The Effect of Variation of Catalyst Ratio on Polyester Resin on Shrinkage and Ability to Absorb Mechanical Load on MiFUS® Case

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Abstract: This study discusses the implementation of rapid tooling in the manufacture of MiFUS casing to find out what happened and the optimal catalyst. The rapid tooling method is used because standard injection plastic is less efficient for making low-scale products. Rapid tooling applications are realized by using concrete epoxy resin as a product and polyester resin as a product. The use of polyester resin in products usually requires booster because the material is well known and has a high uniqueness of 5-12%. The solution offered is to adjust the ratio of the polyester resin in order to get the strength to receive optimal and minimum mechanical loads. The shrinkage that occurs will be used as a design rule or a rule in increasing the size of each catalyst ratio so that the size obtained is more precise than the function of the product can be achieved. The method begins with the process of planning, manufacturing, and testing. The result of this research is for the tensile test, the optimal catalyst ratio is 2.5:100 at 41 MPa while for the flexural test at 3: 100 it is 71 MPa. To distinguish the minimum is at a catalyst ratio of 1.5: 100.

1 INTRODUCTION

Among the additive manufacturing processes based on photopolymerization of liquid resins, RP (Rapid Prototyping) technology using SLA is the oldest and most popular. The importance of different operation areas and industries can be predicted from Figure 1.

Driven by the expanding industrial concern of LM, a variety of technologies - all summed up under the term RP - have acquired (Aceto et. al., 2019). Diverse methods to classifying the diversity of technologies have been reported in the literature. In addition to the individual application domains (Figure 1(b)), RP processes can also be classified according to the initial physical state of the material being treated and the physical or chemical transformations underlying integrating each layer (Abdulhameed et. al., 2019). Nowadays, RP processes are used not only to visualize design ideas (idea modeling), but also to manufacture molds and tools in rapid tooling (RT) applications (Touri et. al., 2019). Furthermore, additive and freeform layered manufacturing of 3D models is no longer limited to the visualization of prototype designs in rapid prototyping (RP), but is applied to the preparation of prototypes. and Rapid Tooling (Modi, Y. K., and Sanadhya, S., 2018).

Rapid tooling is a process of prototyping in a short time. Rapid tooling parts are produced rapidly to test and validate them prior to tooling production, especially in the plastic injection molding process (Bagalkot, 2019).

Rapid tooling parts are a perfect solution for testing and evaluating prototypes and producing several hundred parts before actually going into full production (Ahmed, N., 2019). Fast feed techniques enable the creation of inserts such as cores, side cores and part cavities. The whole manufacturing process depends on the quick tool used; It is also possible to

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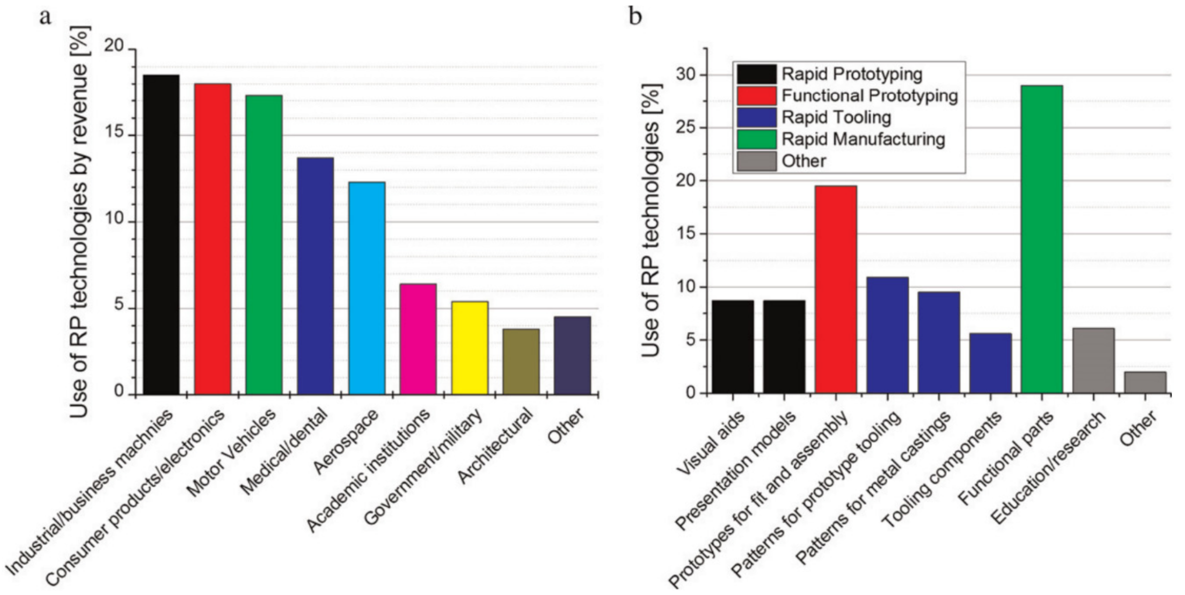

