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Infill Density Effects on Impact Strength of PLA+

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ABSTRAK

3D print merupakan metode manufaktur yang bersifat aditif (penambahan). Dalam prosesnya ada beberapa parameter yang dapat diatur agar mencapai hasil cetak yang sesuai dengan keinginan. Penelitian ini melihat bagaimana pengaruh persentase *infill* terhadap kekuatan impak *Charpy* pada material PLA+ yang dibuat menggunakan 3D printer dengan metode *Fused Deposition Modeling* (FDM). Spesimen yang digunakan mengikuti standar ISO 179-1 tipe 1 tanpa takik dan dibuat dengan variasi *infill* 20%, 40%, 60%, 80%, dan 100%. Setiap variasi dilakukan pengujian sebanyak lima kali menggunakan alat uji impak *Charpy* JB-S300. Energi yang diserap kemudian dikalkulasi menjadi kekuatan impak *Charpy* (kJ/m²) sesuai dengan standar ISO 179-1. Hasil menunjukkan bahwa kekuatan impak meningkat seiring dengan meningkatnya *infill*, dari 10,9 kJ/m² pada *infill* 20% hingga menjadi 30,4 kJ/m² pada *infill* 100%. Hasil ini menegaskan pengaruh *infill* terhadap penyerapan energi dan pentingnya pengendalian parameter untuk meningkatkan konsistensi hasil pada komponen PLA yang dicetak dengan FDM.

Kata kunci :
3D Printer, PLA+, ISO 179-1, Kekuatan Impak.

ABSTRACT

3D printing is an additive manufacturing method. In its process, several parameters can be adjusted to achieve the desired printing results. This study examines the effect of infill percentage on the Charpy impact strength of PLA+ materials made using the Fused Deposition Modeling (FDM) method. The specimens used follow the ISO 179-1 type 1 standard without notches and are made with infill variations of 20%, 40%, 60%, 80%, and 100%. Each variation is tested five times using a JB-S300 Charpy impact tester. The absorbed energy is then calculated into the Charpy impact strength (kJ/m²) according to the ISO 179-1 standard. The results show that the impact strength increases with increasing infill, from 10.9 kJ/m² at 20% infill to 30.4 kJ/m² at 100% infill. These results emphasize the effect of infill on energy absorption and the importance of parameter control to improve the consistency of results in FDM-printed PLA components.

***Keywords* :**
3D Printer, PLA+, ISO 179-1*, Impact Strength.*

1. INTRODUCTION

Additive manufacturing using 3D print with Fused Deposition Modeling (FDM) has become widely adopted for quick prototyping and functional components due to its simple operation, versatility, and low production cost. However, the mechanical properties of FDM-printed parts is strongly influenced by its parameters, as the layer-by-layer deposition may introduces porosity and anisotropy. From all controllable parameters, infill density is one of the most critical factors that influence structural integrity, energy absorption, and overall durability. Higher infill density reduces internal voids and improves interlayer bonding, which can significantly enhance impact strength of the printed parts [1], [2].

The Charpy impact test, can be seen on ISO 179-1 standard, provides a standard method for determining the impact strength of polymer materials and has been increasingly applied to determine the mechanical behavior of additively manufactured parts [3]. While PLA is one of the most commonly studied materials, enhanced variants such as PLA+ offer improved impact resistance and are widely used in engineering applications. Despite this, limited data are available on how infill density affects the Charpy impact strength of PLA+ printed on newer consumer-grade machines such as the Bambu Lab A1 Mini.

This study objective is to answer this problem by calculating the impact behavior of 3D printed parts that printed using eSun PLA+, with variation in infill densities. The objective is to determine how infill variation affects Charpy impact strength and to compare the results with trends reported in the literature. The findings provide insight into optimizing print settings for applications requiring improved toughness and impact resistance.

