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# Characteristics of Filament From Extrusion Result of Low-Density Polyethylene Plastic Waste using Extrusion Method for 3D Printing Filament Applications

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**Abstract**

Low-Density Polyethylene (LDPE) plastic is a material that is widely used by the industry as packaging. However, the manufacturing industry players do not place environmental issues as the main focus in the supply of products. This study aims to analyze the characteristics of LDPE plastic waste that is formed into filaments for 3D printing filament applications. The research variables analyzed were the temperature of the test sample at 170 °C, 180 °C, 190 °C, 200 ºC, 210 °C, and 220 °C. The filament analysis process is to form LDPE plastic waste into 3D printing filaments using a plastic waste extrusion machine. The hardness test was then carried out using a digital Shore A Durometer Hardness tool. Furthermore, a microstructure test was also carried out using SEM (Scanning Electron Microscope). The results of the hardness test obtained show that the specimen temperature of 210 °C has the highest hardness value, which is in the range of 83–89.5 HA. In the meantime, specimens at 180 °C had the lowest hardness values, ranging from 59.5 to 71.5 HA. In addition, the SEM test resulted in the sample surface not being very flat at temperatures of 170 °C, 180 °C, and 190 °C, while the sample surface was quite flat at temperatures of 200 °C, 210 °C, and 220 °C.

*Keywords:* Low-density polyethylene; plastic waste; scanning electron microscope; shore a durometer

## 1. Introduction

Many plastics produced and used by humans end up in nature, causing damage to living things and the environment [1]. However, the handling of plastic waste has not been given much attention by several manufacturing industries that produce goods. The reason is that the players in the manufacturing industry do not place their main focus on environmental issues. In addition, some industries only use plastic as an ingredient in production without thinking about recycling it into new products. This results in the absence of plastic waste handling by the industry itself. Even though the level of plastic waste produced in the world continues to increase, reaching around 381 million tons in 2015 [2].

A Plastic extruder machine is a machine that serves to extrude plastic into solid filaments. After extruding plastic, many benefits can be utilized from plastic, for example in the blow molding extrusion process which makes it into hollow plastic products such as bottles, tubes, and gallons [3]. The plastic extrusion process is a widely recognized technique in the polymer industry [4].

From this extrusion technique, the industry has developed an extruder machine for plastics. By relying on heating from the barrel and lead screw, the plastic can be melted and delivered to the end of the barrel. To produce good-quality plastic products, the hot temperature in the barrel is very influential. Therefore, temperature control on the engine is very necessary because each type of plastic has a different heat character [5]. One of the uses of extrusion machines is that the results of the extrusion produce 3D printing filaments. 3D printing filament made from plastic waste is one solution for the manufacturing industry to reduce the presence of plastic waste today [6].

Hardness testing is a test indicator to determine the hardness of a material. One of the hardness testing tools for plastic materials that can be used is the Shore a Durometer. There are eight types of durometer scale classification, namely A, B, C, D, DO, O, OO, and M. The determination of the scale used depends on the type of material and the level of hardness of the material [7].

A Scanning Electron Microscope (SEM) is an electron microscope designed to directly observe the surface of solid objects. SEM testing is intended to determine the particles in the sample and the surface flatness of the sample. The combination of high magnification, large depth of field, good resolution, and

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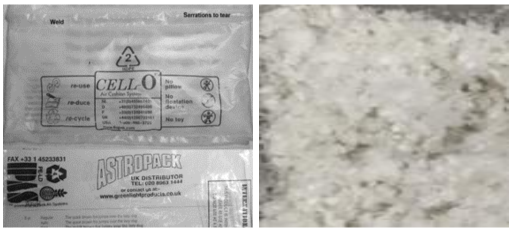
the ability to know the composition and crystallographic information makes SEM widely used for research and industrial purposes [8].

To get the performance level of the extrusion machine process as expected, it is considered necessary to analyze the plastic waste category of low-density polyethylene on the extruder machine by producing 3D printing filaments so that the exact control parameters of the melt extrusion machine can be known and are expected to improve performance.