Figure 1: Market share relevance of RP technologies. Revenue earned is related to (a) industry and (b) application sectors.

produce parts through multiple mold cycles. However, rapid tooling technology need to consider many factors to get the most out of these benefits, as they vary in size, consistency, technology, precision, and materials (Zhou, L. Y., Fu, J., and He, Y., 2020).

Currently, many methods have been developed to produce a product with the low quantity, the method is commonly called Rapid Tooling (RT). The term RT refers to the manufacture of tools that are made quickly and cheaply, only now the definition of RT is starting to develop into tools that refer to the age of the RT itself (Barnhoorn et. al., 2015).

There are several types of Rapid Tooling, namely RTV (Room-temperature Vulcanizing) Mold, Rapid Aluminium Tools (RAT), CAFÉ Bridge Tool, and Direct AIM Rapid Bridge Tool (Wolf et. al., 2018). Of all the available rapid tooling methods, the RTV Mold was chosen which was applied by changing the core and cavity with epoxy resin and polyester resin materials for the product.

It is just that the problem with the use of polyester resin in the product is the size deviation caused by shrinkage. Shrinkage in polyester resins ranges from 5% – 12% (Gao et. al., 2019). The shrinkage that occurs is expected to be as minimal as possible so that deviations in the size and function of the product can be achieved.

In addition to shrinkage, the problem with RTV molds with resin-based products is the need for reinforcement in the form of fibers in the resin (Celik, K., & Belli, S., 2015). With the addition of reinforcement in the form of fiber, the product will have better mechanical load-bearing strength. It is just that the product to be made will not use fiber or reinforcement so that the strength of the product will be reduced. So that even without reinforcement, it is expected that the strength to receive optimal mechanical loads is obtained.

Although much research addressed obtaining a good quality product with the optimal solution, shrinkage has not yet been finished with the optimal ratio. The solution given to this problem is to try to adjust the catalyst ratio in the polyester resin to get the optimal ratio. By adjusting the ratio of the catalyst to the resin, it is hoped that the shrinkage and strength to receive the most optimal mechanical load will be obtained in order to provide a higher quality product to the user.

2 METHODOLOGY

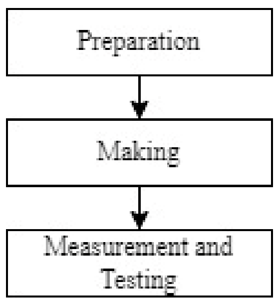

Figure 2: Research methodology.

2.1 Preparation

2.1.1 Hypothesis

All scientific thought begins with a hypothesis or initial guess. In this study, the author made a hypothesis based on the literature which was further validated through trials. The following is the hypothesis in this research:

1. There is an effect of variations in the ratio of catalysts in polyester resin to shrinkage.
2. The greater the ratio of the catalyst given, the greater the shrinkage that occurs.
3. The greater the ratio of the catalyst given, the greater the strength to receive the mechanical load.

2.1.2 Products Identification

There are 4 products to be made, namely front and rear MiFUS cases, tensile test samples, and flexural test samples. For the tensile test the standard size used is 572-2 while for the flexural test it is ASTM D790-10.

The front case has several functions, namely as a battery holder, indicator light holder, and buzzer holder. In addition, the material of the product must have heat resistance due to electrical components, withstand impact loads, and be elastic enough to fulfil the snap-fit function.

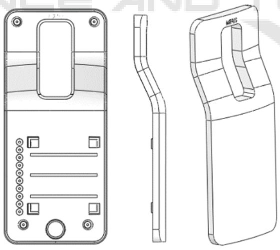

Figure 3: MiFUS front case.

