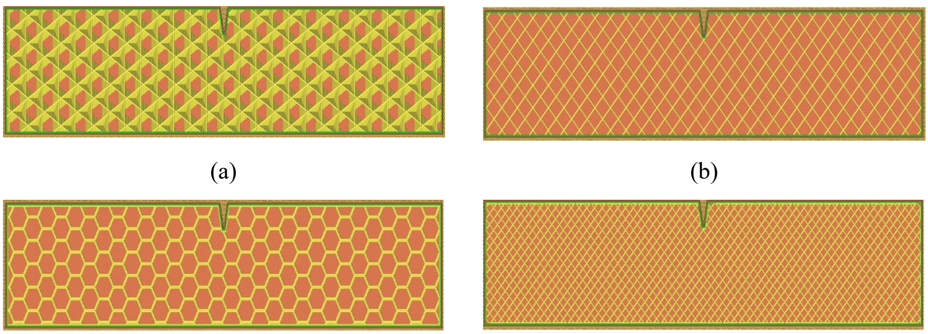
Table 1 Constant printing parameters for ABS filaments

Parameters	*ABS*
Nozzle temperature (°C)	250
Bed temperature (°C)	100
Nozzle diameter (mm)	0.4
Printing speed (mm/sec)	100
Layer thickness (mm)	0.2

Table 2 Process parameters and their levels

Parameters	*Levels*
Infill density (%)	40, 60, 80, 100
Printing orientation	Flat, vertical, edge
Infill pattern	Grid, rectilinear, honeycomb, cubic

Figure 1 Infill pattern for 3D printed specimen, (a) cubic (b) grid (c) honeycomb (d) rectilinear (see online version for colours)



(a) (b)

(c) (d)

2.2 *Methods*

2.2.1 *Fabrication of the sample*

3D Raise N2 model with an automatic material feeding system and a larger build chamber volume of 300 × 300 × 300 mm, was used to create FDM samples. Since the machine has dual extruders, other materials can be added. The fabrication support material is made of brittle material that is easily shattered with the hands. Because to its temperature-controlled extrusion head, the machine deposits the material in layers. There are five important processes in the fabrication process of 3D printing. The necessary geometry is constructed in a CAD model in step one. In the following stage, the model is transformed into an STL file that the printing machine software can read. The third stage, called pre-processing, is when the perfect conditions are created for the component's location and choice of support structure. The actual fabrication process is done in the fourth stage. Depending on the complexity, support materials are first deposited using one nozzle, and then the primary material, ABS with a diameter of 1.75 mm, is deposited using a second nozzle, continuing until the desired thickness is reached. The ABS material is heated to the glass transition temperature during the extrusion process in order to liquefy it. The fifth and final stage, post processing, involves removing the manufactured component from the machine chamber and breaking apart the support materials.

Figure 2 Process flow diagram for experimental analysis of 3D printed specimens

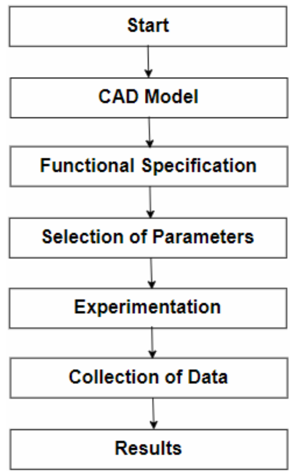
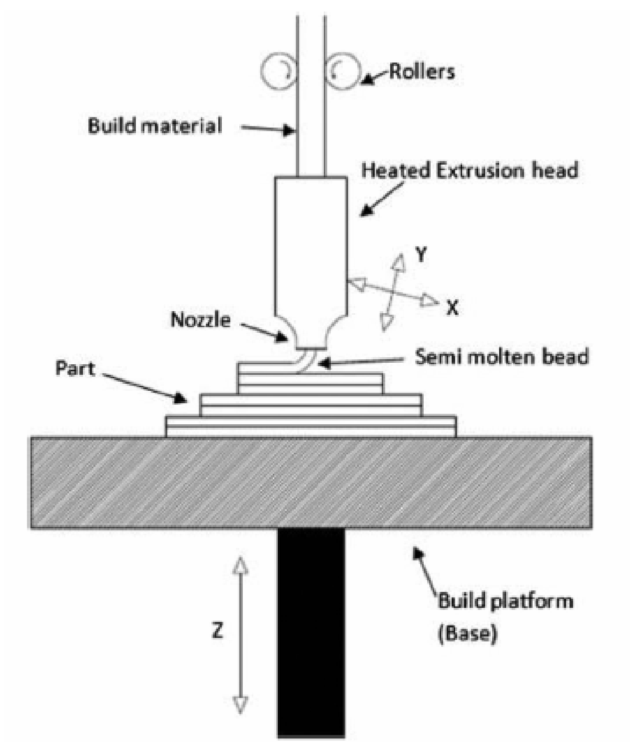


