Experimental Study and Mechanical Characterization of Recycling Hdpe Plastic Waste Through Extrusion Process for Self-Supplying the 3D Printed Material

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EXPERIMENTAL STUDY AND MECHANICAL CHARACTERIZATION OF RECYCLING HDPE PLASTIC WASTE THROUGH EXTRUSION PROCESS FOR SELF-SUPPLYING THE 3D PRINTED MATERIAL

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Abstract

Globally, Indonesia is the second-largest contributor of plastic waste with millions of metric tons dumped into oceans yearly. Therefore, this research describes the process of recycling HDPE waste to produce new products in the form of filament for self-supplying 3D printed material in two phases. The first is the preparation which focuses on shredding HDPE waste, while the second implements the extrusion process at various levels. The parameters selected in this process are the time span, the temperature, and the shrew speed. The input material for the extruder machine is set for four variations of HDPE and resin ratio, namely 90:10, 95:2.5, 95:5, and 97.5:2.5. In the extrusion process, the parameter and level variation are studied to produce the desired filament. The mechanical properties of each filament are tested to determine their tensile and bending strengths. The tensile test result showed that the greater the ratio of HDPE and resin, the smaller the elasticity value of the filament. Conversely, the bending test result indicated a linear relationship between the elasticity value and the ratio. The slope of -43.40 MPa and 35.70 MPa for tensile strength and bending tests signifies that for every increasing one percent of composition, the elasticity filament decreased by 43.40 MPa and increased by 35.70 MPa, respectively. This study provides numerous academic benefits, such as minimizing plastic waste in the surrounding environment, becoming a topic of study for the students, and self-supplying the 3D printed material.

Keywords: extrusion, HDPE recycling, tensile, linear regression.

Introduction

Indonesia is the second largest contributor of plastic waste in the world, according to Jenna R. Jambeck (2015). Indonesia is estimated to produce 64 million tons of waste every year. Based on data from the Ministry of Environment and Forestry (KLHK) in 2019, plastic waste occupies the second position at 14% after organic waste at 60%. Meanwhile, based on research from Sustainable Waste Indonesia (WSI) quoted from CNN, of the 65 million tons of waste produced in Indonesia every day, there is 24% of waste that is not managed and 14% of it is plastic waste (Yosi, 2019). One of the most widely used plastic materials in modern life is High Density Polyethylene (HDPE). HDPE is a type of plastic that is often used for shampoo bottles, oil bottles, and others. This type of plastic has strong characteristics and easy to recycle.

All Currently, in Indonesia, the demand for 3D printed filaments is increasing significantly. Meanwhile, commercial 3D printed filaments available in the market are limited in supply and expensive. Most of them are still imported. Therefore, there is a problem need for solutions, especially the fulfillment of alternative 3D printed filaments for teaching and learning needs on campus. On the other hand, recycling of plastic waste has been done by many researchers. Based on the Plastic Waste Management Institute, plastic waste processing is categorized into three ways, namely, mechanical recycling, chemical recycling, and thermal recycling (M. Mohammed, 2018).. Based on the problem of recycling HDPE waste and supplies of 3D printed materials, the main objective of this study is to design how to recycle HDPE into 3D printed materials. The focus of this research is to limit the study of waste recycling to the mechanical recycling process. In this process, plastic waste is sorted and shredded into small pieces, then melted by extrusion without changing the plastic components.

Literature Review

According to M. Mohammed (2018) other alternative materials as 3D printed filament materials are thermoplastics, for example mineral water bottle caps. This research has succeeded in developing 3D printing filaments from polyethylene therephtalathe (PET) through the extrusion process. This process for thermoplastic materials has almost the same principle for metal extrusion, except that in extruding polymer materials, we no longer use ram as well as metal extrusion, but use a screw. The raw materials used in the thermoplastic extrusion process are also different from the extrusion of metal materials. In metal extrusion the raw materials are included in the form of bars, plates or sheets, while in polymer extrusion the raw materials used are in the form of plastic pellets.

