# Effectiveness Teston Hardness Performance of Plastic Waste and Sawdust Composite

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# Effectiveness Teston Hardness Performance of Plastic Waste and Sawdust Composite

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***Abstract: The strength of a material is one option used to determine the use of forms. The use of plastics on product packaging is an efficient choice because plastics is light, practical and easy to forms. This study is done to measure the plastic waste hardness of mixed HDPE and PET type with teak tree sawdust which melted into two portions by the amount of 18 gram. This study finds the highest hardness index was achieved by the mixture of 1.5 gram of sawdust, 5 gram PET and 11.5 gram HDPE with the hardnesss point of 131. 3 N/mm under the 5000 gram pressure and temperatureof 100°C while the lowest point of 86.6 N/mm by the mixture of 1 gram sawdust, 625 gram PET and 10.7 gram HDPE under the 5000 gram pressure and temperature of 100°C. It can be seen that the lower the temperature of the mixture compositions, the better the hardness because the mixture is merged and binded better.***

***Index Terms*:*Temperature, Pressure, Hardness Test, Composition***

## I. INTRODUCTION

Wood Plastic Composite (WPC) is a promising and sustainable and is able to biodegraded in order to achieve the durability without using the poisonous chemical substances. The use of plant fibre and its product was done because their characteristics such as low density, relatively strong modulus and stiffness, non-abrasive characteristic, the suitable filling material, biodegradability and environmentally friendly. Plant fibre is a renewable raw material that can be used every year and it has abundant availability so that the wood and plastic waste can be used again instead of being heaped or burned that release CO2 into environment [1]-[4].Indonesia government's movement to use the plastic bag for shopping in the last 3 years have indicated that the amount of plastic garbage has reached 187.2 million ton per year or 520000 per day.Mixing the wood polymer in a suitable condition can be an alternative to perform the plastic recycling within a reasonable price and has potential to be applied in new products and in the households [5].

This research is expected to find the new thing and use it as a model to develop biocomposite mainly polymer of plastic Polyethylene Terephalate and sawdust by conducting an experiment to find out the hardness index of the material produced. The experiment was done by making the sample based on standard ASTM D 790 for tensile strength, pressure and hardness. These informations are hoped to give the new insight on the function and the use of new material that can be adjusted with other necessities.Wood element that is used in polymer composite has several forms and they can be used alone or combined with other materials.

## II. BASIC THEORY

Wood plastic can be used to replace the wood for construction, mainly for the outdoor applications where plastic is considered to be getting along well with the weather and it is better than wood. However, the structural characteristics from wood plastic is quite difficult to understand and the use of wood plastic on structural application is not recommended for its strength and stiffness become lower under weather and hot temperature and the wood plastic characteristics on high termperature will determine the desired strength and stiffness. Wood plastic modulus are 5.79, 1.03, and 1. 12 GPa by using hot temperature during compression process and the strength points in hot temperature are 16.8, 12.0, and 1.45 Mpa. The result shows that the wood plastic has higher shear strength than wood and may easily cracked and broken [6].

The mixture of acrylic and sawdust co-polymerization makes it possible to achieve the efficient adsorbent; for easier moving process of metal element from water, with low price because these materials are taken form the farms or subsidiary industries. These used materials have the promising prospect to be reprocessed again from waste industry. The non-volatile material can be processed into sawdust and can be burned and can be made into new material after processing it in waste recycling [7]. The composite strength resulted can be worse than the original produced by low density polyethylene with higher hardness and stiffness level compared with the reference. The effect of wood flour with weight of 54 % on composition of polymer (PBs) is stronger and more stiff compared to the sample produced by LDPE [8]. The use of thermoplastic recycling and wastes has been considered to produce waste plastic composite (WPC). They have big potential to produce WPC according to previous researches. Recycled plastic is considered as new material in WPC production and it is important to first understand the elements and the structures of these materials [9].

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**Fig. 1 HDPE Plastic waste**


**Fig. 2 PET Plastic waste**

**Fig. 3 Sawdust**

Two kinds of recycled plastics were also selected: recycled HDPE (noted as RPE) with a melt flow index of 18.4 g/10 min (170°C) and recycled polypropylene (RPP) with a melt flow index of 65 g/10 min (190°C).WPC making can be well-controlled and the relation between the characteristics of recycled plastic and its mechanism aspect can be happened and will be easily understood according to the WPC produced.

