Research of Injection Molding Parameters with Acrylonitrile Butadiene Styrene Composition Recycled Against Mechanical Properties

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Abstract. Injection molding is the most common method for mass manufacturing plastics product. The process is influenced by injection parameters, i.e.: melting temperature, injection pressure and holding pressure. The recycled material of ABS combined with pure material on 10%:90%, 20%:80% and 30%:70%. Both can affect the mechanical properties as evidenced by tensile and impact test. The ability to resist the load of tensile is obtained from the yield point, whereas the ability to resist the load of the impact is obtained from the potential energy that be able to be received. Based on the best parameters, the optimal value is generated from 10% ABS recycled, i.e. 45.87 [J] for impact strength and 34.08 [N/mm²] for tensile strength, then the optimal value is generated from 20% ABS recycled, i.e. 45.40 [J] for impact strength and 34.40 [N/mm²] for tensile strength, and then the optimal value is generated from 30% ABS recycled, i.e. 45.17 [J] for impact strength and 34.80 [N/mm²] for tensile strength.

1. Introduction
The rapid development of technology is comparable with the increasing use of products made of plastic because it easily and quickly created through mass production as well as good quality and recyclable. The total production of plastics is currently more than 230 million tonnes/year, which will increase to 400 million tonnes in 2020, based on a very conservative growth rate about 5% per year [1, 2]. Most plastics are produced in large quantities every year from industrial, agricultural and household activities. One of the greatest challenges in the effective use of plastics is the efficient treatment of their waste at the end of their life.

A significant increase in the use of plastic. However, in the production process there is material that is not used. This can be used to mix raw material injection molding. On the other hand, the process of plastic injection molding needs to consider the parameters used to obtain product quality and optimal mechanical properties, i.e. melting temperature, injection process, charging process and holding process [3]. Temperature effect on viscosity and flow rate of a material, pressure and speed injection will affected on the process of melting materials charging into the mold. Holding pressure is the ending of the emphases of the material that is already filling of the mold cavity while already a form of the product, it will influence on the density of the product.

Mechanical properties in general are a consideration of a material, including: tensile strength to determine the ability of a material against tensile strength and the length increase of material when experiencing withdrawal. While impact strength is used to measure the potential energy absorption capability of a material when receiving shock loads [4].

C. Wick argues that injecting material into the mold there are parameters that affect the product results including the material properties [5]. Bociaga conducts research on mechanical and thermal
properties for HDPE molds at mold temperatures and injection speeds. He realized that tensile strength, yield stress, tensile modulus and higher hardness were obtained when the mold temperature was increased [6].

Ali Mohd conducted a study of mixing ABS recycled material (r-ABS) and obtained the parameters selected in the optimization experiment, the melting temperature and injection pressure found to be the most determining factor simultaneously affecting the mechanical properties of r-ABS [7].

Sadabadi and Ghasemi examined the effects of injection molding process parameters including flow rate injection, temperature, packing pressure using composite fibers reinforced by polystyrene can affect the elasticity and tensile modulus that forms part [8]. Ozelik argues that the important parameters affect the module elasticity, tensile strength and tensile strain on the tensile test results are melting temperature and the effect is determined for steel molds as 84.90%, 86.78%, 50.05% and 42.99% respectively. Another parameter that is influenced by flexural modulus (73.26%) is injection pressure. The most important parameter that affects the tensile strain during the experiment is the resistance pressure of 52.48% [9]. Rahimi, et al. examines the mechanical properties of ABS polymers but is more focused on the right mixture of pure and recycled material, the results obtained after recycling for 5 times the structure of the polymer leads to a smaller molecular chain. This has an impact on the impact strength and shrinkage of a plastic product [10].

2. Methods

Response Surface Methodology (RSM) is a collection of mathematics and statistical techniques that is useful for modeling and analysis in applications where a response of interest is influenced by several variables and the objective is to optimize this response [11]. An experiment involving k factors includes: $X_1, X_2, ..., X_k$, where k factors are called control variables and produce Y, where Y is a response variable. All variables are measure and it is known that Y is the response of $X_1, X_2, ..., X_k$, so it is said that Y is a function of $X_1, X_2, ..., X_k$ and generally written in the form $Y = f(X_1, X_2, ..., X_k)$. The function is said to be a response surface [11]. The RSM implementation starts from determining the first-order equation model for data collection and research direction, then determining the level of factors, after that determining the second-order equation model by conducting experimental design and the predetermined level after the steepest descent method is done, finally determining the optimum point of the factors researched. [12].