2. RESEARCH METHODS

2.1. Specimen Preparatiom

Specimens were prepared following ISO 179-1 for unnotched charpy impact samples with specified dimension: length l = 80±2 mm, width b = 10±0.2 mm, thickness h = 4±0.2 mm. All specimens were printed using eSun PLA+ filament on a Bambu Lab A1 Mini printer. The process parameters were: 0.2 mm layer height, using standard 0.4 mm nozzle, standard Bambu Lab A1 Mini printing speed, monotonic line surface pattern, rectilinear spars infill pattern, and infill percentages of 20%, 40%, 60%, 80%, and 100%. Rectilinear pattern used because it supports 100% infill pattern, while the other pattern won't. All of the specimens were printed at the same time as can be seen on figure 1. Five specimens were printed for each infill condition. Before testing specimens were weighted to record its mass (g). While during testing, absorbed impact energy (J) were measured.

Figure 1. Specimens Printing Process

2.2. Impact Test

Charpy impact testing was performed using a JB-S300 pendulum impact tester as seen on figure 2. The test performed following the general procedure of ISO 179-1 for unnotched specimens. For each infill percentage (20%, 40%, 60%, 80%, and 100%), five specimens were prepared and tested.

Figure 2. JB-S300 Pendulum Impact Tester

Before testing, all specimens were checked for visible defects and deformation, measured for width and thickness using a digital micrometer, and weighted using digital scale to make sure that all specimens were identical. The JB-S300 was also inspected to ensure proper alignment, calibration, and smooth pendulum operation in accordance with the standard given.

During testing, each specimen was positioned flat horizontally on the supports with the impact point was centered between the anvils. After the safety cover was opened, the pendulum was released to deliver a single impact. The instrument automatically recorded the absorbed impact energy, which was documented for each specimen. The fractured pieces were collected and the general fracture characteristics were noted.

3. RESULT & DISCUSSION

Data results from this test can be seen on table 1. Table 1 summarizes the mean absorbed energy and Charpy impact strength values for each infill density. The results show that the impact strength increases as infill percentage rises, consistent with previous findings [4], [5], [6].

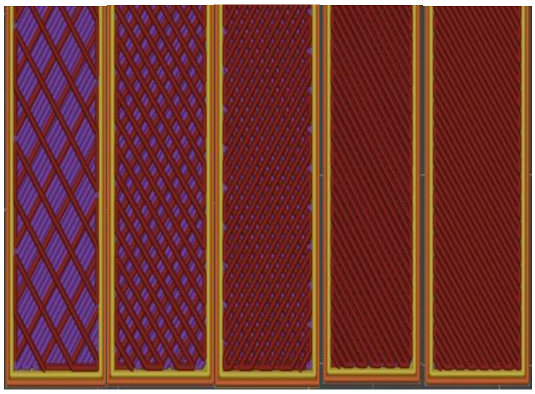
Charpy impact strength (in kilojoules per square meter) was calculated using equation 1 based on ISO 179-1 for unnotched specimens [3].

$$a_{cU} = \frac{E_c}{h \cdot b} \times 10^3 \quad (1)$$

Where:
This results primarily caused by how the slicer slice the specimen. In this experiment Bambu Studio used as the slicer. As seen on Figure 3, pattern on the infill is automatically assigned by the slicer and may results in several variations. Also the limitation from print nozzle that resulted a few gap on the corner of the specimens.
Ec : the corrected energy, in joules, absorbed by breaking the test specimen.
h : the thickness, in millimeters, of the test specimen.
b : the width, in millimeters, of the test specimen.

3.1. Infill Density and Weight

Based on table 1, there were increase of weight for each increase of infill density. Based on the data the increase of weight were ranged from 3-5 gram. The increase is not uniformed with the infill density. For example, from 20% infill density to 40% infill density the weight increase by 3g, from 40% infill density to 60% infill density was 4g, from 60% infill density to 80% infill density was 5g, and 80% infill density to 100% infill density was 4 g.



(a) (b) (c) (d) (e)

Figure 3. Specimen infill in slicer (a) 20%, (b) 40%, (c) 60%, (d) 80%, (e) 100%.

3.2. Effect of Infill Density on Absorbed Impact Energy

Based on Table 1, the measured absorbed energies show a consistent increase with infill percentage, from 0.48 J at 20% infill to 1.26 J at 100% infill. The increase is proportional up to 80% infill but increased drastically from 80% infill to 100% infill, indicating a transition from a structure with void to a solid one as can be seen from figure 3. In the 20% infill density there were much more void rather than internal structure like in Figure 3 (a). In the 60% infill density specimen become more solid with majority of structure as can be seen on Figure 3 (c).