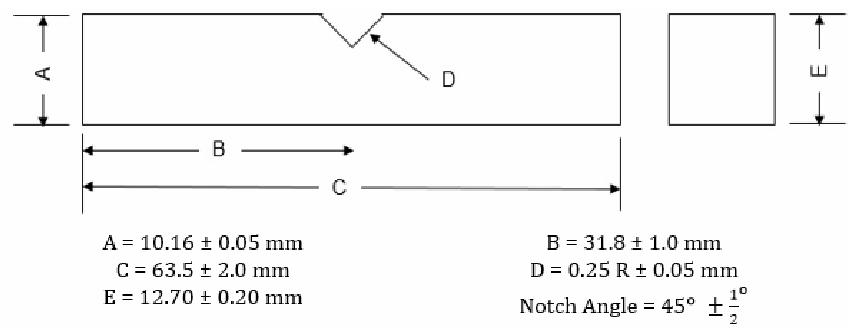
Figure 3 Schematic diagram of FDM process



2.2.2 Specimen design and testing

Solidworks CAD modelling software was used to design the test samples used in this investigation complying with ASTM D256 standards (Ansari and Kamil, 2022), with dimensions as given in Figure 4. The five stages are followed by the fabrication procedure. The .STL format is transferred to slicing software called IdeaMaker. The main roles of the slicing program include layering the CAD model, providing projection support, setting process settings, and adjusting the object's position on the 3D printer bed. For printing test samples, a 3D Raise 2N FDM machine was utilised with a sliced file containing G codes. The three categories of process parameters – infill pattern, infill density, and printing orientation are printed on the test specimens in various combinations. These printed specimens are tested using impact testing machine to obtain Izod impact strength property.

Figure 4 Specimen configuration as per ASTM D256



2.2.3 Dimensional and part weight measurements

The printed parts were stacked one by one on a scale to calculate the amount of material used to print every individual example. A digital scale was used to weigh the object, and the precision was 0.001 g.

2.2.4 Izod impact test

The Izod impact test on ABS FDM produced components was carried out in accordance with ASTM D256. For the purpose of analysing each sample using the mechanical Izod impact equipment, the pendulum was raised, locked, and clamped in the raised position at a standard angle of 140°. The Izod impact test rig consists of a 140° pendulum drop angle, a strike weight of 21.4 kg, a speed of 5.3466 m/sec, and an impact energy of 170 J. In general, the pendulum must first reach a certain height before being released. As it swings in the direction of a mounted, moulded specimen made of the test material, the weighted end of the pendulum picks up speed. The test specimen is broken as it strikes it, and the pendulum loses energy in the process. As a result, the swing is not as high. As the test specimen breaks, the energy wasted by the pendulum is equivalent to the energy absorbed by it. The test specimen can be mounted in a variety of ways, and there are many specimen sizes and preparation techniques (ASTM D256-10e1, 2018). Impact testing is used to assess the material's impact toughness. This is defined as the material's durability and capacity to absorb energy while withstanding abrupt loads. When determining toughness, the ductility and strength of the material under examination are taken into consideration (Chua and Leong, 2014).

Table 3 Sample dimensions and experimental conditions

	H (mm)		*A (mm)*		*C (mm)*		*E (mm)*		*Humidity (%)*		*Temperature (°C)*	
	Mean	*[St dev]*	*Mean*	*[St dev]*	*Mean*	*[St dev]*	*Mean*	*[St dev]*	*Mean*	*[St dev]*	*Mean*	*[St dev]*
Observed	3.28	[0.08]	10.16	[0.01]	63.50	[0.28]	12.72	[0.14]	51.00	[2.75]	22.17	[0.81]
Nominal	3.25		10.16 ± 0.06		63.50 ± 2.00		12.70 ± 0.20		50.00 ± 10.00		23.00 ± 2.00	