The second-order model is a polynomial equation in the form of a square. The general form of the second-order model for three variables, i.e. [11]:

$$Y = b_0 + b_1 . x_1 + b_2 . x_2 + b_3 . x_3 + b_{11} . x_1^2 + b_{22} . x_2^2 + b_{33} . x_3^2 + b_{12} . x_1 . x_2 + b_{13} . x_1 . x_3 + b_{23} . x_2 . x_3$$

(1)

Description:

$Y$ : Response

$x_i$ : Predictor

$b_i$ : The Predictor coefficients

To build a second-order model, first done with the experimental design data collection so as to determine the coefficient of regression on the second-order model, every variable $X_i$ must have at least three different levels. This indicates that $3^k$ factorial design may be used, where a three-level coded as -1, 0 and 1 [13].

3. Results

Determination of injection process parameters or called predictor is defined as follows: $X_1$ is the melting temperature, $X_2$ is the injection pressure and $X_3$ is holding pressure, while the variable response ($Y_1$) is the result of the effect of the test and ($Y_2$). Table 1 shows the notation and the level of the independent variables used for testing.

| Table 1. Notation and second-order model. |
|----------------------------------------|
| Level | Melting Temp. (A) | Injection Press. (B) | Holding Pressure (C) | $X_1$ | $X_2$ | $X_3$ |
|-------|--------------------|----------------------|---------------------|-------|-------|-------|
|       |                    |                      |                     |       |       |       |
3.1. The design of research and results

In this research, ABS was combined with recycled materials ranging from 10%: 90%, 20%: 80% to 30%: 70%. Table 2 shows matrix design of experiment results to material combination.

| Run | Melting Temp. (°C) | Injection Pressure (bar) | Holding Pressure (%) | ABS 10% | ABS 20% | ABS 30% |
|-----|-------------------|--------------------------|---------------------|---------|---------|---------|
|     |                   |                          |                     | Y_1     | Y_2     | Y_1     |
| 1   | 210               | 50                       | 25                  | 19.10   | 42.88   | 29.90   |
| 2   | 210               | 50                       | 35                  | 22.65   | 38.54   | 31.10   |
| 3   | 210               | 50                       | 45                  | 34.16   | 31.32   | 38.82   |
| 4   | 210               | 60                       | 25                  | 36.91   | 29.10   | 41.09   |
| 5   | 210               | 60                       | 35                  | 45.87   | 34.08   | 40.58   |
| 6   | 210               | 60                       | 45                  | 42.64   | 34.00   | 41.99   |
| 7   | 210               | 70                       | 25                  | 43.24   | 33.20   | 44.79   |
| 8   | 210               | 70                       | 35                  | 45.70   | 32.66   | 41.09   |
| 9   | 210               | 70                       | 45                  | 45.61   | 33.47   | 40.49   |
| 10  | 225               | 50                       | 25                  | 42.85   | 33.85   | 31.10   |
| 11  | 225               | 50                       | 35                  | 40.75   | 33.68   | 34.37   |
| 12  | 225               | 50                       | 45                  | 39.93   | 33.43   | 33.95   |
| 13  | 225               | 60                       | 25                  | 40.53   | 33.65   | 32.77   |
| 14  | 225               | 60                       | 35                  | 41.39   | 33.53   | 32.40   |
| 15  | 225               | 60                       | 45                  | 43.24   | 33.69   | 32.60   |
| 16  | 225               | 70                       | 25                  | 43.07   | 32.49   | 32.90   |
| 17  | 225               | 70                       | 35                  | 42.55   | 32.42   | 33.32   |
| 18  | 225               | 70                       | 45                  | 42.64   | 32.29   | 34.66   |
| 19  | 240               | 50                       | 25                  | 40.88   | 33.57   | 40.06   |
| 20  | 240               | 50                       | 35                  | 36.14   | 33.65   | 41.61   |
| 21  | 240               | 50                       | 45                  | 37.42   | 33.64   | 42.04   |
| 22  | 240               | 60                       | 25                  | 29.32   | 34.42   | 45.40   |
| 23  | 240               | 60                       | 35                  | 29.77   | 32.92   | 43.71   |
| 24  | 240               | 60                       | 45                  | 36.48   | 33.53   | 44.79   |
| 25  | 240               | 70                       | 25                  | 36.74   | 31.64   | 45.09   |
| 26  | 240               | 70                       | 35                  | 36.53   | 33.28   | 45.91   |
| 27  | 240               | 70                       | 45                  | 32.35   | 33.80   | 44.23   |

The data then processed using software Minitab 18 to produce the equation used to find out the parameters that have the force of the impact and tensile strength and be able to predict optimal response surface that will come and determine the value of the variable to optimize response.

The graph of the results impact test on ABS material recycling 10%
These results show the higher the injection pressure and the lower the melting temperature will produce higher impact strength, this is better if the melting temperature approaches the low level or level -1 while the injection pressure is between the upper level, level 0.5 to level 1.