## 2. Research methods

Low-density polyethylene (LDPE) plastic is commonly used to make goods that require flexibility but are strong. This type is indestructible but safe for storing food (food grade). Commonly used for food wrap, bread wrap, and dry-cleaning bags, The level of hazard posed is low, but the difficulty of decomposing with nature is categorized as moderate [9]. Fig. 1 shows the LDPE Plastic (a) and Shredded plastic result (b).

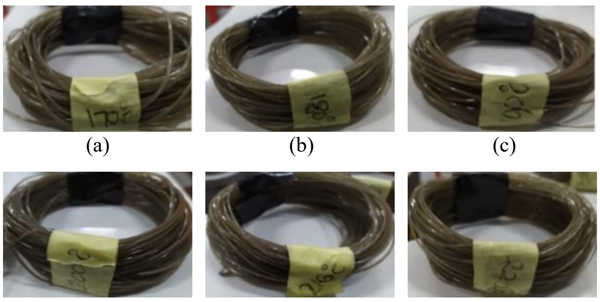



(a) (b)

Figure 1. (a) LDPE plastic; (b) Shredded plastic result

The filament of LDPE plastic waste is physically white, as shown in Fig. 2. The shape of LDPE plastic waste is classified as irregular and also a sponge. The shape is caused by the process of making it using a chopping machine.

The results were then extruded using an extruder machine with a motor speed of 72 rpm and a rolling speed of 54 rpm at a nozzle size of 1.75 mm. Six samples were made for each extruder machining process with various variables. The variables in the analysis are temperature, 170 °C, 180 °C, 190 °C, 200 °C, 210 °C, and 220 °C. The results of the extrusion can be seen in Fig. 2.



(a) (b) (c)

(d) (e) (f)

Figure 2. Samples of LDPE plastic (a) 170 °C, plastic (b) 180 °C, (c) 190 °C, (d) 200 °C, (e) 210 °C, (f) 220 °C

Samples of LDPE plastic products have different dimensions depending on the nozzle diameter of the extrusion machine. The nozzle diameter on the extrusion machine used is 1.75 mm. Changes in diameter after undergoing the machining process on the extrusion machine are shown in Table 1.

Table 1. Machining process data on extrusion machine

| No. | Temperature (°C) | Extrusion time (minutes) | Nozzle diameter (mm) | Sample diameter (mm) |
|---|---|---|---|---|
| 1 | 170 | 29.06 | 1.75 | 1.6 |
| 2 | 180 | 29.04 | 1.75 | 1.4 |
| 3 | 190 | 29.02 | 1.75 | 1.4 |
| 4 | 200 | 28.57 | 1.75 | 1.3 |
| 5 | 210 | 28.49 | 1.75 | 1.2 |
| 6 | 220 | 28.01 | 1.75 | 1.1 |

From Table 1 increasing temperatures (170 °C, 180 °C, 190 °C, 200 °C, 210 °C, and 220 °C) will reduce machining process time and decrease sample diameter. The largest diameter value is at a temperature of 170 °C. 1.6 mm with a time of 29.06 minutes, and the smallest diameter value is at a temperature of 220 °C, which is 1.1 mm with a time of 28.01 minutes. As a result, at a temperature of 220 °C, the diameter of the samples is significantly smaller. This is because the heat input is getting larger. Furthermore, thermal softening occurs, where the plastic melts faster.

The test sample that has been obtained is then subjected to a hardness study to determine the hardness of LDPE plastic waste after extrusion. A durometer, also known as ashore, is used to perform an International Standard Test. This test uses a digital Shore A Durometer Hardness test tool to determine the hardness value of a material. In this case, the ability of the material to be loaded with an iron indenter measuring 0.79 mm and having a geometric shape in the form of a flat cone point, with a hardness range of 0 to 100 HA. Durometers have various types of scales where the use of the scale is based on the type of specimen being tested and the level of hardness of the specimen being tested.

The available durometer scale in the materials laboratory is shore A, B, and D. Shore A is used for specimens with hardness values between 20 to 90, such as soft rubber and natural rubber. On the other hand, shore B and shore D are used for specimens with hardness values above 90. In this study, the shore used was shore A because the specimen tested had a hardness value below 90. The assumption that can be made is based on research conducted by Cheung and Zhang that the material used for orthotic shoe insoles usually has a hardness value of between 30 to 50 The unit of hardness value in this study is HA which means the Hardness of Shore A or hardness value using Shore A. Fig. 3 shows the LDPE Plastic shore a durometer hardness testing.