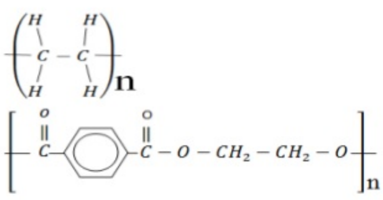

**Fig 4. Formula 1 Chemical Elements of PET Plastics and HDPE**

## III. METHODOLOGY

### A. Materials

Recycled plastic types that are often found and commonly used as this study are: recycled HDPE (recorded as RHD) with a melt flow index of 20.3 g / 5 minutes (170 ° C) and polyethylene terephthalate recycling (RPET) with flow indices melting 25 g / 5 minutes (170 ° C).Recycled high density polyethylene was obtained from milk bottles with a melt flow index of 18.54 g/10 min (170°C). The filler was the sawdust of softwood produced from a band saw mill. Sawdust was dried in an oven for 24 h at 100 °C[10].

### B. Preparing the sawdusts

Sawdust which is used as the filling materials is obtained by filtering the housing furniture industry and then make it into 50-mesh size particle. This material is later dried by using the natural sunlight for 20 hours (2 days) on 28-34 ° Ctemperature of sunny days.Before preparation of samples, wood flour was driedin an oven at (65±2)°C for 24 hours [11]. The sawdust was dried in at 70 ºC for at least two days, being periodically turned over and weighed untilconstant weight was attained [12].The drying process will gain the final water amount of 5.8 % which is the desired lowest level – less 10 % from its original level.

### C. Mixing Process

Recycled plastic is melted under temperature between 160°C -200° C, then the heat is turned off and the sawdust is filled into the recycled plastic by 15 rpm by lowering the temperature from 170° C to 130° C for every mixing formula with the planned temperature variation when pressing the surface of the processed material. This process takes approximately 5-7 minutes.
Thermoplastics have a melting point of 90-120 °C and the mixture has a very good process capabilitiesprocessed on polyolefin processing machines at a temperature of 160-200 °C [13].

The experiment is done under the nitrogen blanket with rotor speech up to 60 rpm and under the temperature of 270 until 290°C. PET is processed first for 4 to 6 hoursunder the vacuum on 120°C until the humidity level reach > 0,01% . The mixture of polymer and sawdust is added into the mixing room and composite samples is prepared under 180 ° C for 10 minuteswith the speed of 60 rpm. The molding sheets with 0.99 thickness is produced under 190 ° C and 4 MPafor 5 minutes in Carver C press.

### D. Specimen Preparation

The liquid composite that has been mixed into the mold is being fitted with the mold and spread evenly, and later pressed by hydraulic press until it reaches the desired pressure for HDPE, PP and sawdust formula. The specimen for mechanical experiment is made into 30 specimens following the design of experiment.

### E. Testing the Material Hardness

Mechanical characteristic of recycled plastic and sawdust is measured by its hardness. The hardness of recycled plastic and sawdust is determined based on the specification and composition on the design of experiment.

This testing process is carried out by using the Universal Testing Machine Autograph with Brinell testing parameter. All experiment is carried out under room temperature (25°C) with relatively constant humidity by using 3 testing point from 30 speciments (main responses). These speciments is conditioned in constant temperature and relative humidity before the testing.

This study used 3 types of mixed materials with variation of pressure and temperature : high density polyethylene (HDPE), polyethylene terephthalate (PET) and sawdust. To further elevate the use of plastic waste, this research which oriented on the use and the knowledge on how strong the hardness of a product is being tested and made. Mechanical properties decrease with the increase in the percentage of wood flour [14].

The results of the test depends upon the preparation during research and there some things to be considered such as the preparation for testing tools, wire connection to the computer and testing samples and the speciments result.Samples for Hardness Testing are shown in Fig. 5.

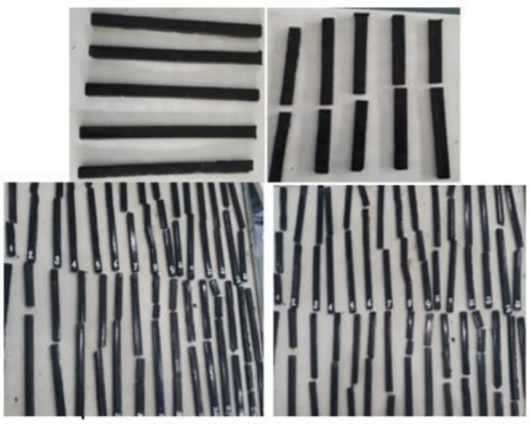

**Fig. 5 Sample for Hardness Testing**

## F. Response Surface Methodology

As one of the reliable statistical methodology, response surface methodology is used to understand the effect of process variables, the interaction among them and their contribution to the performance measures.