This back-casing product has a function as a holder for all electrical parts ranging from circuits, micro-USB, and also sensors. In addition, the function of this product is as a binder between the front and back covers.

2.2 Making

Making includes making product masters using 3D prints, making molds, and making products. The following is a description of each manufacturing process.

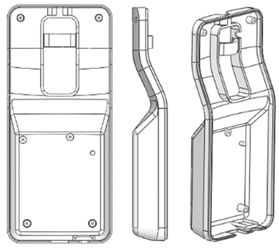

Figure 4: MiFUS back case.

2.2.1 Products Master Making

The product master is a prototype product that is used as part of the positive mold. The manufacture of this product master uses 3D Print technology with ABS material. For the finishing process on the product to smooth the surface, the sandpaper process is used for the MiFUS casing product and vapor smoothing for the tensile test and flexural test samples.

2.2.2 Mold Making

The molds are divided into 3, namely the molds for the front MiFUS casing, the front, and the mechanical load test sample products. It's just that the process is the same, what makes the difference is the manufacture of the holder for the MiFUS casing. This is needed because the formation of the product is less stable without a stand.

2.2.3 Product Making

Before starting the experiment, it must be determined in advance the variation of the ratio of the catalyst to the resin in order to know how many samples to make. Based on research conducted by Ansari et. al. (2020) on composites, the variation in the ratio of catalysts to polyester resins is 0,5:100; 1:100; 2:100; and 2,5:100 with each ratio made 3 samples. From the 3 samples, the best 1 was taken to be plotted in the graph. In the end, it was concluded that the most optimal ratio of all these variations was 2.5:100 and the less good one was 0.5:100.

Because the mechanical test graph for each sample shown in previous studies continues to rise, the authors try to make slightly different variations. This is intended to obtain a more optimal variation and to know the limits of the use of a less than optimal catalyst. Because the more catalyst, the longer the product will dry and become sticky. Therefore, the authors make variations in the ratio to 1,5:100; 2:100; 2.5:100; 3:100; 3,5:100.

Furthermore, these variations are presented in tabular form in order to know the exact volume composition between catalyst and resin for each test product. The volumes in the table are obtained from the SolidWorks software.

Table 1: Design of total resin volume of each specimen.

Products	Volume (mL)
Front Casing	36
Back Casing	45
Tensile Test	10
Flexural Test	6
Total Volume	97 ≈ 100

So, the total resin volume required for 1 experimental batch of sample making is 100 mL. Next is to calculate the volume of catalyst needed. The following is a table showing the volume of resin required for each ratio variation.

Table 2: Resin required for each batch.

Total Volume	Catalyst required (Catalyst: Resin)				
	1,5:100	2:100	2,5:100	3:100	3,5:100
100	1,5	2	2,5	3	3.5

2.3 Measurement and Testing

Tests for products are generally divided into 2, namely measurement of shrinkage with a 3D Scanner and testing of mechanical loads. Specific shrinkage measurements for MiFUS casing products so that later these measurements can be used as a design reference for materials using polyester resin. For mechanical load testing, standard samples are made whose dimensions have been adjusted to existing standards.

2.3.1 Shrinkage Measurement Using 3D Scanner

The 3D Scanner machine used for measurement is the METRASCAN CREAFORM machine. The advantage of this machine is that it can capture up to 800,000 points every second. Therefore, the following are the specifications of the 3D Scanner engine that will be used.

Measurement of depreciation using 3D Scanner produces a product in the form of a point cloud. This point cloud cannot be edited using ordinary CAD software. The software used to help editing and 3D Compare is Geomagic. The following are the stages in using software for the 3D Compare process. No dot should be included after the section title number.

In addition, this measurement also determines the dimensions that must be measured with a calliper. This aims to determine the shrinkage in certain parts, especially in pairs, in order to obtain parameters for later design. The following are the dimensions that must be measured with a calliper.

