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The Effects of Printing Orientation on the Fused Deposition Modeling Process of the Robot Gripper Object–Moving Force

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Abstract. HIPS (High Impact Polystyrene) is one of the materials used in 3D printing. Research studies and applications of this material have not been made extensively, especially in works which require flexural strengths. The purpose of this study is to determine the correct orientation to produce grippers with the highest flexural strength which can serve as an alternative material for aluminum grippers. This research indicates that orientation 2 produces the highest flexural strength at 4.16 kN with lattice fill pattern, a 75% fill density, and a layer thickness of 0.125 mm. Orientation 2 is defined as the specimen's thickness parallel to the surface's width.

INTRODUCTION

The growth and development of automatic machines and robot utilization have become an essential part of human lives due to consistency and precision. The 3D multiplane printing concept using robots is undergoing an intense development [1]. For example, machines which combine additive, formative, and subtractive multiplane processes in one robotic platform with end effectors swap need to consider certain modes [2]. One way to achieve this is to use machines with Rapid Prototyping technology.

Rapid prototyping is a technique which can be used to change Computer Aided Design (CAD) data into 3D objects using Additive Manufacture or 3D printing technology. The development of Rapid Prototyping technology which applies 3D printing techniques makes product design and development more time-efficient. The most commonly used Rapid Prototyping process is Fused Deposition Modeling (FDM). FDM is a technology which releases plastic filaments and layer-forming metals as working objects [3,4,5,6].

In his previous experiments, Sood discussed the tensile strengths of PLA and ABS materials as a response to orientation position, in which orientation 2 (the specimen's width in perpendicular position with the bed) produces the highest tensile strength at 7.66 MPa [3]. Tanoto, et al. also discussed about the flexural strength of HIPS materials as a response to fill pattern, fill density, and layer thickness where the average flexural strength value is shown at 32.68 MPa in orientation position 3 (specimen's length is in perpendicular position with the bed, with lattice fill pattern, 75% fill density, and 0.125 mm layer thickness [7]. However, previous studies only examined the flexural test specimen from 3D printing, and not application product. This experiment no longer used a test-standard specimen but application product as a research object using the same printing-process parameters as of Tanoto, et al. with two orientations.

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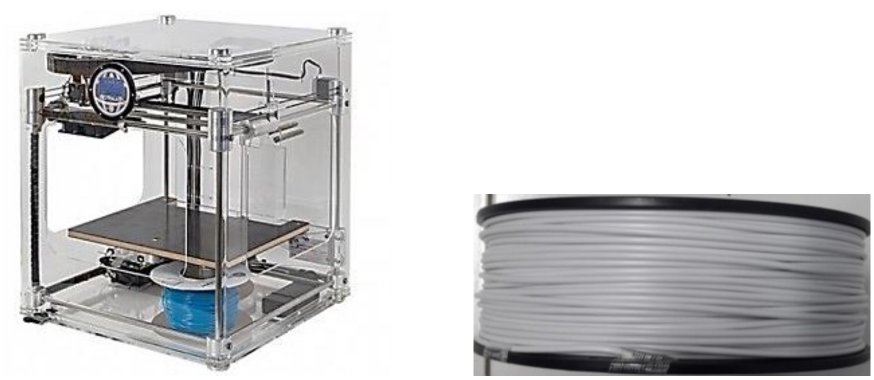
METHODS

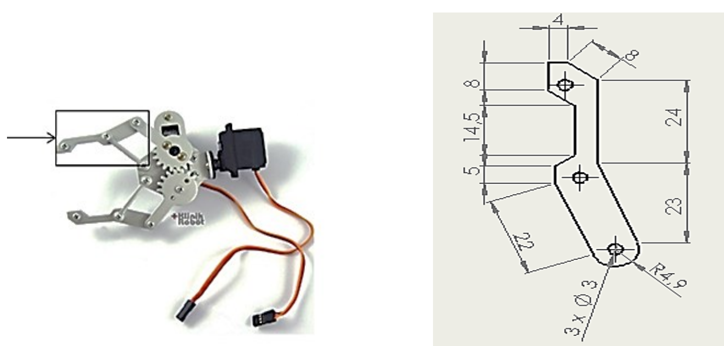
3D printer FDM BFB 2000 was used to manufacture the grippers, as seen in Figure 1. The printer uses firmware version 5.3. The material is made from ESUN white HIPS with 3 mm diameter and an extrusion temperature of 220°C-260°C, as shown in Fig. 1.

The gripper used in this experiment is 1Axis gripper. This gripper will be the blueprint for polymer-based gripper manufacturing by means of 3D touch devices. This experiment uses the gripper part that makes contact with the working object, as shown in Fig. 2a. The 3D CAD data of the gripper is illustrated using SOLIDWORKS 2009 software. Furthermore, the dimensions of the gripper are as shown in Fig. 2b and have a thickness of 5.5 mm.