In general, extrusion in thermoplastics is a process of forming material by heating it until it reaches the melting point and melting due to external heat or due to friction heat which is then flowed into the mold by a screw to produce material with a cross-sectional shape according to the shape of the die. This process is a continuous process that produces several products such as plastic films, ropes, pipes, pellets, plastic sheets, fiber, filaments, cable sheaths, and several other products. This process has several advantages, including the equipment required is cheaper than the injection molding process, and the thickness of the material can be adjusted accurately (Mengeloglu, 2007). The extrusion process can also increase productivity because it can produce objects with complex shapes. This has the opportunity to become one of the fields of business that has economic value for the community. The business is an activity to recycle plastic waste into a filament for 3D printing basic materials.

In this process, the polymer raw material in the form of pellets is fed into the hopper and moved through the barrel by using a helical threaded shaft (screw conveyor) and then conveyed to the die. The threaded shaft consists of three main parts, namely: feeding section, compression section and die. The first is the feeding section, which is a section that has a constant thread diameter and an area where the material flows constantly. Furthermore, the raw material is pushed to the compression section. In this section, the diameter of the screw shaft increases continuously while on the contrary the free flow area of the material decreases and here the polymer material is softened and stretched. In this area, the polymer material is heated to a certain temperature. In order to flow smoothly, while keeping the barrel from overheating, a blower is installed to regulate the temperature of the barrel so that it remains at a certain temperature. After passing through the compression section, the material then goes to the final section, namely the die.

Michaeli. W (2004) through his paper describes a new method of die geometry design for extrusion. This method uses a combination of finite element analysis (FEA) and flow analysis network (FAN). The result of his research is an algorithm for automatic flow optimization in the extrusion dies channel. He also investigated the friction of polypropylene (PP) in the feed section of a single screw extrusion, which produces additives, fillers and pellet shapes that affect friction in the extruder. In addition, the results of Miriam (2019) show that there is an effect of melting point temperature of the polymer extruded using a single screw. Another study by M.N. Alghamdi (2021) has made a single screw extrusion machine, using the shape and dimensions of the extruded as an indicator of success for a single screw machine at a ratio of L/D = 14 and a temperature in the range of 180°C. (Michaeli, W., 2004).

Materials and Methods

This research is using experimental method. The method used in this study is divided into three main phases covering the entire experimental approach. The three phases are first, the preparation phase; second, implementation phase, and third, analysis phase. The preparation phase is the most important phase of the experiment to provide the desired information. The preparation phase is when the factors and levels of the extrusion process are selected, and are, therefore, the most important steps in the experiment. The second most important phase is the implementation phase to get the desired results according to the planning phase. If the experiment is planned and carried out properly, the analysis will be easier and tend to produce positive information regarding the most optimum factors and levels. The analysis phase is when positive or negative information related to the selected factors and levels is generated based on the previous two phases. The analysis phase is the last important thing which is whether the researcher will be able to produce positive and optimal results. The plastic filament will be used for 3D printed material needs for students who carry out practical activities at the Engineering Materials Laboratory. A brief description of the stages of this research is described in Fig, 1.

The material for this research is HDPE plastic waste. There are two types of HDPE plastic waste used in this study, the first is the white HDPE type, this type is more elastic than the black one because the first HDPE is from pure petroleum which is used as bottles such as soap, shampoo, medicine etc. While the second type is black HDPE, this type is more brittle than white HDPE because HDPE has been recycled and mixed with various substances that are used as buckets, tubs, oil bottles, cable pipes and others. The tools used include a plastic shredder machine and an extruder machine for making plastic filaments.