The contour plot on the impact test results between injection pressure and holding pressure shows the better response from the mid-level approaching to level 1.
Contour plots on the impact test results show the holding pressure tends to be evenly distributed but more likely to level 1. Unlike the case with the melting temperature which tends to provide good impact strength between levels 0.5 to 1. Overall, the impact test on the recycled ABS composition of 10% with the optimal value lies in the position of the melting temperature at the lower level, which is between level -1 and level 0, while the injection pressure is at the upper resistance level which is at the level 1.

The graph of the results tensile test on ABS material recycling 10%
Figure 5. Contour Plot of Second Order Tensile Test on 10% recycled ABS between Melt Temperature vs Holding Pressure.

Response of the higher tensile strength value at level -1, both from injection pressure and from holding pressure itself.

Figure 6. Contour Plot of Second Order Tensile Test on 10% recycled ABS between Melting Temperature vs Holding Pressure.

Contour plot images show that the response generated tends to be the same as the two previous factors, namely at the level below or level -1 even though the surface response shown is not significant the difference between the melting temperature and holding pressure. Overall, the optimal tensile test results of recycled ABS composition of 10% are shown in the same trend as the previous equation, namely at the low level approaching -1. This is slightly different from the impact test results which tend to be more varied.
The graph of the results impact test on recycling material ABS 20%

Figure 7. Contour Plot of Second Order Impact Test on 20% recycled ABS between Melt Temperature vs Injection Pressure.

Results of contour plot a comparison between the melting temperature and injection pressure showing the optimal melting temperature at the top and bottom levels while the injection pressure approaches level 1.

Figure 8. Contour Plot of Second Order Impact Test on 20% recycled ABS between Injection Pressure vs Holding Pressure.

Contour plot shows the higher injection pressure and the lower of holding pressure is the higher the impact strength, ie for injection pressure at the top level or level 1 while for holding pressure is at the lowest level or level -1.
Contour plots on the impact test results show that holding pressure tends not to have a less significant effect. Unlike the case with the melting temperature which tends to provide good impact strength at level 1. Overall for impact testing on recycled ABS composition of 20% with an optimal value that is at the melting temperature level at the top level that is at level 1, as well as injection pressure which is at the upper level but different from holding pressure which does not significantly affect the impact test results.

The graph of the results tensile test on recycling material ABS 20%

Results show that the melting temperature produces a higher tensile strength which is close to level 1, while the injection pressure is more evenly, which is between level 0 to level -1.
Figure 11. Contour Plot of Second Order Tensile Test on 20% recycled ABS between Injection Pressure vs. Holding Pressure.

These results indicate that the injection pressure factor with the holding pressure where the response shown by the contour plot is linear towards the lower level, the higher the value of the tensile test results on recycled ABS 20% is at level -1.

Figure 12. Contour Plot of Second Order Tensile Test on 20% recycled ABS between Melt Temperature vs Holding Pressure.

The result of the melting temperature factor where the response shows a tendency in the upper level or level 1, while for the holding pressure is more constant and not too effectful. Overall, the results of the tensile test of the optimal 20% recycled ABS composition are indicated by the tendency of the melting temperature at level 1, the injection pressure at level -1 but different for the holding pressure which has little effect on tensile strength.
The graph of the results impact test on recycling material ABS 30%

![Contour Plot](image1)

**Figure 13.** Contour Plot of Second Order Impact Test on 30% ABS recycling between Melt Temperature vs Injection Pressure.

The result of the response ratio between the melting temperature and injection pressure shows that the optimal melting temperature is between levels 0 to level 0.5, while the injection pressure has a higher tendency towards level -1.

![Contour Plot](image2)

**Figure 14.** Contour Plot of Second Order Impact Test on 30% recycled ABS between Injection Pressure vs Holding Pressure.

Contour plots from the results of the comparison between injection pressure and holding pressure show a tendency to focus on one point as well as holding pressure, i.e., for injection pressure at the lowest level or level -1 while for holding pressure is at the top or level 1.
The contour plot shows holding pressure tends to focus on high areas like the previous experiment. The same is true for the melting temperature that focuses in level 1, but is located at level 0. Overall for impact testing on the composition of recycled ABS 30% with an optimal value that is at the level of melting temperature at the middle level which is level 0, in contrast to the injection pressure which is at the lower level and different from holding pressure at the upper level namely at the level 1.

The graph of the results tensile test on recycling material ABS 30%

The results of the contour plot show that the melting temperature produces a higher tensile strength between levels of -0.5 to level 0, while the injection pressure is more evenly, which is between level -1 to level 1.
Figure 17. Contour Plot of Second Order Tensile Test on 30% recycled ABS between Injection Pressure vs Holding Pressure.