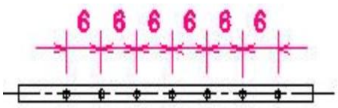



Figure 3. LDPE plastic shore a durometer hardness testing (ASTM D2240)

Hardness value data collection on the results of the LDPE plastic waste sample is studied by testing the hardness at 7 points along the horizontal line of the specimen. As shown in Figure 4, the distance from the point to the next point is 6 mm. The change in these properties will not be significant if it is not accompanied by changes in the microstructure of the LDPE plastic. To find this, a scanning Electron Microscopy test analysis was used. And the detector used for analysis is the backscatter electron because this detector can distinguish different phases/elements by showing differences in color intensity.

A scanning electron microscope (SEM) is a type of electron microscope that is used to look at the surface of solid objects. SEM magnification ranges from 10–3,000,000 times, depth of field ranges from 4–0.4 mm, and resolution ranges from 1–10 nm. SEM is widely used for research and industrial reasons because it combined high magnification, large depth of field, good resolution, ability to know composition, and crystallographic information [10].

## 3. Results and discussion

### *3.1. Shore a durometer hardness testing*

The results of the hardness test were carried out on samples of LDPE plastic waste. The results of the test on temperature variations using the hardness of Shore A or hardness values using Shore A are presented for each specimen. A hardness test is carried out on the horizontal plane with 7 points. The specimen with the highest hardness was at a temperature of 210 °C with an average hardness of 86.57 HA. The specimen with the lowest hardness was at a temperature of 180 °C with an average hardness of 66.07 HA. Table 2 shows the result of the hardness test.

Fig. 4 shows the overall hardness distribution of temperature variations. It can be seen that the maximum temperature that occurs in the extrusion process of LDPE plastic waste affects the maximum hardness value. The higher the maximum temperature, the more even the distribution of hardness values. This can be seen at temperatures of 210 °C and 220 °C.

Fig. 5 shows that the hardness of the 180 °C specimens has the lowest hardness value compared to the 170 °C and 190 °C temperature specimens. The highest hardness value for specimens at 170 °C is 76.5–8.5 HA. On the other hand, the specimen temperature is 190 °C with a hardness value of 66.5–78.5 HA.

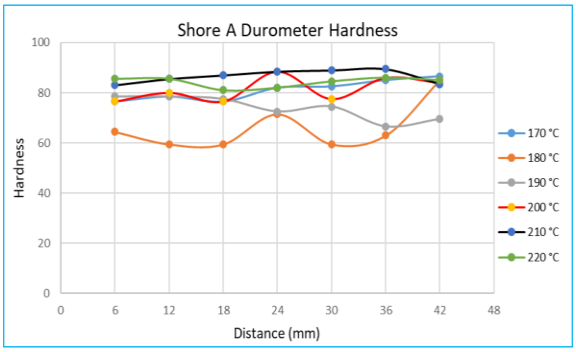



Figure 4. LDPE plastic hardness distribution

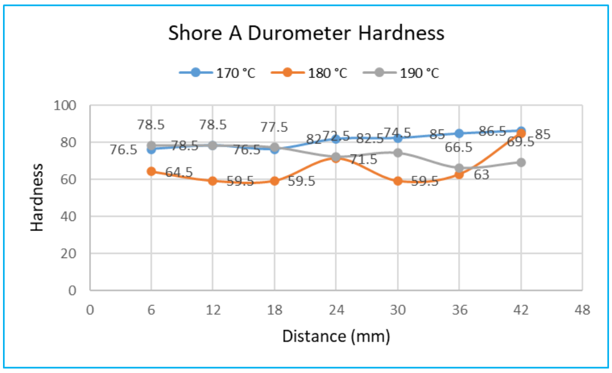



Figure 5. LDPE plastic hardness distribution at temperatures 170 ºC, 180 ºC, and 190 ºC