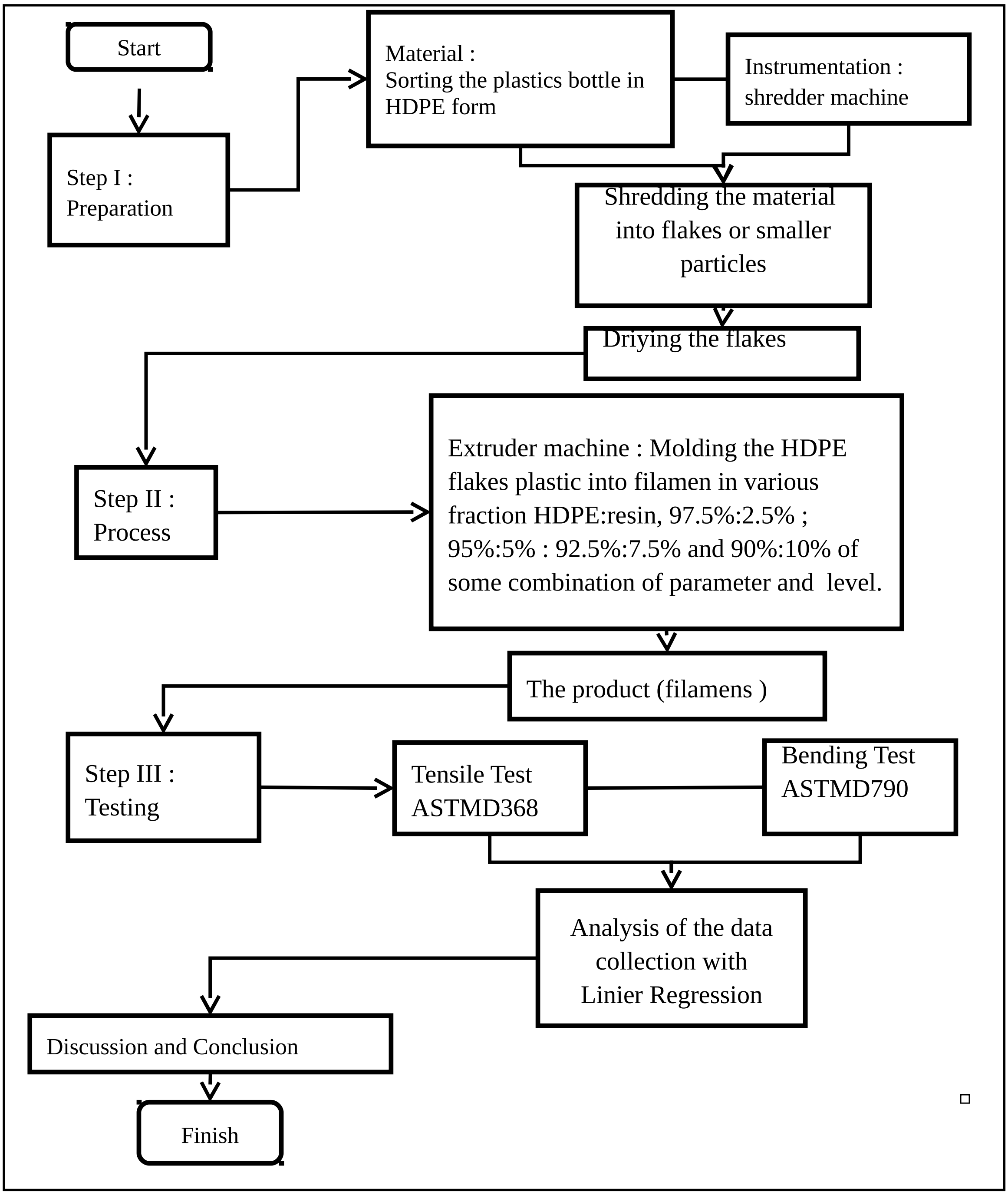

Fig. 1. Proposed steps flow

The shreddng process aims to obtain a plastic filament in the form of a flakes. The results of the HDPE shredding process in the form of flakes are shown in Fig.2. The shredded results are then dried in the sun before the extrusion process is carried out for the manufacture of plastic filaments. The manufacture of plastic filaments is carried out through the extrusion process. This process aims to obtain plastic filaments that will be used for 3D printed materials. This material to supply experimental material needs. HDPE flakes that have been dried are then processed using an extruder machine at the Faculty of Engineering, University of Pembangunan Nasional Veterans Jakarta. This extruder machine is the result of a previous research conducted in 2020 with the topic "Design and Analysis of 1.50 mm Filament Extruder Machine". Fig. 3 illustrate the extruder machine that produces recycled plastic filament. In the extrusion process, four variations of HDPE: Resin composition were determined, namely 97.5%: 2.5%; 95%:5%; 92.5%:7.5%; 90%:10%. In the extrusion process, four variations of HDPE composition were determined: resin, namely 97.5%: 2.5%; 95%:5%; 92.5%:7.5%; 90%:10%. In each of these compositions, the variation of the extruder process parameters and levels is determined. The results of the extrusion process for each parameter and level variation were sampled to test the mechanical quality of the resulting filament. The Table 1 briefly describes the combination of variations in physical parameters and levels used in the extrusion process.