(a) (b)

FIGURE 1. (a) 3D touch FDM BFB 2000 (b) HIPS filament



(a) (b)

FIGURE 2. (a) Commonly used gripper (b) Gripper's dimension

Once the CAD modeling is completed, the next step is to save the file in stereolithography format before importing it to the Axon v2b2 slicing software. Axon will process the specimen's model according to the parameter set in the Build settings. The Axon software display and the build settings for layer thickness adjustment, fill density, fill pattern, and more [8] can be seen in Figure 3. This research uses the printing process parameters used in previous research which results in the best flexural strength compositions of lattice fill pattern, 75% fill density, and 0.125 mm layer thickness. Meanwhile, there are two orientation levels: specimen's thickness in perpendicular position with the bed for orientation 1; and specimen's thickness parallel to the surface's width.

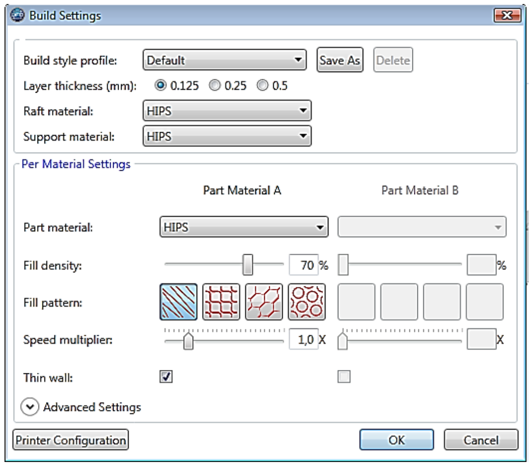


FIGURE 3. Axon build settings

The purpose of this experiment is to determine the flexural strength of aluminium grippers. The indicated flexural strength will be used as a benchmark for polymer grippers manufacturing. The gripper test did not follow the standard flexural test, which was ASTM D790-2010, because the shape was neither square iron nor square plate. The one-point flexural strength testing style can be seen in Fig. 4. The device used to test the flexural strength was Gotech Testing Machine INC with the capacity of 300 kN. This experiment was conducted in BLK (Work Experiment Hall) in Surabaya, East Java.

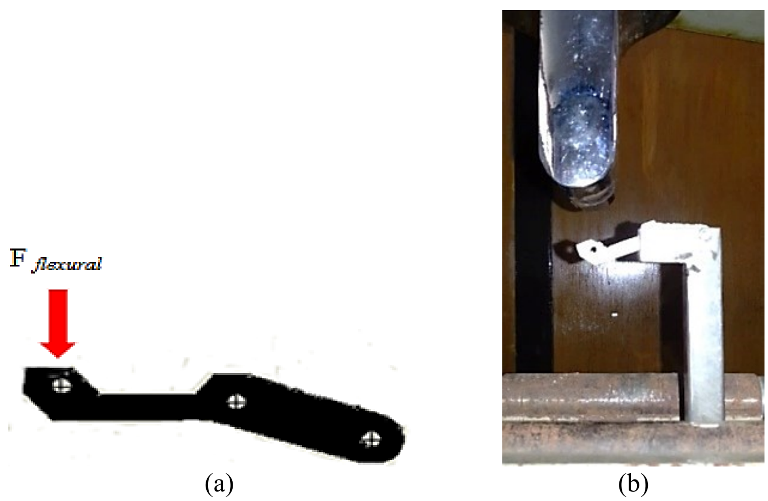
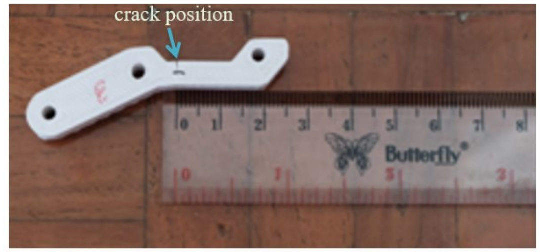


FIGURE 4. Product flexural strength experiment illustration (a) Flexural strength test illustration (b) Testing-machine experiment

Once the examination was completed, the next step was to measure the crack on the gripper, which involved: The crack distance from point 1 or arm 1 to the surface's crack point, measured with a ruler (Fig. 5); and the crack angle which was measured using a protractor (Fig. 6).