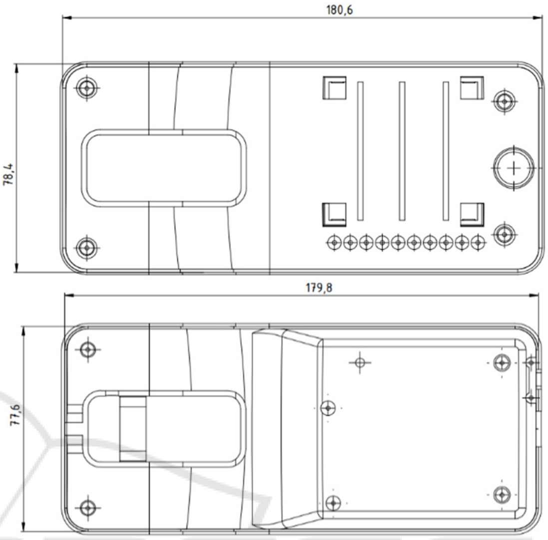

Figure 5: Dimension that will be measured.

2.3.2 Tensile Test and Flexural Test

The purpose of carrying out this flexural test is to obtain material properties and find out how much flexural load the product can withstand. It is hoped that later it will be known whether the product can fulfil the snap-fit function or not. As for the tensile test, the goal is to get the tensile strength so that it is expected to know how brittle the material is.

3 RESULTS AND DISCUSSION

3.1 Shrinkage Data Analysis

To collect depreciation data, two methods are used. The first method is to measure using a digital calliper with an accuracy of 0.01 mm and then see the size deviation that occurs. The second method is to use a 3D Scan tool so that later a standard deviation is obtained to represent the deviations that occur.

3.1.1 Manual Measurement

Manual measurement is done by determining the dimensions to be measured first. After that it was measured 3 times and the results were averaged. In addition, the number of samples measured was 15 pairs of product samples (front cover and back cover) with 3 samples in each ratio variation.

The product that is the measurement reference is the master product which is made to be negative on the mold. Before measuring on the product, measurements are made on the master product which is compared with 3D CAD. The following are the measurement results along with the deviations that occur. So the percentage of deviations that occur is the result of a comparison between the master product and the printed product

After that the average deviation of the product is displayed in the form of a graph to see the increase in the deviation. The following is the deviation data from manual measurements for the front cover and back cover which have been averaged for each catalyst ratio.

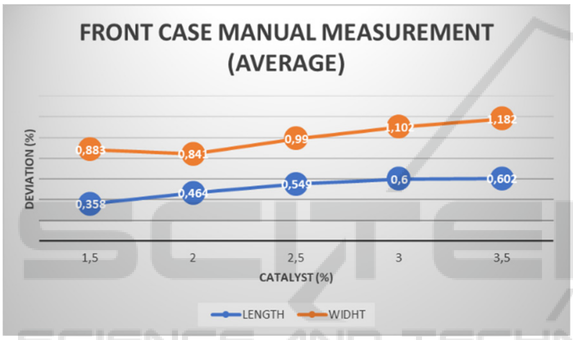

Figure 6: Manual measurement graphic for Front Case.

From the two graphs, it can be concluded that the more catalysts are included, the larger the deviation or in this case the shrinkage of the measured part. In addition, the graph shows that the largest shrinkage for the front cover and back cover occurs at a catalyst ratio of 3.5: 100. Meanwhile, the smallest shrinkage at a catalyst ratio of 1.5: 100. The depreciation that occurs is lower than the depreciation in the given

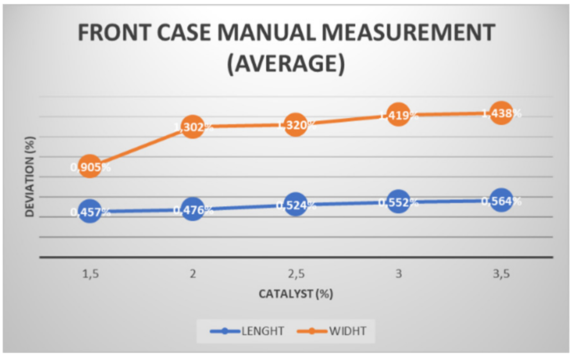

Figure 7: Manual measurement graphic for Back Case.

theory, which is 5%-12%. This is caused because the product is made too thin so that the shrinkage that occurs is getting smaller.

In both graphs there are similarities, namely the average deviation of the largest deviation in the width. This is because the contact area in the width dimension is longer than the long dimension. In addition, because the process of taking the product is carried out when the product is half dry to make it easier to take, this can cause the product to be deformed.