In this present study, the **historical data** of response surface methodology type design is employed because its effectiveness for optimizing the operating parameter for a process without limitation in the number of design factors besides utilizing the data that already exists.

The results from the experiment are fitted to a response surface methodology function form as shown in equation.

$$\hat{y} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_{11} {X_1}^2 + \beta_{22} {X_2}^2 + \beta_{111} {X_1}^3 + \beta_{222} {X_2}^3 + \beta_{12} X_1 X_2 + \beta_{112} {X_1}^2 X_2 + \beta_{122} X_1 {X_2}^2 \quad (1)$$

where $\hat{y}$ is the response or dependent variable. The β symbols represent coefficients to be fitted via regression. $\beta_0$ is the model constant; $X_1$ and $X_2$ are independent variables; $\beta_1$ and $\beta_2$ are linear coefficients; $\beta_{12}, \beta_{112}$ and $\beta_{122}$ are cross-product coefficients; $\beta_{11}$ and $\beta_{22}$ are quadratic coefficients; and $\beta_{111}$ and $\beta_{222}$ are cubic coefficients.

The DOE design is generated and analyzed using Design-Expert 7 software.

**Table 1** Factors and experiment design levels

| Process | Factors | Unit | Levels | |
|---|---|---|---|---|
| | | | -1 | 1 |
| Processing Parameters | A:Temperature | °Celcius | 100 | 120 |
| | B:Pressure | gram | 1000 | 5000 |
| Composite Mixture Fraction | C:Sawdust | gram | 0.5 | 1.5 |
| | D:PET | gram | 4.5 | 7.5 |
| | E:HDPE | gram | 8.5 | 12.5 |

## IV. RESULT AND DISCUSSION

The results obtained from the analysis of variance (ANOVA) based on experimental data are presented in Tables 3 and Table 4. By employing ANOVA, the relationship of developed model is derived from reduced quadratic model of Ra as summarized in Table 3. According to the statistical analysis, the developed model accords with the experimental data, model adequate, no significant lack of fits, and has satisfactory coefficient of determination ($R^2$) values of Ra and MRR. Likewise, some of the terms is set aside in the model despite it is insignificance to preserve model hierarchy, to ensure the reasonable agreement between the "Pred R-Squared" and "Adj R-Squared", and also to attain insignificant lack of fit. The results of $R^2$ are obtained 0.9737 and Adeq precision (AP)= 12.237. AP greater than 4 is desirable, as it measures the signal-to-noise ratio.

Table 3 show the result of the ANOVA. In this trial for Hardness Index response, the terms A,B,C,D,E,AB, AC,AD,AE, BC,BD,BE,CD,CE,DE are statistical significant with confident level, p-values less than 0.05. The other model terms are not significant.

## A. Effect of Parameter Study

The perturbation plots for the coded values of the process factors and their influence on the hardness test is showed in Figure 6. The graph is a helpful tool in statistical analysis that simplifies the observation on the influence of the factors on the response through analysis.