Fig.2. The HDPE plastic waste

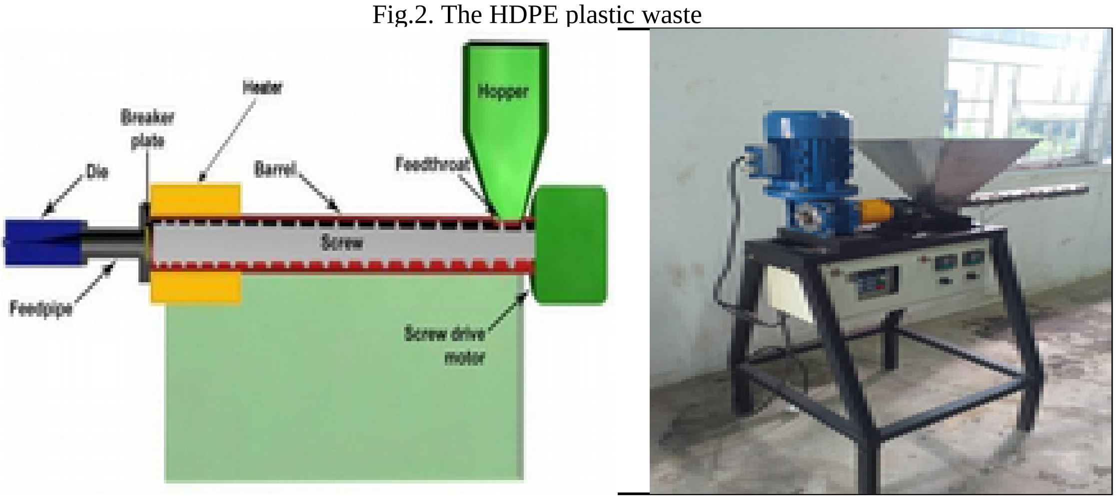

Fig.3. The extruder machine

Table 1. Parameters and levels in the extrusion process

Factor	Parameter	Level		
		1	2	3
A	Time span(minute)	10	12	16
B	Temperature(0C)	150	165	180
C	Srew speed(rpm)	12	16	20

Fig. 4. The extrusion process of producing theHDPE waste filament

Parameter variation is barrel temperature T(°C) and screw speed (rpm). Temperature variations were determined at 260°C, 280°C, and 300°C; while the screw speed variations are 30 rpm, 35 rpm, and 40 rpm. For each combination of extrusion processes, the extrusion process time settings were determined for 10 minutes, 12 minutes and 16 minutes. As shown in Fig. 4, the extrusion process is assumed to have reached steady-state within that time span.

The material from the extrusion process of each HDPE: resin composition was sampled for mechanical properties tests, namely tensile tests and bending tests referring to ASTM standards. For tensile test using ASTM D368, and bending test using ASTM D790. The process of making test specimens is carried out by a cutting process that is adjusted to the specified specimen design. Fig.5.a and Fig.5.b show the design of the tensile and bending test specimens.

