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The effect of honeycomb and rectangular structures made with PLA 3D printing on the impact strength of sandwich composite

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Abstract

Composite with a sandwich structure with a core using polymer materials has been widely applied, 3D printing technology makes polymer structures with various geometric variations, but research on the influence of geometric shapes made with 3D printing machines with PLA materials bonded using a one-step manufacturing process with a hand lay up method is still not widely done. The purpose of this study is to determine the comparison of the impact strength of sandwich composite materials with core honeycomb and rectangular made from PLA 3D printing made with a one-step process manufacturing system with the hand layup method. The sandwich composite composition used is fiberglass as the face skin and the matrix uses epoxy resin, where this resin also functions as an adhesive. The absorption energy data obtained with the best value was a honeycomb core specimen with an average value of 3.2758 Joules compared to the absorption energy data from the rectangular core which had an average value of 3.1552 Joules. The impact price data obtained with the best value was the honeycomb core with an average value of 0.0225 J/mm^2, when compared to the impact price data from the rectangular core which had an average value of 0.0217 J/mm^2. From this study, it can be concluded that sandwich composites with honeycomb cores have better impact strength property values because they have a more compact arrangement of materials that are bonded to each other on 6 sides, and also because honeycomb structures have a higher weight of 20 grams compared to rectangular structures that weigh 18.

Keywords:
composite, sandwiches, PLA, 3D printing, hand lay-up.

1 Introduction

Additive Manufacturing which is now better known as 3D printing technology is a modern manufacturing technology used to make three-dimensional products as a result of data representation from CAD designs on a particular printing machine that carries out the process of adding materials that are bound and leveled gradually[1]. This technology is rapidly growing around the world, mainly used to create three-dimensional objects from engineering designs into various forms of manufactured products. Materials that can be used in manufacturing using 3D printing machines are metals, resins, and polymers. For polymer-type materials, one of the most commonly used is using Polylactic Acid (PLA) material [2][3][4].

Polymer-type 3D printing technology is highly developed, mainly based on a new mixed material, namely filament PLA. A new way of developing materials by 3D printing forming continuous filaments has also been developed, thereby limiting the loss of mechanical properties of these materials when compared to traditional or manual manufacturing processes of composite materials. Carbon, and 3D printing composites, are often bonded with polyamide and epoxy resin types to exhibit shear properties, namely transverse as well as longitudinal [1][3].

The development of 3D printing machine composites is relatively advanced compared to composites made from natural fiber. However, filaments made from natural fibers have advantages when compared to filaments made from fossils. Natural fibers that are environmentally friendly, can be easily found in various parts of the world, and have relatively cheap or affordable prices, and are also easy to use in all aspects of various material applications in the industrial and technical fields. The effectiveness of recycling in 3D printing composites with natural fiber filament types was developed using a thermoplastic matrix such as poly (lactic acid-PLA) which can be melted and decomposed again and again[5][6].

1.1 Composite

Composites are a new class of engineered materials consisting of two or more materials that differ in their respective properties, both chemically and physically, and remain separate in the final product (material). With the difference in material composition, the constituent materials between materials must be tightly bound, so it is necessary to add a binder in liquid form (wetting agent) explained [7].

PMC (polymer matrix composite) is a composite whose basic material is polymer resin. Polymer is another word for plastic and is classified into two types, namely thermoplastic and thermoset. In general, thermoplastics are polymer resins that have the property of being able to be melted again after curing (a plastic chemical process, from liquid to characteristic), unlike thermosets. Thermosets cannot follow temperature changes after curing and will deform and decompose into charcoal if at high temperatures [8][9].

1.2 Composite sandwiches

Sandwich is a type of structural mix that is feasible to develop. Sandwich composites are composites consisting of 3 layers composed of a flat composite such as a skin surface and a core material in the middle (between the two)[8] as shown in Fig. 1.