**Table 2 Results of Hardness Test**

| Run | Temperature (°C) | Pressure (gram) | Sawdust (gram) | PET (gram) | HDPE (gram) | Hardness Test ($N/mm^2$) |
|---|---|---|---|---|---|---|
| 1 | 120 | 1000 | 0.5 | 5 | 12.5 | 121.5 |
| 2 | 100 | 5000 | 1.5 | 5 | 11.5 | **131.3** |
| 3 | 110 | 3000 | 1 | 7.5 | 9.5 | 92.8 |
| 4 | 120 | 5000 | 0.5 | 7.5 | 10 | 125.9 |
| 5 | 110 | 3000 | 1 | 6.25 | 10.75 | 109.2 |
| 6 | 120 | 5000 | 1.5 | 5 | 11.5 | 120.1 |
| 7 | 110 | 1000 | 1 | 6.25 | 10.75 | 112.5 |
| 8 | 100 | 3000 | 1 | 6.25 | 10.75 | 122.6 |
| 9 | 110 | 3000 | 1 | 6.25 | 10.75 | 104.8 |
| 10 | 100 | 1000 | 0.5 | 5 | 12.5 | 90.8 |
| 11 | 120 | 5000 | 0.5 | 5 | 12.5 | 94.7 |
| 12 | 120 | 5000 | 1.5 | 7.5 | 9 | 104.0 |
| 13 | 100 | 5000 | 1.5 | 7.5 | 9 | 107.4 |
| 14 | 110 | 3000 | 1 | 6.25 | 10.75 | 105.6 |
| 15 | 100 | 1000 | 0.5 | 7.5 | 10 | 98.1 |
| 16 | 100 | 5000 | 0.5 | 7.5 | 10 | 125.5 |
| 17 | 100 | 1000 | 1.5 | 5 | 11.5 | 110.6 |
| 18 | 120 | 3000 | 1 | 6.25 | 10.75 | 110.1 |
| 19 | 110 | 3000 | 0.5 | 6.25 | 11.25 | 105.0 |
| 20 | 110 | 3000 | 1 | 6.25 | 10.75 | 112.0 |
| 21 | 120 | 1000 | 1.5 | 5 | 11.5 | 108.9 |
| 22 | 100 | 1000 | 1.5 | 7.5 | 9 | 121.9 |
| 23 | 110 | 3000 | 1 | 5 | 12 | 112.2 |
| 24 | 110 | 3000 | 1 | 6.25 | 10.75 | 104.9 |
| 25 | 110 | 3000 | 1 | 6.25 | 10.75 | 124.3 |
| 26 | 120 | 1000 | 0.5 | 7.5 | 10 | 115.4 |
| 27 | 110 | 5000 | 1 | 6.25 | 10.75 | **86.8** |
| 28 | 110 | 3000 | 1.5 | 6.25 | 10.25 | 126.6 |
| 29 | 100 | 5000 | 0.5 | 5 | 12.5 | 120.6 |
| 30 | 120 | 1000 | 1.5 | 7.5 | 9 | 120.1 |
| 31 | 100 | 1000 | 1.5 | 5.5 | 10 | 119 |
| 32 | 120 | 1000 | 0.5 | 4.5 | 12 | 116.1 |
| 33 | 120 | 5000 | 1.5 | 7 | 8.5 | 103.7 |
| 34 | 120 | 1000 | 0.8 | 5.2 | 11 | 103.1 |
| 35 | 100 | 5000 | 0.5 | 6 | 10.5 | 102.8 |

A steep slope for factor C and Factor E is very sensitive followed by factor B and factor A while factor D undergoes significant changes at the beginning of the test –decrease and eventually rise again.

In addition, the trend for C and E has similar configuration. By increasing each parameter value, the Ra value is increased. In addition, the trend for B and A also has similar picture. By increasing the value of each parameter, Ra decreases. It can be concluded that factor C and factor E are directly proportional to Ra which is different from factor B and factor A because they are inversely proportional to Ra while factor D undergoes changes.

Ra has a statistical significance effect and decreases with a decrease in C and E from 1.5 Gram to 0.5 gram, 12.5 to 9 grams and increases the hardness value from 86.8 N / mm to 131.3 N / mm.

By comparing the experimental results to the literatures [15] hardness of PP/wood composites containing different sawdust amounts, it can be seen that the presence of wood sawdust fibre greatly reduced the toughness of the PP/wood composites with an increase in the composite hardness, although the effect became less pronounced as the wood content was.

According to the literature, these results are consistent with the research that states the decrease in hardness is due to the presence of sawdust mixture which results in degradation of the material.