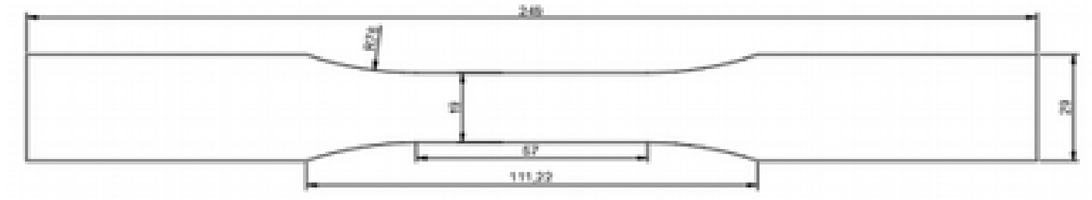

Fig.5.a. Tensile test specimen based on ASTMD368

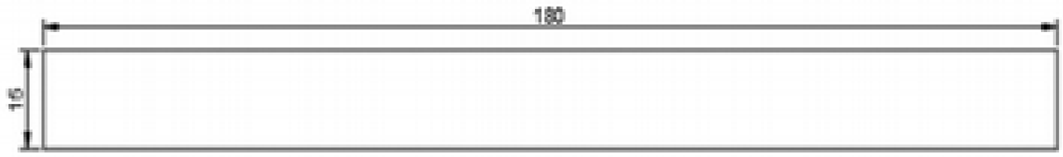

Fig.5.b. Bending test specimen based on ASTMD790

Each filament sample from the extrusion process in every combination of parameters and levels for each HDPE:resin composition was tested for tensile strength and tested for bending. The raw data of the tensile strength and bending test results were statistically processed. The average value of stress and strain is obtained from the formula,

$\overline{Stress} = \sum_{i=1}^{N} Stress_i / N$ and $\overline{Strain} = \sum_{i=1}^{N} Strain_i / N$. (1)

The values of each standard deviation are $\Delta\,\overline{Stress} = \left[\sum_{i=1}^{N} \frac{(Stress_i - \overline{Stress})^2}{N-1}\right]^{1/2}$ and $\Delta\,\overline{Strain} = \left[\sum_{i=1}^{N} (Strain_i - \overline{Strain})^2 / (N-1)\right]^{1/2}$.

The average of elasticity $\bar{E}$ is defined by $\bar{E} = \frac{\overline{Stress}}{\overline{Strain}}$ and the uncertainty of elasticity is determined through the propagation of error,

$$\Delta\bar{E} = \left[\left(\frac{\partial\bar{E}}{\partial\overline{Stress}}\Delta\overline{Stress}\right)^2 + \left(\frac{\partial\bar{E}}{\partial\overline{Strain}}\Delta\overline{Strain}\right)^2\right]^{1/2}$$
$$= \left[\left(\frac{1}{\overline{Strain}}\Delta\overline{Stress}\right)^2 + \left(-\frac{\overline{Stress}}{\overline{Strain}^2}\Delta\overline{Strain}\right)^2\right]^{1/2} . \quad (2)$$

The relatif error of elasticity, is defined by $\% RE = \frac{\Delta\bar{E}}{\bar{E}} x100\%$.

Based on the data variations of HDPE: resin composition and the elasticity value of the filament sample, the predictions were made of the relation between changes in the elasticity value of the extruded filament and the composition of HDPE: resin. The mathematical relation is obtained from Linear Regression based on the Least Square Method (LSM),

$$\hat{y} = \bar{y} + m(x - \bar{x}), \quad (3)$$

where $\bar{x}$ is the composition of HDPE: resin (%), $\bar{y}$ is the average value of the elasticity (MPa), and *m* is the slope of graph (MPa/%).