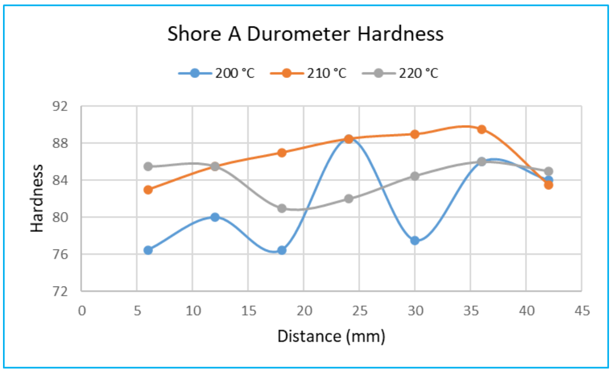



Figure 6. LDPE plastic hardness distribution at temperatures 200 ºC, 210 ºC, and 220 ºC

Fig. 6 shows that the hardness of the 210 °C specimens has the highest hardness value range compared to the 200 °C and 220 °C temperature specimens. Specimen hardness at a temperature of 210 °C, which ranges from 83 to 89.5 HA. Meanwhile, at 200 °C, the highest hardness is in the range of 76.5–86 HA. Similarly, the specimen temperature was 220 °C and the highest hardness ranged from 81–85.5 HA. Table 2 shows the hardness test result data on LDPE plastic waste samples.

The hardness of the specimen temperature at a temperature of 210 °C is very high due to a decrease in the temperature of the amorphous content in the material. According to Asror M. F., amorphous content is brittle and hard [11]. From the graph of the hardness distribution of Shore A Durometer, the high temperature in the process of making LDPE plastic waste extrusion specimens greatly affects the hardness value obtained. The higher the extrusion process temperature, the lower the hardness value.

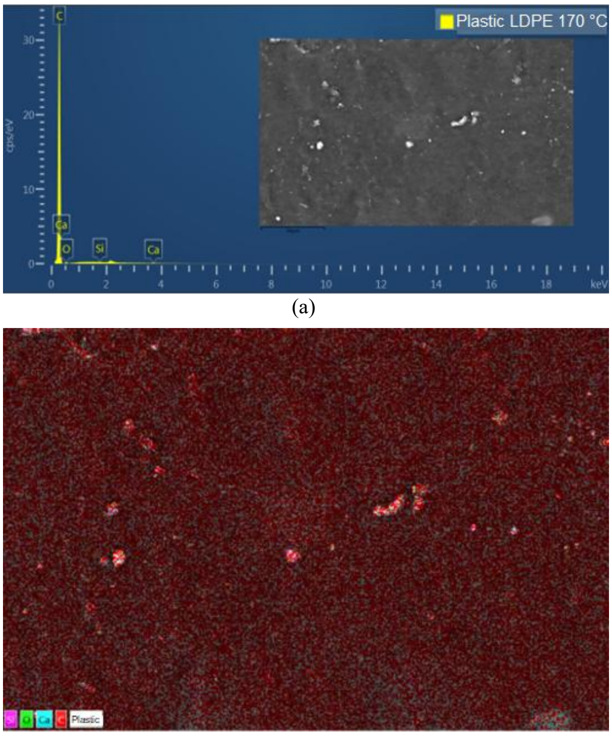
This is due to the difference in hardness values in each test because of a speed that is too slow, which causes the material to freeze first. In addition, this is caused by the uneven distribution of temperature. Another variable is that many possible extrusion processes in the extrusion machine, such as Nozzle temperature, coolant, workbench temperature, as well as nozzle path, and speed are important for processing variables that affect the performance of the final molded part.

Table 2. Hardness test results data for LDPE plastic waste samples

| Point number | Point distance (mm) | Hardness (HA) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 170 °C | 180 °C | 190 °C | 200 °C | 210 °C | 220 °C |
| 1 | 6 | 76.5 | 64.5 | 78.5 | 76.5 | 83 | 85.5 |
| 2 | 12 | 78.5 | 59.5 | 78.5 | 80 | 85.5 | 85.5 |
| 3 | 18 | 76.5 | 59.5 | 77.5 | 76.5 | 87 | 81 |
| 4 | 24 | 82 | 71.5 | 72.5 | 88.5 | 88.5 | 82 |
| 5 | 30 | 82.5 | 59.5 | 74.5 | 77.5 | 89 | 84.5 |
| 6 | 36 | 85 | 63 | 66.5 | 86 | 89.5 | 86 |
| 7 | 42 | 86.5 | 85 | 69.5 | 84 | 83.5 | 85 |
| Average | | 81.07 | 66.07 | 73.93 | 81.29 | 86.57 | 84.21 |

### *3.2. Microstructure testing using SEM*

There are elements that makeup LDPE plastic, such as calcium (Ca), silicon (Si), and oxygen. This is due to the migration process of atoms in the material in gas, liquid, and solid conditions at hot temperatures, which is called diffusion [12]. Through the diffusion of LDPE liquid plastic, it is possible to produce a new bonding phase in other elements. Morphological analysis using SEM in the extrusion process with a temperature of 170 °C for 29.06 minutes is shown in Fig. 7.