**Table 3 ANOVA for response of tensile strength-reduced cubic model**

| Source | Sum of Squares | df | Mean Square | F Value | p-value Prob> F | |
|---|---|---|---|---|---|---|
| Model | 3867.20 | 27 | 143.23 | 8.24 | 0.0072 | Significant |
| A-Temperature | 348.62 | 1 | 348.62 | 20.06 | 0.0042 | |
| B-Pressure | 0.032 | 1 | 0.032 | 1.836E-003 | 0.9672 | |
| C-Sawdust | 439.85 | 1 | 439.85 | 25.31 | 0.0024 | |
| D-PET | 88.45 | 1 | 88.45 | 5.09 | 0.0649 | |
| E-HDPE | 328.07 | 1 | 328.07 | 18.88 | 0.0048 | |
| AB | 532.22 | 1 | 532.22 | 30.63 | 0.0015 | |
| AC | 233.76 | 1 | 233.76 | 13.45 | 0.0105 | |
| AD | 299.26 | 1 | 299.26 | 17.22 | 0.0060 | |
| AE | 278.34 | 1 | 278.34 | 16.02 | 0.0071 | |
| BC | 0.39 | 1 | 0.39 | 0.023 | 0.8852 | |
| BD | 52.20 | 1 | 52.20 | 3.00 | 0.1338 | |
| BE | 47.40 | 1 | 47.40 | 2.73 | 0.1497 | |
| CD | 352.18 | 1 | 352.18 | 20.27 | 0.0041 | |
| CE | 263.47 | 1 | 263.47 | 15.16 | 0.0080 | |
| DE | 188.25 | 1 | 188.25 | 10.83 | 0.0166 | |
| A^2 | 228.06 | 1 | 228.06 | 13.12 | 0.0111 | |
| B^2 | 137.49 | 1 | 137.49 | 7.91 | 0.0306 | |
| C^2 | 116.83 | 1 | 116.83 | 6.72 | 0.0411 | |
| D^2 | 179.53 | 1 | 179.53 | 10.33 | 0.0183 | |
| ABC | 242.32 | 1 | 242.32 | 13.94 | 0.0097 | |
| ABD | 141.21 | 1 | 141.21 | 8.13 | 0.0292 | |
| ACD | 76.68 | 1 | 76.68 | 4.41 | 0.0804 | |
| ACE | 75.01 | 1 | 75.01 | 4.32 | 0.0830 | |
| BCD | 559.98 | 1 | 559.98 | 32.22 | 0.0013 | |
| BCE | 425.28 | 1 | 425.28 | 24.47 | 0.0026 | |
| CDE | 212.84 | 1 | 212.84 | 12.25 | 0.0128 | |
| A^2C | 320.45 | 1 | 320.45 | 18.44 | 0.0051 | |
| Residual | 104.27 | 6 | 17.38 | | | |
| Lack of Fit | 63.81 | 2 | 31.91 | 3.15 | 0.1505 | not significant |
| Pure Error | 40.45 | 4 | 10.11 | | | |
| Cor Total | 3971.47 | 33 | 143.23 | 8.24 | 0.0072 | |

**Table 4R-squared analysis for response surface quadratic model of hardness index**

| | | | |
|---|---|---|---|
| Std. Dev. | 4.17 | R-Squared | 0.9737 |
| Mean | 110.78 | Adj R-Squared | 0.8556 |
| C.V. % | 3.76 | Adeq Precision | 12.237 |

Hardness Test =

+29274.53831-271.03113*Temperature-159.95770*Pressure-15817.91561*Sawdust-2775.84147*PET-1199.98649*HDPE-1.39625*Temperature*Pressure+204.67538*Temperature*Sawdust+5.18805*Temperature*PET+5.38955*Temperature*HDPE+498.20462*Pressure*Sawdust+9.18962*Pressure*PET+18.07129*Pressure*HDPE+724.81822*Sawdust*PET+471.21011*Sawdust*HDPE+116.21145*PET*HDPE+0.81691*Temperature^2-1.82300*Pressure^2-90.94130* Sawdust^2+78.32323*PET^2+0.38917*Temperature * Pressure * Sawdust+0.11883*Temperature * Pressure * PET-2.65033 * Temperature*Sawdust*PET-2.59833* Temperature * Sawdust*HDPE-35.81000*Pressure*Sawdust*PET-30.93333*Pressure*Sawdust*HDPE-35.01333*Sawdust*PET*HDPE-0.72300*Temperature^2*Sawdust