Results and Discussion

Each filament in every combination of parameter and levels of the extrusion process was sampled. Each sample was tested for tensile and bending test. From the tensile and bending test results, the average stress and strain values were calculated based on equation (1) for each HDPE:resin composition. The results of the tensile strength test is shown in Table 2. The value of the elasticity uncertainty was calculated based on equation 2. From the results of the tensile test for each pair of data for variations in the HDPE: resin composition and the average elasticity value is plotted as Fig.6. This horizontal axis is the percentage of HDPE: resin composition and the vertical axis is the average value of elasticity accompanied by its uncertainty. From the results of linear regression, it can be found that there is a linear relationship between variations in the composition of HDPE: resin which gives a slope value of -43.40 MPa per percent. This means that for every 1% increasing in the composition of HDPE: resin, the elasticity value of the tensile strength of the extruded filament decreases by 43.40 MPa. From the data processing, it is obtained that the standard deviation is 10.08 and the coefficient of determination is -0.95.

Table.2. The average data of mechanical properties of the filamen based on the tensile strength result

No	Composition (%)		Max Load (MPa)	Stress (MPa)	Elasticity (MPa)	Strain
	HDPE	RESIN				
1	97.5	2.5	2739.55	14.32	493.77	0.029
2	95.0	5.0	2809.70	16.52	516.17	0.032
3	92.5	7.5	3070.25	18.50	545.37	0.034
4	90.0	10.0	3889.20	22.61	628.07	0.036

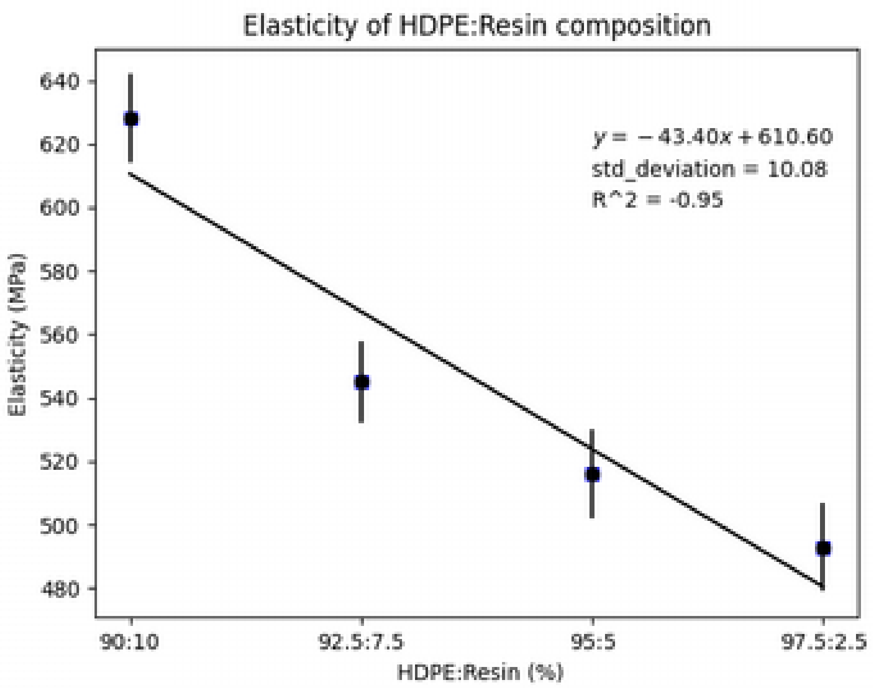

Fig.6. Tensile strength result

Table.3. The average data of mechanical properties of the filamen based on the bending test result

No	Composition (%)		Max Load (MPa)	Stress (MPa)	Elasticity (MPa)	Strain
	HDPE	RESIN				
1	97.5	2.5	3173.15	26.20	987.55	0.026
2	95.0	5.0	3269.60	27.72	963.95	0.029
3	92.5	7.5	3466.90	29.09	924.96	0.031
4	90.0	10.0	3911.20	31.16	880.78	0.035

In addition to the tensile test, a bending test was carried out. The data from the bending test results are summarized in Table 3. Similarly, the results of the bending test of the data pair for variations in the HDPE: resin composition and the average value of elasticity are depicted as Fig.7. From the results of linear regression, it can be found that there is a linear relationship between variations in the composition of HDPE: resin which gives a slope value of 35.70 MPa per percent. This means that for every 1% increase in the composition of HDPE: resin, the elastic value of the bending strength of the filament as a result of the extrusion process increases by 35.70 Mpa. From the data processing of the bending strength, it is obtained that the standard deviation is 3.41 and the coefficient of determination is 0.99.