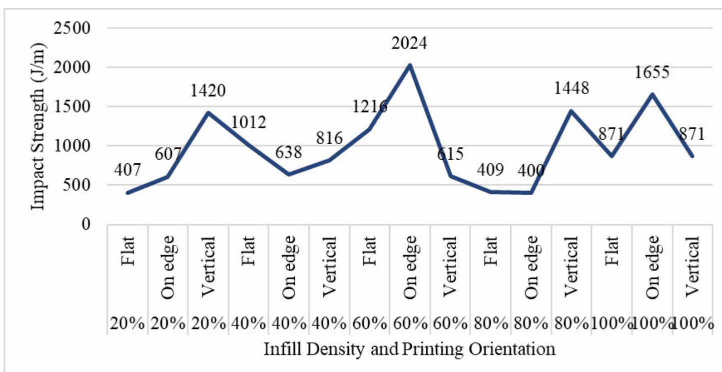
2.2.5 Hardness measurement

The hardness of the 3D-printed ABS specimens was calibrated using a digital Shore D durometer that has a measuring range of 0–100 HD, a depth of indentation of 0–2.5 mm, and a test pressure of 0–45.5 N. Before the test began, test specimens were positioned on a fixed, sturdy surface (Maguluri et al., 2022). The test specimen was indented vertically with an indenter needle, and the reading was noted. Each specimen was subjected to the evaluation five times.

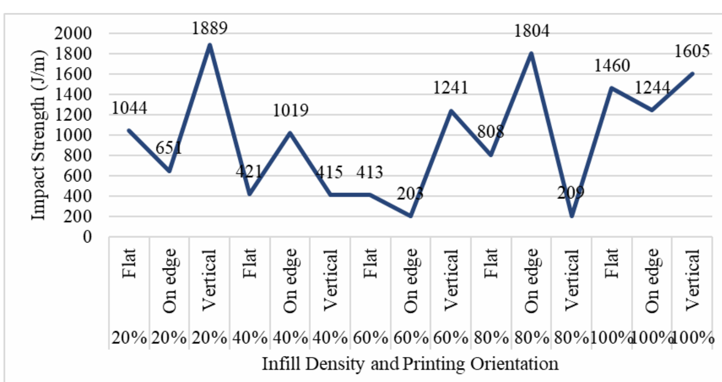
3 Result and discussion

A number of test specimens were printed using the FDM process to experimentally study the effect of process parameters on Izod impact strength and Shore D hardness.

Figure 5 Impact strength based on infill structure, (a) cubic (b) grid (c) honeycomb (d) rectilinear (see online version for colours)

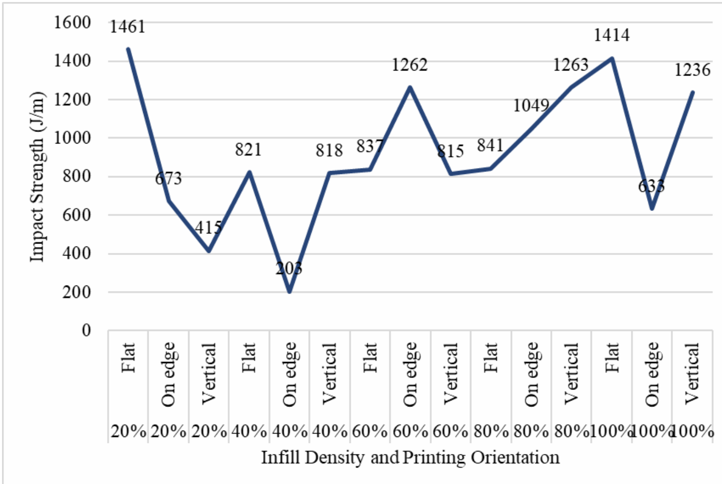


(a)

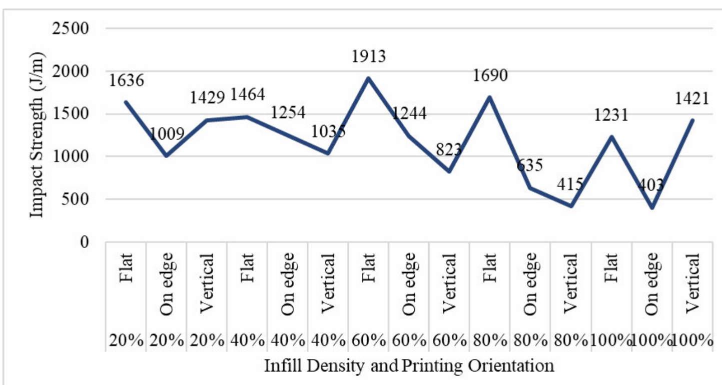


(b)