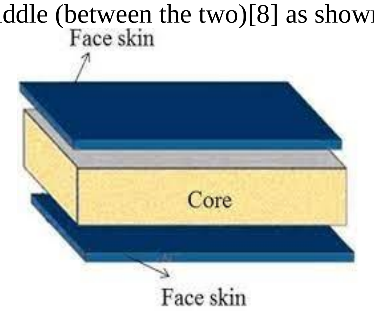

Fig. 1. Sandwich composites[8]

Sandwich composite material is a type of composite that is very suitable for bending resistance, impact load, vibration, and sound absorption. Sandwich composites are made to obtain a material with a light structure but high stiffness and strength. The honeycomb sandwich structure is a technology applied in various industries due to its combination of high strength and light weight. In the aviation and aerospace industry, this material is used in aircraft components such as wings, fuselages, floor panels, doors, and tail sections, which helps to reduce weight and improve fuel efficiency. In addition, it is also applied to satellite panels and rocket fairings, where lightweight and strong materials are required. In the automotive industry, honeycomb sandwiches are used in the manufacture of door panels, bonnets, and car interior components, as well as in racing vehicles, to reduce weight and improve performance. In the marine industry, the material is used in the hulls, decks, and components of boats and yachts, helping them become lighter and more fuel efficient[8][9].

Honeycomb sandwich composites have been widely used in various fields due to their high bending strength and rigidity. This excellent bending behavior is because it has a thick core material but is very low in density. The core material is coated by a thin face but has a high-density sheet (FS) resulting in excellent stress and compression strength [10]. In the research of H. S. Bharath, D. Bonthu and, friends sandwich structure with a syntactic foam core is promising because it can absorb bending energy well, the result is a 3D printed syntactic foam core sandwich that has good shear failure resistance [11].

In the research of Tiantian Li, Lifeng Wang Sandwich structures made with cores filled with materials by 3D printing with honeycomb and rectangular frames, sandwich composites with honeycomb cores significantly improve the energy absorption capability [12]. Salvatore Brischetto and Roberto Torrekon's research on sandwich composite figuration with PLA material that uses honeycombs as a composite core, the material with sandwich arrangement can lead to important weight reduction without significant loss of mechanical properties [13].

1.3 Composite manufacturing method

In this research, the author uses the hand layup method to make sandwich composite materials where the method is the easiest way from other methods. The process of making composites with this method is pouring the resin into the fibers in a shape like knitting, then applying pressure and leveling it using a roller as shown in Fig. 2. This process is repeated several times until the required thickness is met [8][9].

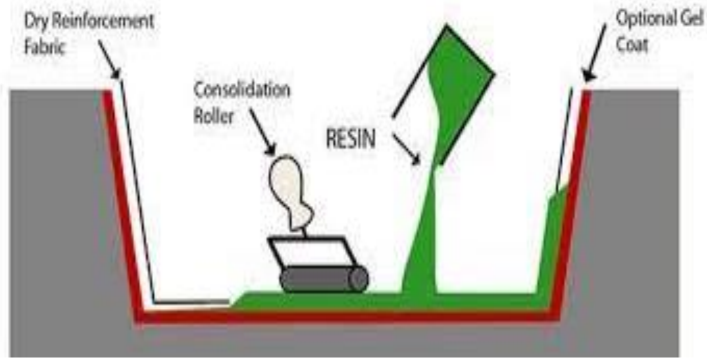

Fig. 2. The hand lay-up method[9]

1.4 Filaments

Currently, very few universities have mastered 3D printing technology. Therefore, it is necessary to conduct studies related to this technology because it can be used for research purposes and laboratory capacity building, especially assistive laboratories Design computers (CAD). Using this technique requires a great deal of knowledge about the type of filament used to print objects. There are many types of filament today, but the most commonly used materials are acrylonitrile butadiene styrene (ABS) and polylactic acid (PLA) [14] as shown in Fig. 3.

Fig. 3. PLA Filaments

1.5 FDM 3D printing method

Fused Deposition Modeling (FDM) is a method very popular in AM (additive manufacturing), where products made with this process have the potential to compete with conventional manufacturing methods (injection molding). FDM applications are wide ranging from medical design and molding to automotive and aeronautics. To date, the FDM method has been widely used in 3D printing due to its ease of use, lower costs, environmental friendliness, and ease of product development, prototyping and manufacturing [14][15][16].