From the measurement data obtained, it is then used as the basis for determining the recommended dimensions for the length and width of the pre-determined product. The following are the suggested dimensions for each variation of the catalyst ratio in the length and width dimensions.

Table 3: Dimension recommendation for length and width for front case.

Catalyst Ratio	Length and Width	Ref. Dim.	Rec. Dim.	Tol
1,5	L	179,86	179,04	± 0,3
	W	77,59	76,89	
2	L	179,86	179,01	
	W	77,59	76,58	
2,5	L	179,86	178,92	
	W	77,59	76,57	
3	L	179,86	178,87	
	W	77,59	76,49	
3,5	L	179,86	178,85	
	W	77,59	76,48	

Table 4: Dimension recommendation for length and width for front case.

Catalyst Ratio	Length and Width	Ref. Dim.	Rec. Dim.	Tol
1,5	L	179,86	179,22	± 0,3
	W	77,59	76,91	
2	L	179,86	179,03	
	W	77,59	76,94	
2,5	L	179,86	178,88	
	W	77,59	76,83	
3	L	179,86	178,78	
	W	77,59	76,74	
3,5	L	179,86	178,78	
	W	77,59	78.71	

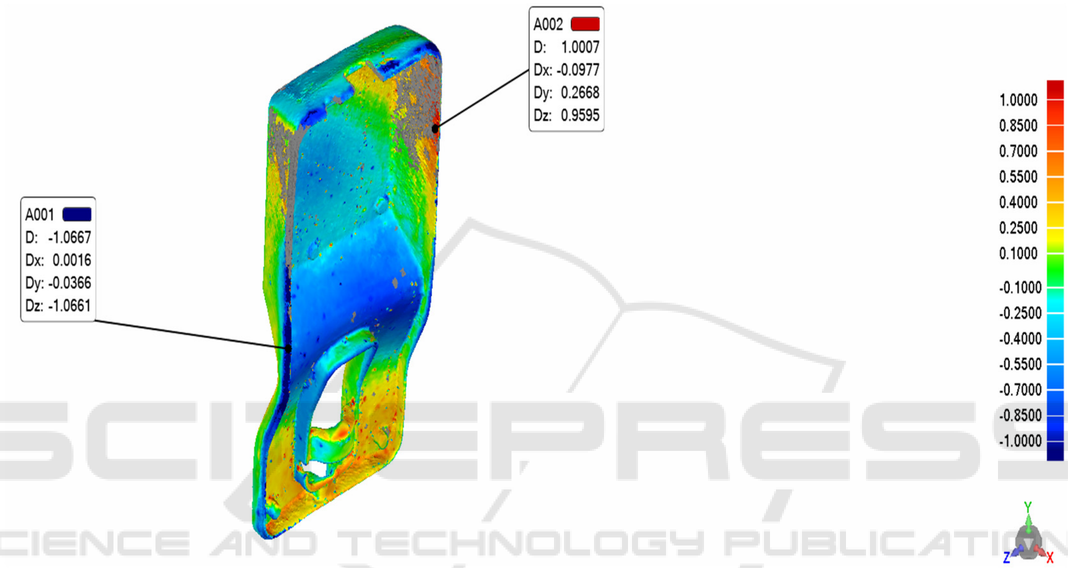

Figure 8: Example of 3D compare product.

3.1.2 3D Scan Measurement

Measurements using 3D Scan were carried out using 5 pairs of product samples (front cover and back cover) with 1 sample for each variation of the catalyst ratio. This is because there are some products with too many voids or trapped air so that they are considered unfit for the 3D Scanning process. The product used is the product with the least trapped air holes or voids on the product display in order to obtain a topology that is closest to the product master. Measurements are made by comparing the master product that is made into a mold with the printed product. After that, it is compared using the Geomagic software using the 3D Compare feature to get the deviation that occurs in each product.The tolerance entered in the software is ±0.1 mm. This is based on a maximum product thickness of 2 mm and follows standard general tolerances. The following is graphics of 3D Scan results along with the maximum and minimum deviations that occur in the product.