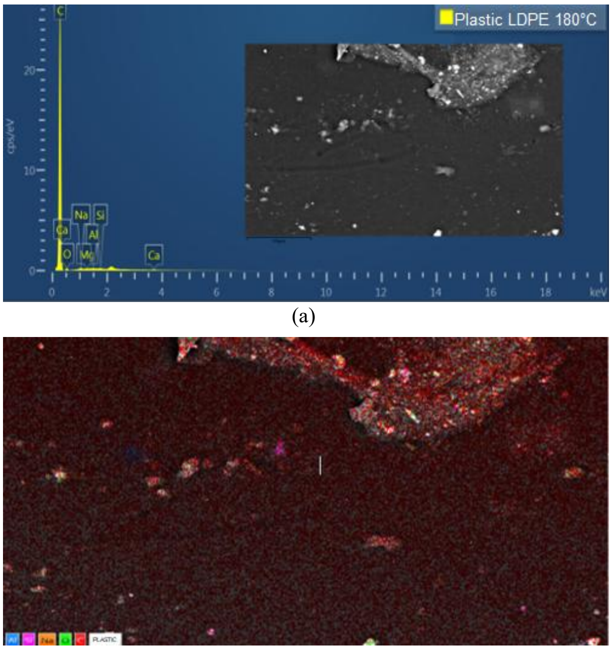

(a)

(b)

Figure 7. EDX analysis results at a temperature of 170 °C (a) Composition LDPE 170 °C, (b) EDS layered 170 °C

Fig. 8 shows the presence of other elements such as sodium (Na), aluminum (Al), and magnesium (Mg) in the EDX SEM test at 500X magnification and the presence of sodium and aluminum only.

Figs. 8 and 9 show the high amounts found in the element carbon, which is the main building block of plastics. The presence of other elements at temperatures of 180 °C and 190 °C is due to the possibility of mixing other materials from waste containing elements of magnesium, aluminum, and sodium during the LDPE plastic waste counting process until the end of mixing in the extruder machine.




(a)

(b)

Figure 8. EDX analysis results at a temperature of 180 °C; (a) Composition LDPE 180 °C; (b). EDS layered 180 C

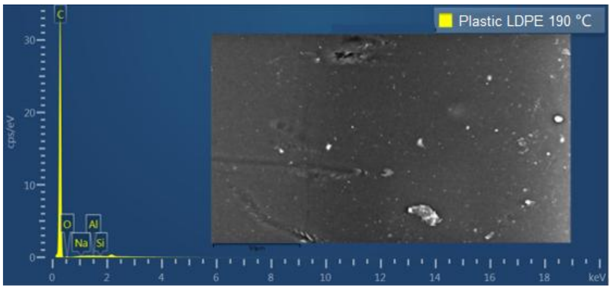



Figure 9. EDX analysis results at a temperature of 190 °C

The observation of the microstructure using SEM for LDPE with a magnification of 500 times, as shown in Fig. 10, it appears that the plastic particles bind to each other. But here, it looks like space or air cavities (pores).

In Fig. 11, the results of the EDX analysis at a temperature of 210 °C allow it to produce a new bonding phase in other elements, new nuclear nucleation, and the presence of empty spaces (pores).