1.6 Matrix (epoxy resins)

The matrix is the elements that are related in combination and constitutional. The substrate of the composite material can be clad from polymer or metal alloys, ceramics, and also carbon materials. The nature of the matrix will determine the operating conditions of the composite properties and also the manufacturing. Resin is a binder of the fiber arrangement and also to help as a determinant of the physical properties of the composite material. Epoxy type resin is a type of resin that has a low viscosity or is liquid, then it will harden at normal room temperature by mixing the catalyst without producing gas during the manufacturing process like other thermosets, so there is no need for additional pressure in the printing process [17].

1.7 Mechanical properties of materials

The mechanical strength of the material is the ability of the material to withstand the stress and strain produced by the testing tool without experiencing significant damage. Mechanical properties can be interpreted as the response or behavior of a material to a given load, either in the form of a torsional force or a combination of the two. The way to obtain the mechanical properties of materials is usually carried out by testing with a destructive nature (destructive test) with examples of tensile tests, flexibility tests, compression tests, crack resistance tests, Young's modulus tests, permeability tests, material toughness tests, hardness tests, and also other types of testing. Testing of mechanical properties or strength has been regulated by organizations concerned with the creation of materials or material testing standards namely ASTM (American Society for Testing and Materials) which contain several limitations to achieve optimal and effective testing [18][19].

1.8 Charpy impact test

The impact test is a test that measures the resistance of a material to impact. This is what distinguishes impact testing from tensile and stiffness testing, where loading is slow. This research uses ASTM D6110-10 to test the impact strength of the sandwich composite material made, the ASTM D6110-10 image as shown in Fig. 4.

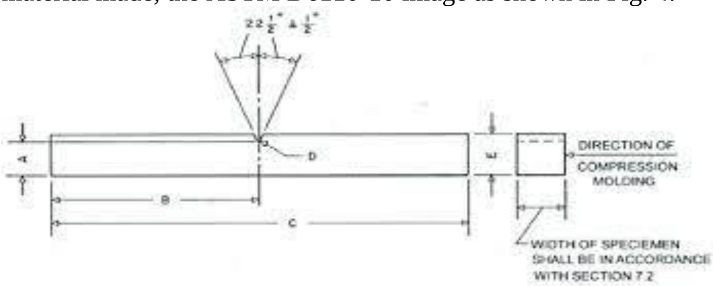

Fig. 4. ASTM D6110-10

Impact testing is an attempt to simulate material operating conditions commonly encountered in transportation or construction equipment, where loads do not always occur slowly but come suddenly. The basic principle of the impact test is to absorb potential energy from the oscillating load pendulum from a certain height and act on the test load, so that the test load is deformed as much as possible, causing damage Eq. (1) and E.q. (2). Impact testing is divided into 2 methods, namely the Charpy and Izord methods. In this study, researchers used the Charpy method as shown in Fig. 5. In this impact testing method, the test object on the support horizontally and with the direction of the load opposite to the direction of the pull [19][20].