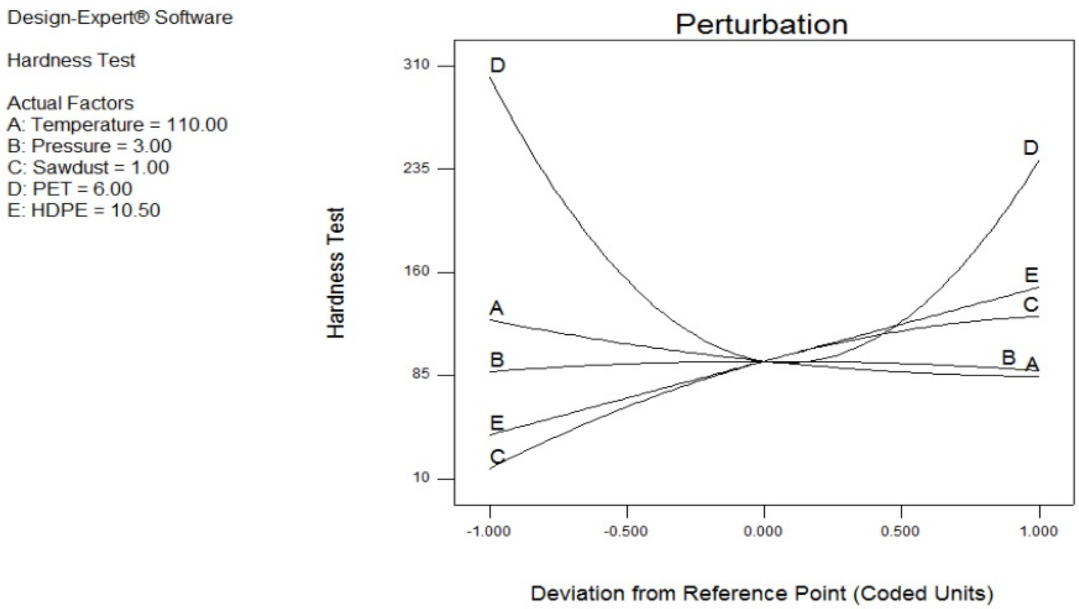


**Fig. 6 Perturbation Plot for Hardness Test**

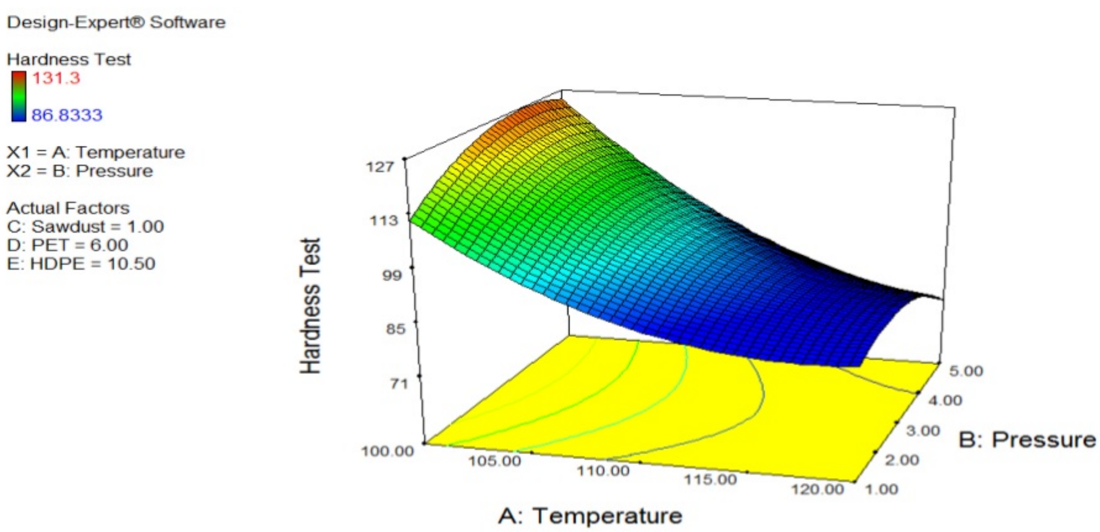


**Fig. 7 Effect of processing parameters Hardness Test**

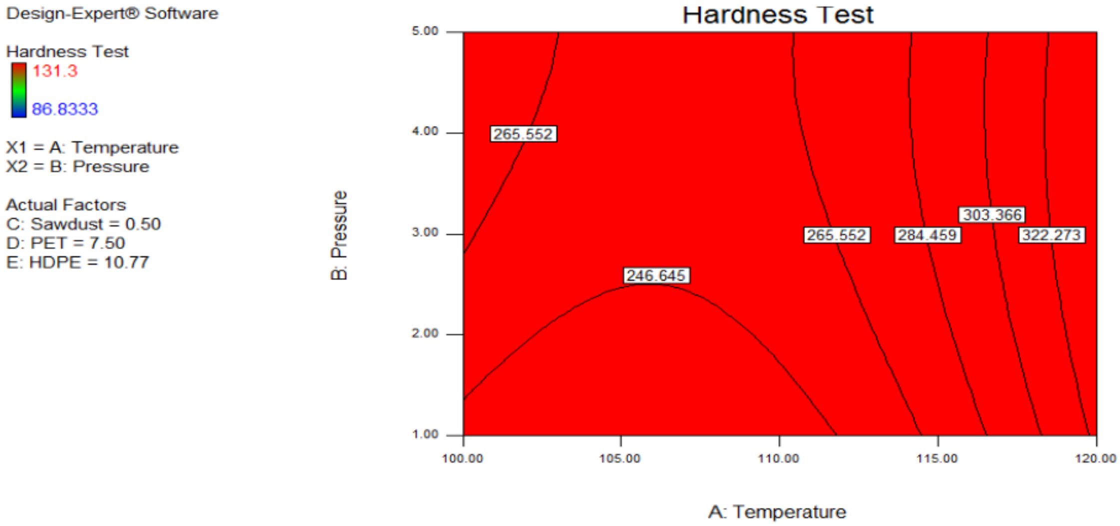


**Fig. 8 Optimization and predict hardness Of DOE**

**Table 5 Optimal solutions generated for single and multi response**

| Type of optimization | Objective | Optimum Parameters | | | | | | Pred. Response | Exp. Response | % of error | Desirability |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | A- Temp | B- Pressure | C- Sawdust | D- PET | E- HDPE | F- SD | | | | |
| | | °Celcius | gram | gram | gram | gram | Downward/ Upward | | | | |
| Single Response | Minimize the Ra | 100 | 1000 | 0.5 | 4.5 | 8.5 | Downward | 790.61 N/mm² | 1261.02 N/mm² | 1.86 | 1 |
| Single Response | Maximize the MRa | 120 | 5000 | 1.5 | 7.5 | 12.5 | Upward | 192.77 N/mm² | 318.83 N/mm² | 1.17 | 1 |
| Multi-Response | Simultaneous minimize Ra and maximize the MRR | 110 | 5000 | 1 | 7 | 12 | Upward | 192.53 N/mm² | 192.53 N/mm² | 5 | 0.9997 |

### B. Response Surface Model/ Interactive Effects

Besides the individual terms that has been found significant, ANOVA results also initiated the significant among the factors as illustrated in Figure 7 with the confident level is less than 0.05.

The effect of Factor C on the hardness index is strongly influenced compared to Factor E and the D Factor. Also, both in Factor A and factor B which are lower and higher, Factor D has a trend pattern which fluctuates on the index of hardness.

### C. Optimization

In this research work, the desirability function approach has been selected for optimization technique, which allows the multi-objective optimization. The desirability provide the estimation according to the responses calculated by the statistical model. Higher desirability valuerepresents the better optimization of the response subject.