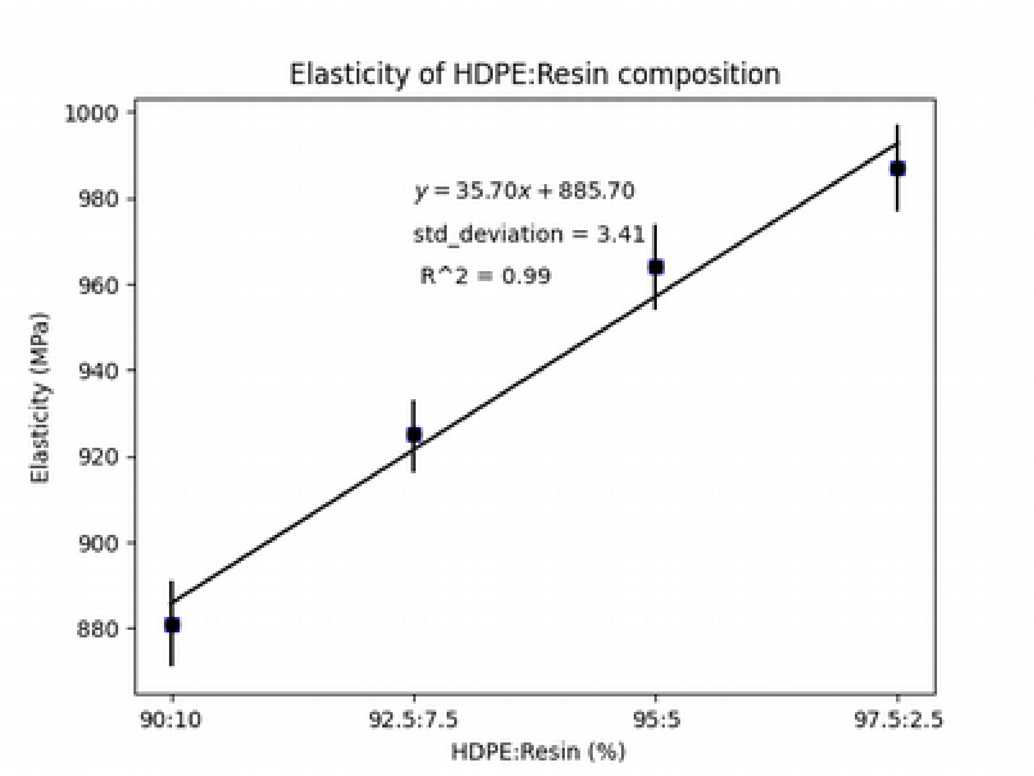

Fig.7. Bending test result

Conclusion

This experimental study succeeded in recycling HDPE waste through the extrusion process. In the extrusion process, several parameters and levels are varied. The parameters applied to the extrusion process were the time range, temperature and rotational speed. The extrusion process obtained a new product in the form of filaments. The mechanical properties of the filament were further characterized by tensile and bending tests. From this study, it was obtained the linear relationship between the elasticity value and of the HPDE: resin composition. From the tensile test result showed the higher the the content of the HPDE: resin composition, the smaller the elasticity value, which the slope value is -43.40 MPa per percent. Meanwhile, from the bending test result showed the greater the content of the HPDE: resin composition, the higher the elasticity value, which slope value is 35.70 MPa per percent. The standard deviation of the tensile strength was 10.08, while the coefficient of determination was -0.95. Similarly, from the bending test had obtained standard deviation was 3.41 and the coefficient of determination was 0.99

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