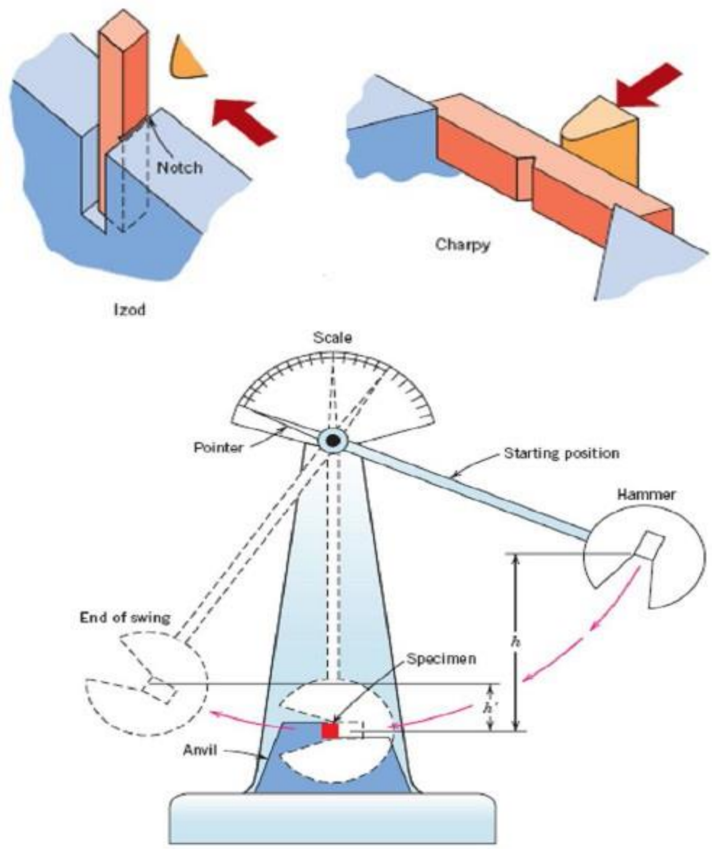

Fig. 5. Charpy impact test[20]

$$E = mgrcos\ (\beta - \alpha) \quad (1)$$

$$HI = E/A \quad (2)$$

where *E* is Impact Energy (j), *r* is arm length, *m* is pendulum mass (kg), *g* is earth's gravity (m/s^2), α is angle before hitting the test object, β is angle after hitting the test object, *HI* is price impact (j/m^2)

1.9 Software Slicers

Before being printed on a 3D printer, 3D model objects must first be processed in a slicing software called SILICER™, it is a program that translates objects from a converted 3D model into machine code or G-code to instruct the printer to 3D print the object. SLICER largely defines how a 3D model is created by a 3D printing tool. G-code generation input in the SLICER is not limited to the 3D model object, input parameters such as model strength, number of parts or printing speed and many other parameter instructions also affect 3D printing results [21].

2 Research methods

The specimen is a composite with a sandwich structure, with a fiberglas composite skin, a 3D printing PLA core with a honeycomb and rectangular structure and a matrix using epoxy resin, here the matrix also functions as an adhesive. The specimen is made by one step proces manufacturing system of han lay up method, which is made according to the size of the charpy impact test specimen. The size and shape of equivalent specimens are divided into 2, i.e. based on different core arrangements, rectangles and honeycombs with the following shapes ASTM D6110-10 as shown in Fig. 6.

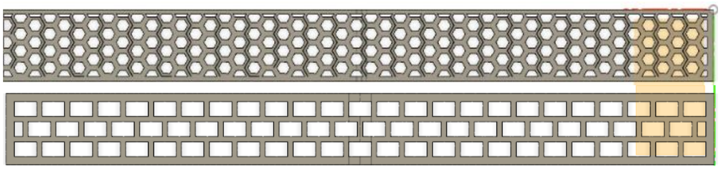

Fig. 6. Core honeycomb and rectangular design

2.1 3D Printing Machine

3D printing is a new breakthrough in the world of technology. This breakthrough was very popular throughout the world, especially among scientists and royalty. Because they believe that 3D printing technology can bring this world to the progress and prosperity of society. In accordance with its own definition, 3D printing is a printer with a certain sophistication that can print objects, just like soft file images, in 3D (no longer limited to only printing images on paper) Fig. 7. Because printing is not in the form of images or writing on paper, 3D printers do not have ink cartridges, but other materials that are the basis for making products. For example, to print key fobs, printer ink is replaced with plastic. This way, someone with a 3D printer will be able to have anything they want, as long as they have an image or images in the form of a software file [14][15].

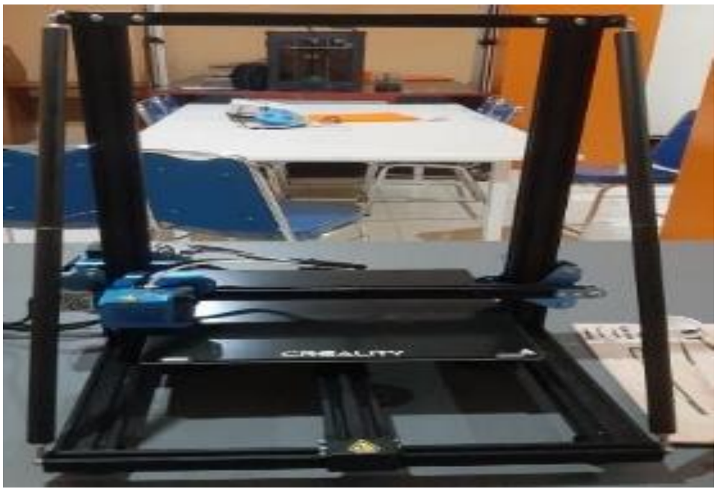

Fig. 7. Ender 5 Pro 3D printing machine

The honeycomb and rectangular cores that have been printed using 3D printing will be manufactured into a composite material with a resin matrix, and glass fiber reinforced to be face skin with hand layup method. The sandwich composite material design as shown in Fig. 8. The sandwich composite design with materials using honeycomb and rectangular cores with 1 layer fiberglass and epoxy resin matrix.