The objectives in optimization in this study can be grouped into two types of optimization, namely single and multiple optimization. Single objective optimization of the recipe for mixing HDPE, PET and Sawdust materials are offered by Factor E 11.5 grams, Factor D 5 grams and Factor C 1.5 grams which produces a hardness index of 131.3 N / mm$^2$. Table 5 presents the optimal solution and confirmation experiment to achieve the maximum hardness index. For multi-optimization, Factor C 1 gram, Factor D 7 grams and Factor E 11 gram suggested shows the achievement of hardness index of 195.48 N / mm$^2$ with criteria reaching mid.

The relative error between the results predicted by the response function and the actual experiment is found to be 5.9% which could conclude that the proposed model for the hardness index is quite accurate.

## V. CONCLUSION

In this research work, the application of response surface method for modelling the waste plastic composite for hardness test is successfully developed. The following conclusions are drawn from the present investigation.

Significant factors that determine this composition lie in the mixture of ingredients from HDPE, PET and sawdust and the dominant in the specific response lies in sawdust. With an increase in the amount of sawdust, the composition the hardness obtained decreases. The achievement of optimization using DOE is to obtain a balanced composition from the total mixture of different specimens. Validating this data can be used as a reference for the development and use of this material for product hardness.

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# Effectiveness Teston Hardness Performance of Plastic Waste and Sawdust Composite

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