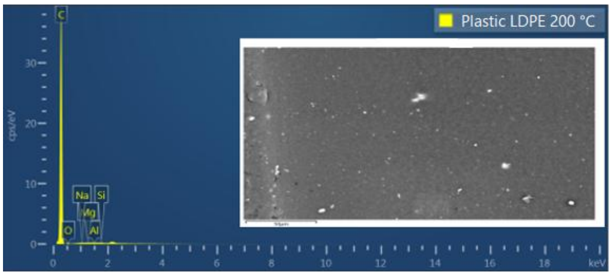



Figure 10. EDX analysis results at a temperature of 200 °C

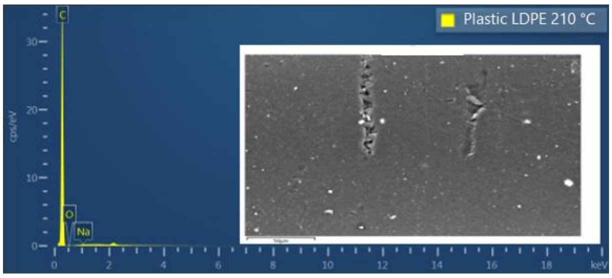



Figure 11. EDX analysis results at a temperature of 210 °C

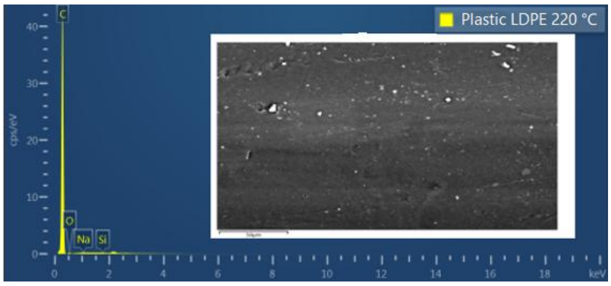



Figure 12. EDX analysis results at a temperature of 220 °C

The presence of empty spaces (pores) shown in Fig. 12 occurred during the extrusion process. In addition, the occurrence of unwanted oxidation cannot be avoided. In addition, it shows that high amounts are found in the element carbon as the main constituent material, along with other materials such as oxygen (O), sodium (Na), and silicon (Si). Based on the results of macrostructural photo testing on the extrusion results of LDPE plastic waste, obtained data on the area (plastic deformation) using image J software, on specimens at 170 °C, 180 °C, 190 °C, 200 °C, 210 °C, and 220 °C. In general, it has additional grooves that are different from other specimens. The pictures of the microstructure of LDPE plastic waste can be seen in Fig. 13.

The filament strengthening of the elements is homogeneously distributed over the entire surface, but there are also clearly visible morphological differences between different temperatures. The possible formation of these different phases is influenced by the rate of diffusion, which is explained by Fick's law. It explains that as the temperature increases, the rate of diffusion also increases.

As a result, the diffusion that occurs between the carbon matrix and other elements, such as liquid, occurs completely. After extrusion molding on samples, LDPE plastic shows good bonding to other elements, which melt well and permeate each other [13].

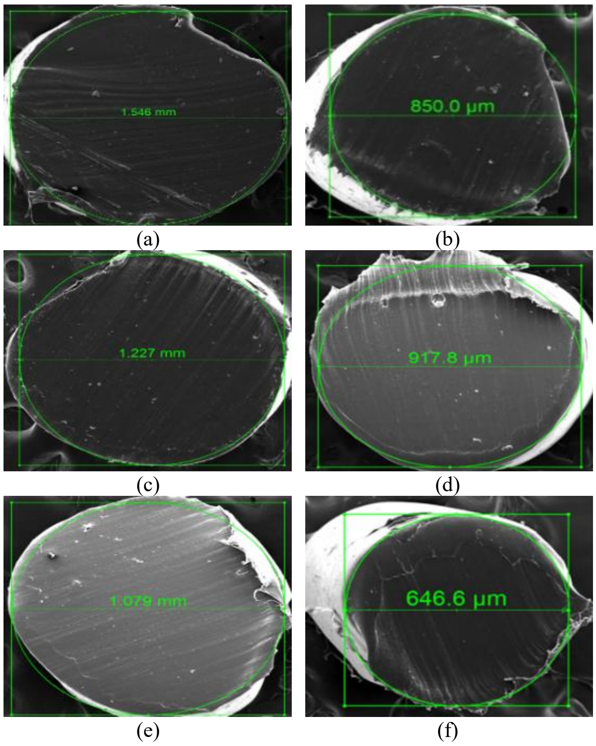



Figure 13. Microstructure using SEM in temperature of (a) 170 °C; plastic (b) 180 °C; (c) 190 °C; (d) 200 °C; (e) 210 °C; (f) 220 °C