3 Results and Discussion

The results of the 3D printing print in Fig. 9 first, we must first prepare the design according to ASTM D6110-10, after drawing and finishing the design, then save the result with STL file in the cura application, select a file, after the design appears, there is a name called draft quality where there to change the file, temperature and etc., select custom and slice, save it in memory, enter the memory in the 3D printing machine after that, wait and the results are as follows for the results.

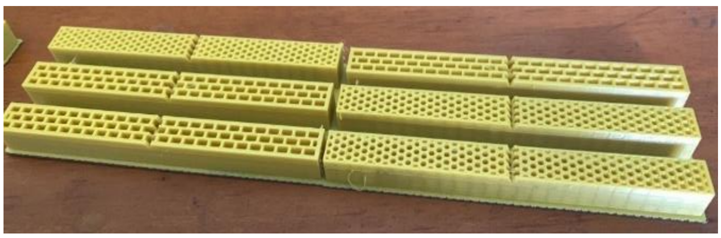

Fig. **8.** Specimen Documentation after 3D Printing.

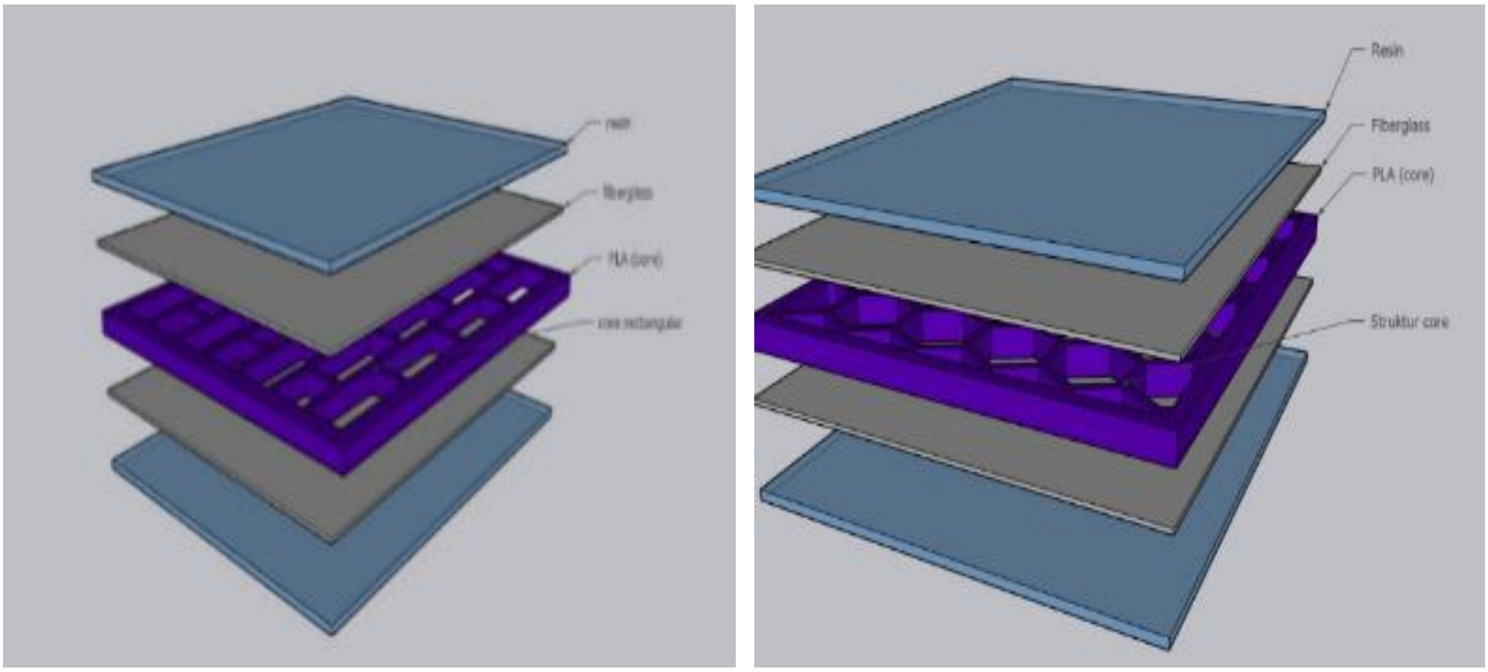

Fig. 9. Honeycomb and rectangular sandwich composite designs.

From the 3D printing core honeycomb and rectangular prints above, sandwich composites will be made with epoxy resin and fiberglass-reinforced faces with the hand lay-up manufacturing method, the first step we have to prepare a baking sheet after preparation, pour it with resin and flatten it on the mold. After that, add fiberglass and apply the resin evenly, pour the resin again, and puree it using a brush until it produces a composite of the desired thickness. After that, add fiberglass and spread it evenly, pour the resin again and smooth it using a brush, the results become specimens as shown in Fig. 10.

Fig. 11 are documentation after the specimen is subjected to impact testing. It shown that after the impact test, there is a fracture in the entire core in the honeycomb and rectangular arrangement variations.

Fig. 10. Specimen documentation of sandwich composites with hand lay-up method.

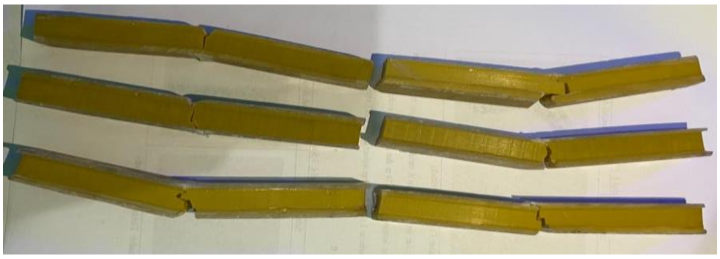

Fig. 11**.** Documentation of Impact Test Specimens.