Figure 5 Impact strength based on infill structure, (a) cubic (b) grid (c) honeycomb (d) rectilinear (continued) (see online version for colours)



(c)



(d)

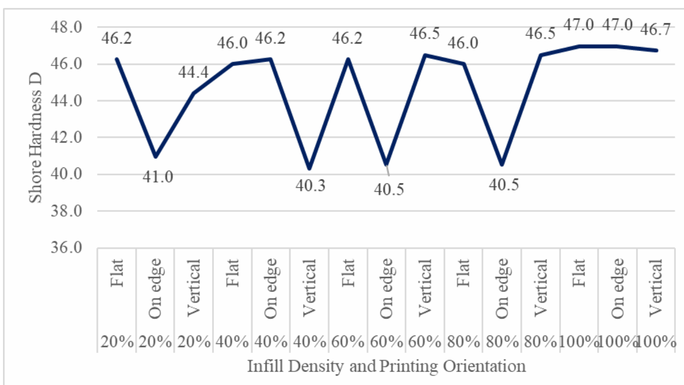
4.1 *Izod impact strength*

The effects of infill density and printing direction while maintaining the infill structure's stability are shown in Figures 5(a)–5(d). It can be observed that the Izod impact strength increases for the cubic infill structure and then goes on decreasing for the other infill structures. Figure 5(a) shows that for cubic infill structure, infill density is 20%, and on edge printing orientation, the highest Izod impact strength of 2,024 J/m is achieved, and the lowest of 400 J/m is obtained for 80% infill density and vertical printing orientation. The experimental result shown in Figure 5(b) shows that the grid infill structure's highest and lowest Izod impact strength is 1,889 J/m and 203 J/m, respectively, for the process parameters 20% infill density and vertical printing orientation and 60% infill density and on-edge printing orientation. Figure 5(c) shows the experimental results for the honeycomb infill structure, where 1,461 J/m and 208 J/m are impact strengths achieved for 20% infill density and flat printing orientation and 40% infill density and on-edge printing orientation. Similarly, in Figure 5(d) for rectilinear infill structure at 60% infill density with flat printing orientation and 100% infill density with on-edge printing orientation, the results achieved are 1913 J/m and 403 J/m, respectively. From the experimental results, it is observed that the infill structure plays an important role along with infill density and printing orientation.

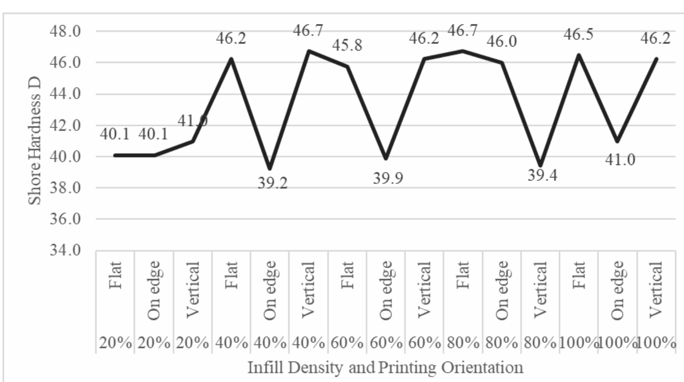
4.2 Shore hardness

Figures 6(a)–6(d) show the effect of infill density and printing orientation on Shore hardness D while keeping the infill structure fixed. Figure 6(a) shows that hardness 47 and 40.3 on the shore D scale are the highest and lowest hardness for cubic infill structures. Similarly, Figure 6(b) shows 39.2 and 46.7 as the lowest and highest hardness for the grid infill structure. Figure 6(c) shows the hardness of the honeycomb infill structure, with the highest and lowest hardness values on the shore D scale being 47.0 and 33.0. Figure 6(d) shows that with a rectilinear infill structure, Shore D hardness of 39.7 and 46.7 is the lowest and highest hardness achieved.