(a)



(b)

FIGURE 5. Gripper measurement techniques (a) The arm as point 1, (b) The use of ruler to measure the gripper from arm 1 to the crack position

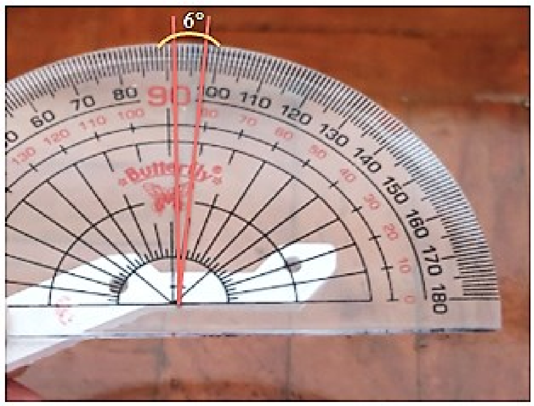
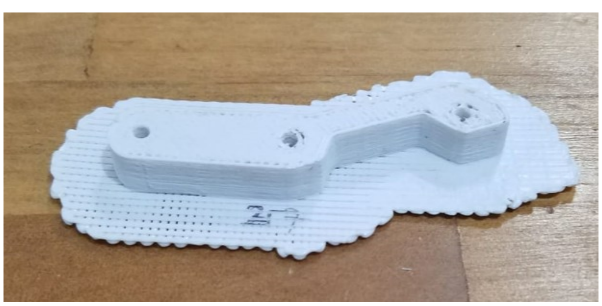


FIGURE 6. Crack angle measurement technique

RESULTS AND DISSCUSION

Once the specimens were printed, the products were examined for any noticeable defects, such as perforated or wavy surfaces. Apart from visual defects, a thorough check was also conducted on each specimen to ensure that they met the desired outcome. The dimension adjustment and wavy defect were processed using sandpaper. Three samples from each orientation were prepared for examination purpose. The print results for orientation 1 and 2 can be seen in Fig. 7. The print results still carried raft and support. Support was noticeable in orientation 1, whereas orientation 1 did not require support in creating the product. The example of a ready-to-use gripper for both orientations can be seen in Fig. 8.



(a)

(b)

FIGURE 7. Grippers (a) Orientation 1 and (b) Orientation 2

FIGURE 8. Ready-to-use gripper

The gripper product from the pressure-force examinations in which three tests were conducted for each orientation in both positions (orientation 1 and 2) can be seen in Table 1. Tests were also conducted on the aluminum grippers purchased from the market. The outcome of the tests was used as a benchmark for the polymer HIPS materials which used orientations 1 and 2 and printed using FDM. Table 1 shows the comparison results from the pressure test and weight scaling.

TABLE 1. Flexural examination dan force weight scaling

Material	Specimen	Force (kN)	Average	Mass (gram)	Average (gram)
Original (aluminium)	1	4.42	4.42	7	7
HIPS (orientation 1)	1	4.13		3	
	2	4.16	4.15	3	3
	3	4.15		3	
HIPS (orientation 2)	1	4.15		3	
	2	4.19	4.16	3	3
	3	4.14		3	

Table 1 indicated that the flexural strength divergence between aluminium grippers and polymer HIPS materials is 2.17% for orientation 1 and 1,93% for orientation 2. Since the percentage of HIPS orientation 2 is smaller than orientation 1, it can be said that the former has better flexural strength. The overall comparison data, which include the flexural strength divergence between aluminium grippers and polymer HIPS grippers with orientation 1 and 2, suggest that there is no significant difference in terms of material use. Furthermore, polymer HIPS is 2.3 times lighter than aluminium.

The gripper's flexural strength was affected by the number of predetermined parameters set before the product manufacturing. One of the parameters is selecting the right orientation position that will result in products with bigger flexural strength. With orientation 1, the composition elements were also in orientation 1, which consisted of large amount of fill pattern and small amount of wall layer. This resulted in smaller flexural strength. Meanwhile, the wall later composition elements in orientation 2 were bigger than the fill pattern. As a result, the flexural strength was also bigger. In objects made with FDM method, the nozzle will form the wall section first. Once the wall is formed on the later, the nozzle will fill up the inner section using predetermined fill patterns. Orientation 2 has a smaller cross-sectional area than orientation 1. As a result, the wall-to-fill ratio is bigger in orientation 2 than in orientation 1.

The gripper's pressure force examination resulted in a crack in the arm section. An evaluation was conducted on the examination results the location and position of the grippers in orientation 1 and 2. The result of this evaluation can be seen in Table 2 and Fig. 9. Table 2 suggested that aluminium grippers did not crack due to the material's malleable and ductile nature. This can be concluded from the Ultimate Tensile Strength, which was shown at 69 GPa, and the Tensile Modulus of 0.11 GPa [9]. On the other hand, polymer HIPS grippers suffered cracks due to their fragile characteristic. Polymer HIPS showed a Tensile Strength of 0.32 GPa and a Tensile Young Modulus of 1.9 GPa [10]. Additionally, the angles between HIPS orientation 1 and orientation 2 are significantly different.