From the fracture images of the specimens that have undergone impact tests, it shown that all specimens experience debonding on average (damage that occurs in composites caused by the fiber not sticking with the binder or resin. The adhesion and composition of the resin also have an important influence on the hardness of the material, and there are also gaps or air bubbles that make space in the resin.

The discussion of the results of this study will be presented in graphical form showing the relationship or correlation between the dependent variable or the parameters studied as a function of changes in the independent variables. Changes in a condition or parameter will be explained either by theory-based analysis or by supporting research findings. The sequence of discussing the results of this study is shown in Tables 1-2.

Table 1. Data from Rectangular Core Test Results

Specimen Variation	E (J)	Hi (J/mm^2)
Rectangular	2.4047	0.0182
Rectangular	3.0179	0.0210
Rectangular	4.0431	0.0259
Average	3.1552	0.0217

Table 2. Data from Core Honeycomb Test Results

Specimen Variation	E (J)	Hi (J/mm^2)
honeycomb	2.5021	0.0190
honeycomb	3.2076	0.0223
honeycomb	4.1176	0.0264
Average	3.2758	0.0225

In Tables 1-2, the data obtained after the test obtained is explained in the form of 6 types of specimens tested with rectangular and honeycomb core variations. From this test, data is obtained in the form of impact energy or absorption energy which is then determined by the impact price value.

In Fig. 12, it can be explained that the effort required or needed to break the honeycomb core type specimen has the highest absorption energy found in the core honeycomb specimen and the absorption energy value is 3.2758 Joules. And the smallest is shown in the rectangular core specimen whose absorption energy value is 3.155 2 Joules.

Fig. 13 shows the difference in the value of the impact price of the specimen with the type of honeycomb core variation. The highest value shown with an average impact price of 0.0225 J/mm^2. While the lowest value shown in the rectangular core specimen with an impact price of 0.0217 J/mm^2.