This result reflects the reduction of internal voids and the strengthening of interlayer bonding. At lower infill percentage, the printed structure contains significant amounts of empty volume, which causes stress concentration and premature brittle failure during impact. As the infill density increases, the internal structure becomes more continuous, resulting in improved energy absorption.

Tabel 1. Test Results

Infill (%)	Mean Absorbed Energy (J)	Mean Charpy impact strength (kJ/m²)	Mean Weight (g)
20	0.48	12.0	2.4
40	0.54	13.5	2.7
60	0.74	18.5	3.1
80	0.84	21.0	3.6
100	1.26	31.5	4.0

3.3. Charpy Impact Strength Behavior

Based on Figure 4, the strength improvement from 20% to 40% infill is relatively small, with only a 1.50 kJ/m² increase in impact strength. This small increase in impact strength indicates that the internal structure at these low densities is still have void majority, as clearly shown in Figure 3(a) and 3(b).

However, the improvement becomes bigger when the infill density was increased from 40% to 60% infill, where the impact strength rises by 5.00 kJ/m². At this infill density, the internal geometry becomes noticeably more solid, and the material become more structure dominant rather than void dominant. The increased filament contact and reduced porosity contribute to a more efficient transfer of impact loads across layers.

The most significant transition occurs between 80% and 100% infill, where the impact strength increase dramatically from 21.00 to 31.50 kJ/m². This substantial increase of 10.50 kJ/m² highlights the influential change from void dominant structure to a solid material. In this range, the remaining voids are minimal, and the specimen behaves closer to a homogeneous polymer, allowing it to dissipate impact energy more effectively [7].

The internal infill structure plays a critical role in determining impact resistance. At low infill densities, the presence of large void restricts the material ability to distribute stresses, leading to be more brittle. As infill density increases, the structure of the internal pattern improves, enhancing stiffness, load transfer, and energy absorption. Lastly, a full density setting provides the most effective mechanical response, confirming that infill density is a major determinant of impact performance in FDM-printed components.

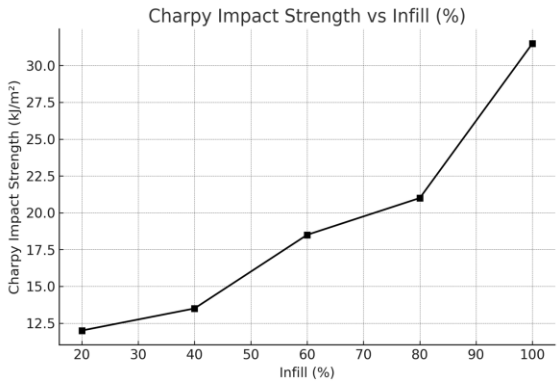


Figure 4. Charpy Impact Strength Behavior

CONCLUSION

This study explored how different infill densities affect the Charpy impact strength of eSun PLA+ printed on a Bambu Lab A1 Mini. The results show a trend of as infill increases, so does the specimen weight increase and the specimens ability to absorb impact. The impact strength rose from 12.00 kJ/m² at 20% infill to 31.50 kJ/m² at full 100% infill, showing that a denser internal structure helps the material resist sudden loads much more effectively.

The medium infill density such as 60% infill and 80% infill offered a sufficient increase in impact strength while still keeping material weight low. These settings are best choices for everyday prints where both strength, efficiency, and price matter. The jump in impact strength between 80% and 100% infill also suggests that fully solid prints behave more like true solid plastic, providing better resistance to impact failure.

Overall, the findings show how important it is to choose the right infill percentage based on what the printed part will be used for. If a part needs to withstand impact or mechanical stress, using higher infill density is recommended. For lighter-duty or prototyping parts, lower infill percentages are still perfectly acceptable.

Future work could look at other parameter setting such as infill pattern, printing speed, and layer height to understand how they work together with infill density. Examining the fracture surfaces could also give deeper insight into how and why the material fails under impact.

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