Figure 6 Shore hardness D based on infill structure, (a) cubic (b) grid (c) honeycomb (d) rectilinear (see online version for colours)

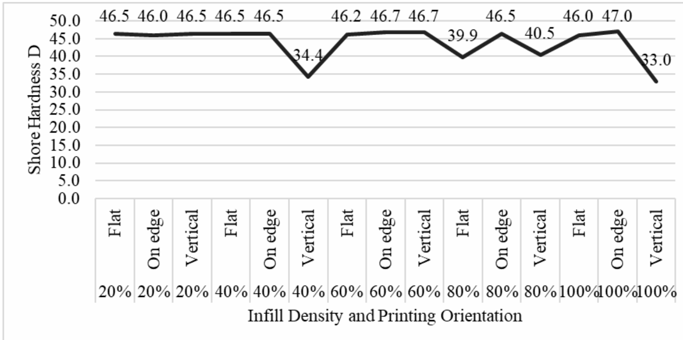


(a)

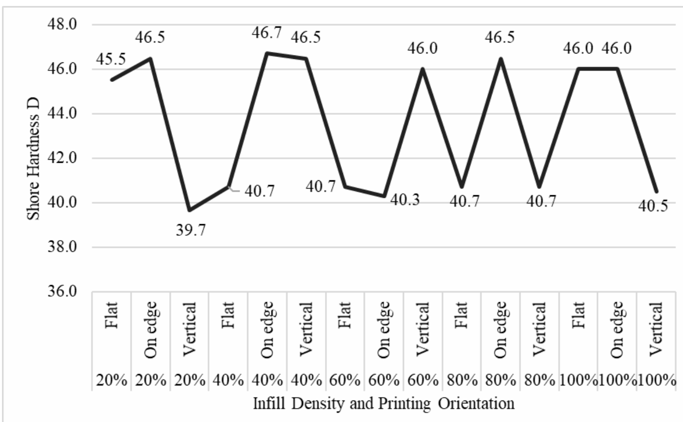


(b)

Figure 6 Shore hardness D based on infill structure, (a) cubic (b) grid (c) honeycomb (d) rectilinear (continued) (see online version for colours)



(c)

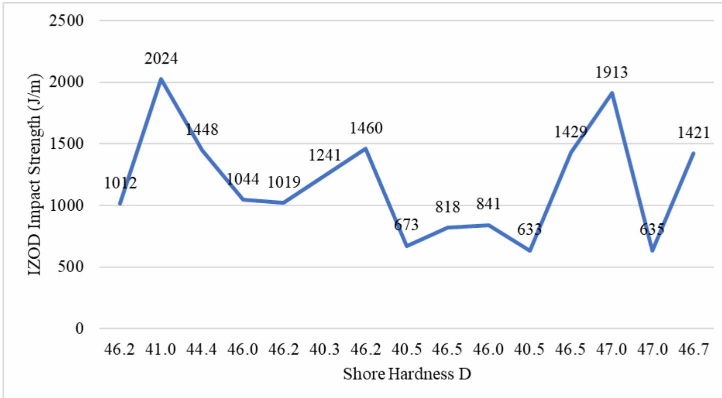


(d)

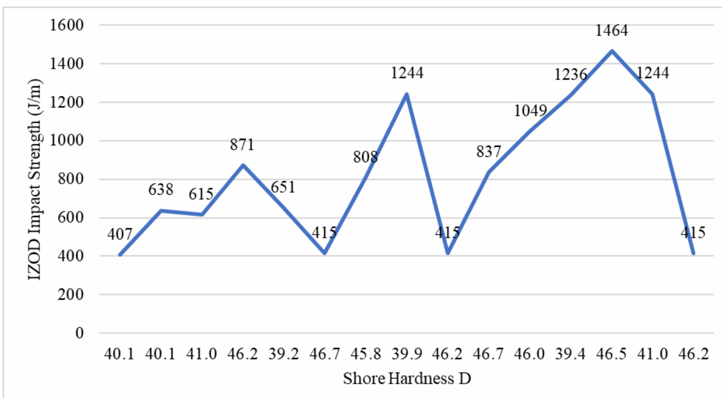
4.3 Relationship between Izod impact strength and Shore D hardness

The relationship between impact strength and Shore D hardness for the cubic infill structure shows that the highest impact strength (2024 J/m) obtained is 41.0 on the Shore D scale, and the lowest impact strength (633 J/m) obtained is 40.5. Similarly, for the grid infill structure, the highest impact strength is 1,464 J/m with a hardness of 46.5 on the Shore D scale, and the lowest impact strength is 407 J/m with a hardness of 40.1. For the honeycomb infill structure, 1,690 J/m is the impact strength and 47.0 is the hardness obtained; similarly, 203 J/m is the lowest impact strength with a hardness of 34.4 on the Shore D scale. The highest and lowest impact strengths for rectilinear infill structures are 1,889 J/m and 409 J/m, respectively, with hardness of 46.7 and 39.7 on the Shore D scale.