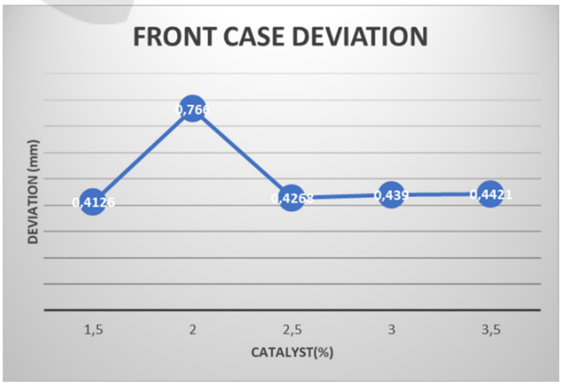

Figure 9: Front case deviation.

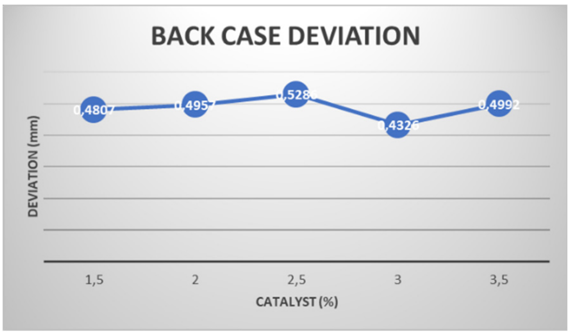

Figure 10: Back case deviation.

In the standard deviation chart on the front cover, the smallest deviation occurs at a ratio of 1.5: 100 and the largest is 2:100 with each deviation of 0.4126 mm and 0.766 mm.

The non-linear increase in the ratio of 2: 100 is most likely due to different treatments during the manufacturing process such as clamping that is not hard enough, room temperature is too low, or uneven stirring. However, after a ratio of 2: 100 the data obtained is quite linear.

In contrast to the back cover, the largest deviation occurred at the catalyst ratio of 2.5: 100. However, the smallest deviation remained at the catalyst ratio of 1.5: 100. This data obtained quite linear data.

3.2 Mechanical Test

Mechanical properties testing carried out is 2 tests, namely flexural test and tensile test. All mechanical load testing is carried out in the material testing laboratory in the metal casting department. The following are the results of the mechanical load testing.

3.2.1 Flexural Test

The number of samples tested in the flexural test amounted to 5 samples. From the test results obtained the following results.

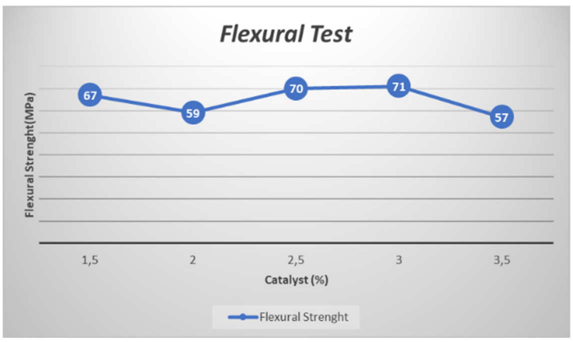

Figure 11: Flexural Test.

Based on the test results, it is found that the greater the catalyst that is inserted into the polyester resin, the higher the load-taking ability. In addition, the most optimal alloy is the 3: 100 alloy with the ability to accept mechanical loads of 71 MPa. This is approximately 38% higher than the theoretical basis that has been given, which is about 40.6 MPa.

While the lowest bending strength is at a ratio of 3.5:100 with a strength of 57 MPa. This is because too much catalyst makes the material more brittle or brittle and unable to withstand bending loads.

3.2.2 Tensile Test

The tensile test uses 5 samples. The following is the tensile test result data presented in the form graphs.

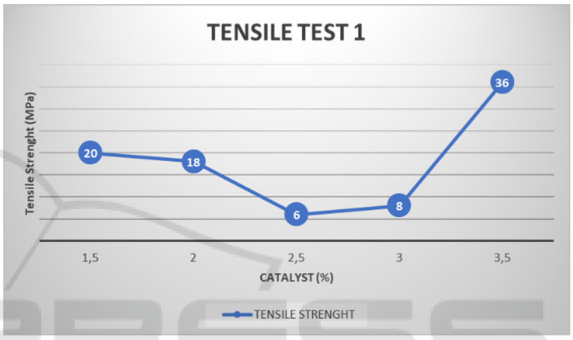

Figure 12: Tensile Test 1.