Figure 9 indicates that the crack depth in orientation 1 side 1 is deeper than side 2 because of the wall-layer compositions. The wall layer in orientation 1 side 1 is looser than orientation 2 side 1 (denser). Meanwhile, the crack depth in orientation 2 side 2 is deeper than orientation 1 side 2 due to the testing machine shift when applying pressure on the grippers. The forward shift makes the crack's depth in orientation 2 side 2 smaller. The visible positions of side 1 and side 2 grippers in each orientation can be seen in Fig.10.

TABLE 2. Data obtained from aluminium and polymer HIPS grippers

Material	Number of Test	Crack Dimension						Standard Deviation
		Crack Angle		Distance				
		Side 1	Side 2	Side 1	Side 2	Side 1	Side 2	
HIPS Orientation 1	1	6	6	12	4.5	4.5	2.8	
	2	4	3	12	2.7	2.7	1.9	
	3	6	4	12	3.2	3.2	3.2	
	Average	5	4.5	12	3.5	3.5	2.6	0.589
HIPS Orientation 2	1	11	11	12	3.2	3.2	3.5	
	2	11	15	12	3.5	3.5	4	
	3	9	9	12	3.2	3.2	2.5	
	Average	10.3	11.7	12	3.3	3.3	3.3	0.023
Aluminium		No Crack (Bent)						

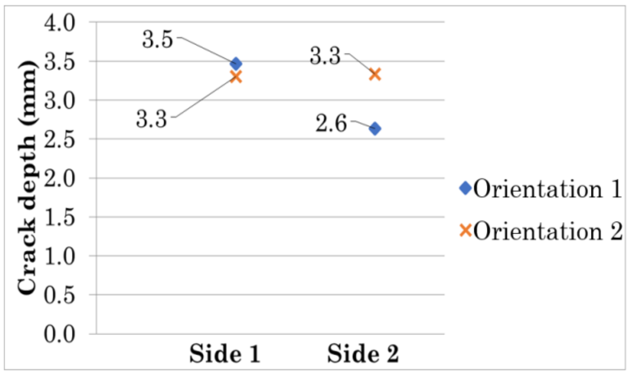


FIGURE 9. Gripper crack depth graph, orientations 1 and 2

The result of the aluminium gripper test can be seen in Fig. 11. The picture indicates that the aluminium gripper's arm bent due to its ductile nature. The bent arm has a critical point, which is defined as the point in which the gripper starts to bend when maximum pressure is applied. The distance between the critical point to arm 1 is 12 mm. The gripper's bent position when pressure is added is always at the critical point due to the arm's width. The arm is smaller than the gripper's head and body. Therefore, when repeated tests are conducted, the bending position stays at the same spot and distance. Result of the flexural examinations of polymer HIPS and the crack depth measurement with the help of a thread can be seen in Fig. 12.

(a) (b)

FIGURE 10. Grippers' look (a) Gripper side 1, (b) Gripper side 2

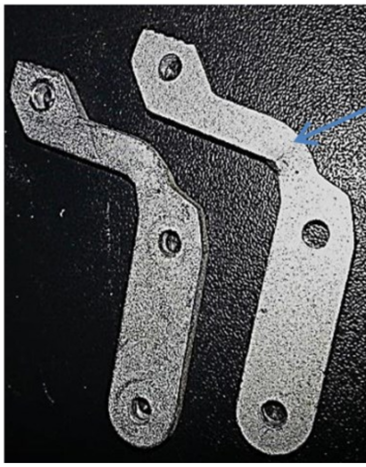


FIGURE 11. Aluminium gripper test results

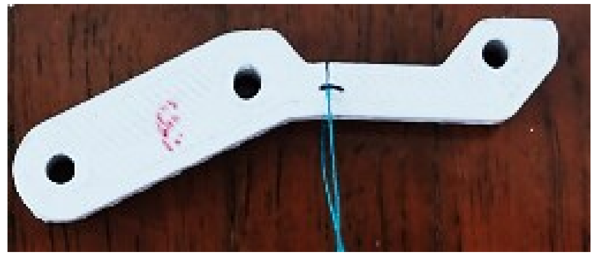


FIGURE 12. Measuring crack depth with a thread

CONCLUSION

Based on the flexural examination results, the robot grippers made from polymer HIPS in orientation 2 has a flexural strength of 4.16 kN, while the flexural strength in orientation 1 is shown at 4.15 kN. Thus, the biggest flexural strength of polymer HIPS is with orientation 2, which almost matches the aluminium strength of 4.243 kN flexural strength. The value between orientation 1 and orientation 2 needs to be analyzed statistically, there is a possibility that the difference is not significant. HIPS Gripper made with FDM can be used as a prototype in gripper product development, moreover FDM products have the opportunity to be used directly not as prototypes. Finally, the angle and crack depth were influenced by the force's direction on the flexural test device with the gripper's wall layer positioned in orientations 1 and 2 during the examination.

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