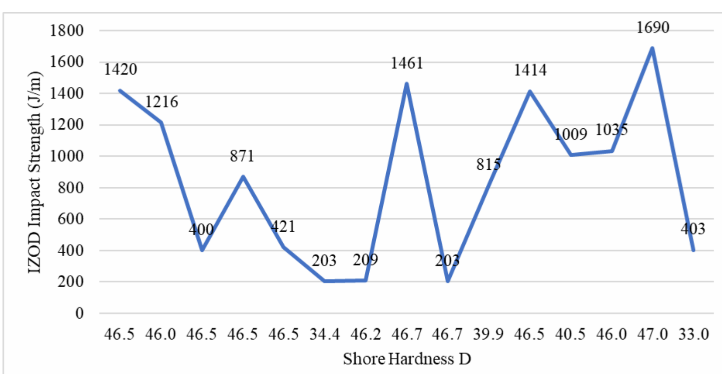
Figure 7 Relationship between Izod impact strength and Shore hardness D according to various infill structure, (a) cubic (b) grid (c) honeycomb (d) rectilinear (see online version for colours)



(a)

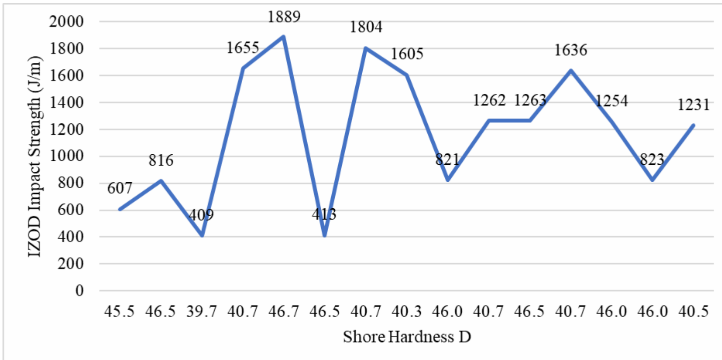


(b)



(c)

Figure 7 Relationship between Izod impact strength and Shore hardness D according to various infill structure, (a) cubic (b) grid (c) honeycomb (d) rectilinear (continued) (see online version for colours)



(d)

5 Conclusions

The experimental results of the Izod impact strength and Shore D hardness parameters of 3D-printed ABS specimens are presented in this research. The impact of different process variables on the Izod impact strength and shore D hardness may be seen when factors like infill density, printing orientation, and infill pattern are taken into account. By changing the infill density and infill pattern, the test specimen can be manufactured as either a solid or hollow object. These are the investigation's results.

1 Shore D hardness and Izod impact strength are influenced by process variables such as infill density, infill pattern, and printing orientation. Experimental investigation has shown that the infill pattern is critical to the ABS material's impact strength and hardness.

2 For the same material and infill density, experimental investigation showed that the infill pattern significantly affected the impact strength and hardness values that are highest and lowest. The highest impact strength of 2,024 J/m with a hardness of 41.0 on the Shore D scale is achieved for 60% infill density, cubic infill structure, and on-edge printing orientation; similarly, the lowest impact strength of 203 J/m and 34.4 on the Shore D scale is obtained for 40% infill density, honeycomb infill structure, and on-edge printing orientation.

3 According to an experimental study, printing patterns with a vertical honeycomb arrangement have lower impact strengths for all infill densities, whereas patterns with rectilinear or cubic flat patterns have the highest impact strengths of ABS materials. The honeycomb vertical has the lowest impact strength, mostly because of the infill pattern's wide empty spaces and the impact test's striking direction.

4 In the case of Shore D hardness, infill structure plays an important role in determining the hardness of the test specimen. The honeycomb structure shows the lowest hardness, while the other structure has a relatively higher hardness.

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