In addition, as can be seen in Fig. 13, the diameter size of LDPE plastic is different for each temperature variation. The different diameters formed were caused by the heat generated by the extrusion process of the LDPE plastic sample. In addition, other parameters are the addition of the load (compressive force) and the speed and heating that occur in the engine and nozzle. These parameters resulted in softening, which undergoes deformation and forms a diameter. These different diameter shapes indicate that a disturbance occurs during the extrusion process. This is most likely due to the partial cooling of the melted LDPE plastic waste as it travels from the extruder head to the nozzle itself [13].

Figure 14 shows the surface of LDPE semi-micro plastic with a different surface for each variation of the test.

At temperature variations of 170 °C, 180 °C, and 190 °C, the surface looks not so flat, while at temperatures of 200 °C, 210 °C, and 220 °C, it looks like a neat surface. The presence of different-sized granules in each variation of the test (differences in surface morphology) because the complex viscosity describes the presence of flow resistance in a material [14]. The viscosity at higher temperatures also contributes to a constant increase in the melt flow of the material. Therefore, it can be concluded that the physical state of the polymer depends on the temperature. The polymer determines its response to heat, which is very important for the extrusion molding parameters [15].

It also shows morphologically that a small amount of crystal nucleation occurs before the polymer melt enters the print head nozzle section. However, this is most likely due to the partial cooling of the LDPE plastic melt as it travels from the extruder head to the nozzle and cannot be attributed to the nucleation effect itself.

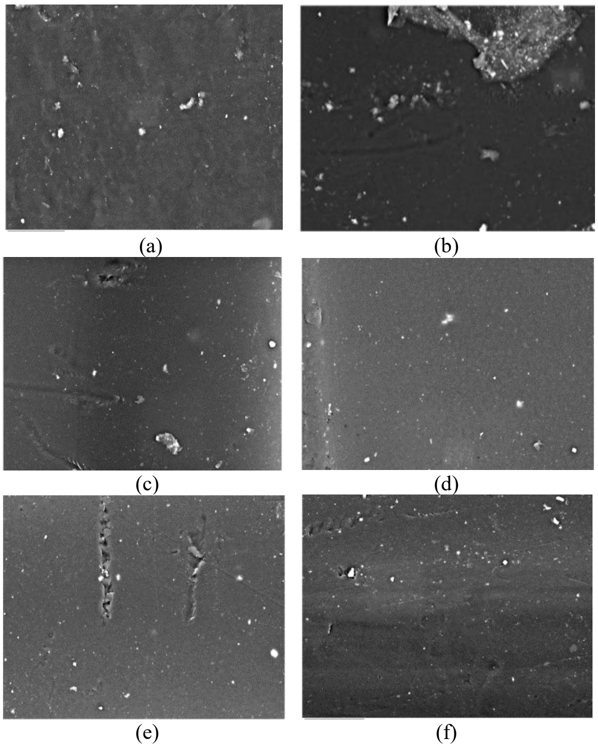



Figure 14. SEM-micro plastic LDPE (a) 170 °C; plastic (b) 180 °C; (c) 190 °C; (d) 200 °C; (e) 210 °C; (f) 220 °C

Extrusion nozzle temperature, coolant speed, and nozzle path and speed are important processing variables that affect the performance of the final molded part.

## 4. Conclusion

The specimen temperature of 210 °C had the highest hardness value, which was in the range of 83 – 89.5 HA, while the specimen temperature of 180 °C has the lowest hardness value ranging from 59.5 to 71.5 HA. The higher the temperature, the higher the hardness value in the manufacturing process (extrusion). Higher extrusion nozzle temperatures lead to better melt fluidity and formability of the impression material. Higher temperatures produce more energy which increases infiltration and diffusion between deposited filaments. The high temperature in the LDPE Plastic Waste Extrusion process; greatly affects the hardness value, but if the higher temperature also allows a decrease in the hardness value, this is due to the many process parameters that affect the printing machine, (waste extrusion process) namely nozzle temperature, speed cooling of the rolling, as well as the path and speed of the nozzles. Extrusions are important processing variables that affect the performance of the final molded part.

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