Based on the test results, it was found that the most optimal yield was 3.5: 100. This was due to the increasing number of catalyst alloys and the harder and more brittle material. In samples 2, 3 and 4 there was a decrease in strength this was due to the poor drying process so that the material was not strong enough to withstand tensile loads. In addition, it is suspected that the stirring process is not good so that the catalyst is not mixed evenly. Therefore, after discussing with the supervisor, it was decided to carry out a tensile test for the second time. The following is the data from the second tensile test which is presented in the form of tables and graphs.

Based on the graph of the test results, it was found that the most optimal alloy was at a ratio of 2.5:100 of 41 MPa and this was 19.5% greater than the given theory, which was 33 MPa. However, the gradient is still not linear even though the time and method of stirring have been the same.

After that the author tries to compare the data from the tensile test results one and two in one graph and see how the difference is. The following is a comparison chart between tensile tests 1 and 2.

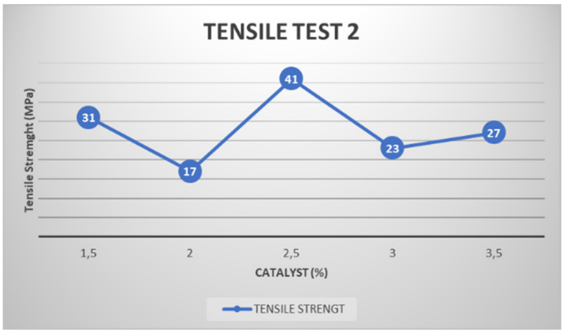

Figure 13: Tensile Test 2.

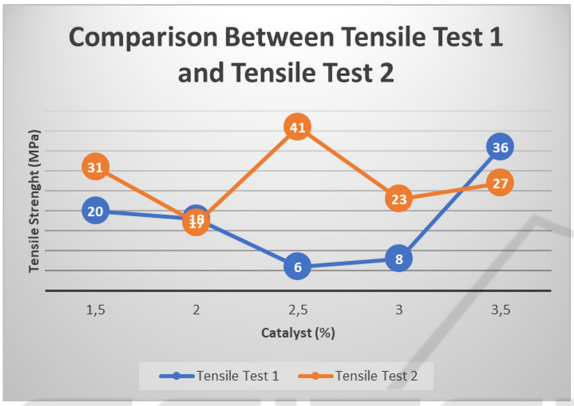

Figure 14: Comparison between tensile test 1 and tensile test 2.

From the graph, it can be seen that there was an increase in the average tensile strength from 17.8 MPa to 27.8 MPa. This shows that the time and method of stirring have an effect on the resin product made

Based on the test results obtained data that is less linear, this has several factors causing the data to be less linear. The following are factors that affect the data to be less linear:

1. Unstable room temperature

The product production process is carried out outdoors because it will be quite dangerous if the production process is carried out indoors due to toxic substances in polyester resin. Due to the outdoor production process, the temperature of the manufacturing environment during the day will be different from the manufacturing temperature in the morning. The higher the temperature, the faster the reaction will occur.

2. Poor Molding

The main problem with the mold is that the ejection process is difficult and lacks rigidity. So that when the product is ejected, the mold is damaged and parts of the mold sometimes stick to the product. In addition, the surface of the resulting product is uneven so that when the test results are gripped by the tensile testing machine there are cracks in the product before the test is carried out.

3. Drying time

In the products made there are several test samples which after being made a few hours later the test is immediately carried out. So that the sample is not completely dry at the time of testing. The optimal drying time for the resin is 1 to 2 days after the product is made for the product to dry completely.

4 CONCLUSIONS

There is an effect of changes in catalyst ratio variations in polyester resins on shrinkage. The hypothesis that the greater the catalyst is inserted, the greater the shrinkage that occurs is true based on the results of manual measurements and 3D Scans. While the results of manual measurements and 3D Scanning obtained the smallest deviation or deviation due to shrinkage is at a ratio of 1.5: 100. In addition, shrinkage parameters are produced for the length and width of the product for each variation of the ratio of catalyst to resin.

There is an effect of changes in catalyst ratio variations in polyester resin on the ability to accept mechanical loads. The hypothesis given is not entirely correct, because the data obtained do not show that the larger the catalyst, the greater the mechanical ability. In the bending test the most optimal alloy is 3:100, which is 71 MPa, while for the tensile test it is 2.5:100 at 41 MPa.

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