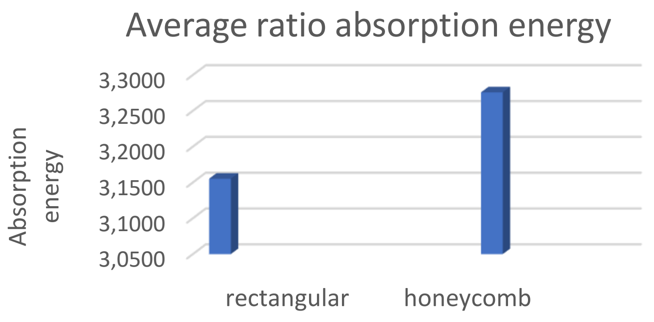

Fig. 12. Absorption energy of specimens with honeycomb and rectangular cores

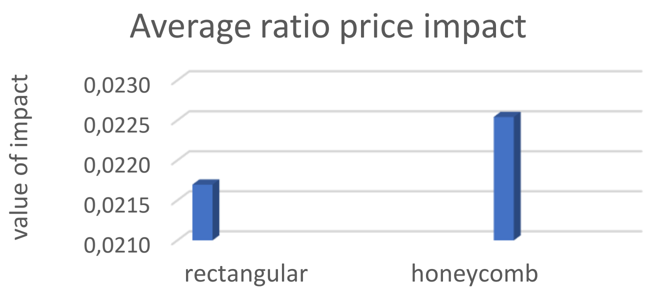

Fig. 13**.** Average impact value of sepesimens with honeycomb and rectangular cores.

Of all the specimens that have been tested using an impact tester, the impact price data obtained with the largest value is the honeycomb core which is its value is 0.0264 J/mm^2. And the lowest value of the impact price of all specimens is a rectangular core with a value of 0.0182 J/mm^2. What causes the difference in the impact price data on the specimens with variations of the honeycomb core and rectangular core is the air bubbles trapped in the resin.

The amount of fiber has a significant effect on increasing the impact value of the specimen. The value of impact and absorption energy on specimens with cores honeycomb is stronger than the rectangular variation , this is due to the difference in the shape of the rectangular arrangement and the honeycomb itself. However, in comparison to each type of specimen, the strength values obtained experienced a significant increase in strength. Which causes an increase in the impact value on specimens with honeycomb core variations .

A more significant difference that occurs is due to the presence of voids or air bubbles trapped on the inside of the resin. This needs to be paid close attention to because during the impact test process the air voids or voids can become a problem in the fracture strength energy transfer process on the entire resin surface.

The same thing happened to previous researchers, namely the value of the test object that was carried out got the lowest value due to the appearance of voids (air bubbles), low particle and matrix density, so that the ability to bind particles with a reinforcing role is also low, this may also be due to less stable bonds between particles. particle. particles lead to the easy formation of air bubbles (gaps) [22].

There are also other studies that experience problems due to voids or air bubbles, namely in the pandan duri fiber composite sample showing the presence of empty air bubbles, many areas of matrix or resin are formed without reinforcing fibers, fiber tears occur because the fiber is not completely mixed with the matrix in the composite material sample [20].

The weakness of this research is that the types of honeycomb structure composites and rectangular structures do not have the same amount of volume as a fixed variable (controlled variable), so the density of the composite reinforcement structure is very clearly influenced by the impact strength. This shown with the weight of the honeycom structure reaching 20 grams, heavier than the rectangular structure which weighs 18 grams.

4 Conclusion

The conclusions that can be obtained from this study are the absorption energy in the impact test that occurred on the specimen with honeycomb and rectangular variations shows that the strength value tested experienced a considerable increase. The best absorption energy is the honeycomb core specimen with the required effort to break the specimen of 4.1176 J, the absorption energy data obtained with the best value is the honeycomb core specimen with an average value of 3.2758 Joules when compared with absorption energy data from rectangular cores that have an average value 3.1552 Joules. From the impact price on the comparison of honeycomb and rectangular cores, you get different values based on the type of core, respectively. The impact price on the best specimen is to get a value 0.0264 J/mm^2 which is the value of the core honeycomb-type specimen Impact price data obtained with the best value is core honeycomb with an average value of 0.0225 J/mm^2, when compared with impact price data from rectangular cores that have an average value 0.0217 J/mm^2.

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