Contour plot shows the response, namely injection pressure tends to be evenly distributed at each level, while holding pressure is between the mid-level, the level of -0.5 to level 0.5.

Figure 18. Contour Plot of Second Order Tensile Test on 30% recycled ABS between Melt Temperature vs Holding Pressure.

Contour plot shows the yield of melting temperature shows a response that tends to be in the middle level or level 0, while for holding pressure is more constant and there is a tendency in the mid-level or level 0. Overall results of the tensile testing of the optimal 30% recycled ABS composition are indicated by the tendency of the melting temperature at level 0, the injection pressure at the mid-level and so with the holding pressure at the middle level, level 0.

3.2. Lack of fit models

Lack of fit models against second-order models is carried out as a follow-up of the analysis which serves to determine the optimum point factors and suitability of the data model that was built against the results of the experiment. The process of testing is done using software, as follows:

The results of the hypothesis tested is compared between the F-Value with P-Value, when the F-Value > P-Value then $H_0$ is rejected and $H_1$ is accepted. Otherwise, if F-Value < P-Value $H_0$ is accepted and $H_1$ then rejected. Testing the source that is as follows:
H₀ = Linear model having not effect on the amount of the value generated from the response.
H₁ = Linear model having effect on the amount of the value generated from the response.

**Table 3. An Experimental Model of Second Order Liner**

| Experiment On Linear Model | F-Value | Symbol | P-Value | Description |
|---------------------------|---------|--------|---------|-------------|
| 10% recycled ABS          |         |        |         |             |
| Impact Test               | 1.79    | >      | 0.153   | H₁          |
| Tensile Test              | 0.95    | >      | 0.484   | H₁          |
| 20% recycled ABS          |         |        |         |             |
| Impact Test               | 14.84   | >      | 0       | H₁          |
| Tensile Test              | 6.95    | >      | 0       | H₁          |
| 30% recycled ABS          |         |        |         |             |
| Impact Test               | 2.09    | >      | 0.1     | H₁          |
| Tensile Test              | 1.93    | >      | 0.125   | H₁          |

The test results indicated that the F-Value > P-Value then H₁ accepted and concluded in a linear model for the experiment have compliance against the value of the force of the impact and tensile generated.

**Table 4. Lack of fit an experimental model of second order**

| Experiments | Melting temperature F-Value | P-Value | Desc | Injection pressure F-Value | P-Value | Desc | Holding pressure F-Value | P-Value | Desc |
|-------------|-----------------------------|---------|------|-----------------------------|---------|------|---------------------------|---------|------|
| 10%         |                             |         |      |                             |         |      |                           |         |      |
| Impact Test | 2.83                        | > 0.083 | H₁   | 2.18                        | > 0.139 | H₁   | 0.35                      | < 0.709 | H₀   |
| Tensile Test| 0.6                         | > 0.561 | H₁   | 2.04                        | > 0.156 | H₁   | 0.2                       | < 0.817 | H₀   |
| 20%         |                             |         |      |                             |         |      |                           |         |      |
| Impact Test | 36.73                       | > 0     | H₁   | 7.24                        | > 0.004 | H₁   | 0.55                      | < 0.588 | H₀   |
| Tensile Test| 6.84                        | > 0.005 | H₁   | 13.53                       | > 0     | H₁   | 0.47                      | < 0.631 | H₀   |
| 30%         |                             |         |      |                             |         |      |                           |         |      |
| Impact Test | 4.84                        | > 0.019 | H₁   | 0.36                        | < 0.702 | H₀   | 1.08                      | > 0.359 | H₁   |
| Tensile Test| 3.07                        | > 0.069 | H₁   | 2.06                        | > 0.154 | H₀   | 0.66                      | > 0.527 | H₁   |

The results showed that melting temperature is stated with the F-Value P-Value then > H₁ accepted and concluded that the variable has a value to the overall suitability of the impact and power of attraction. Injection pressure test results revealed the F-Value > P-Value then H₁ accepted and concluded that the model has a strength value of compliance against the impact and the resulting drag. But in contrast to the results of the tensile test of recycled ABS 30% stated the F-Value < P-Value then H₀ are received and summed up the variable has a mismatch against the resulting value. The results of the test pressure of the detainees represented by the F-Value > P-Value then H₁ accepted and concluded that the model has a strength value of compliance against the impact and the resulting drag. But in contrast to the results of the tensile test of recycled ABS 30% stated the F-Value < P-Value then H₀ are received and summed up the variable has a mismatch against the resulting value.

Determination of the optimum point model based on second-order factors obtained from tensile test results and test the impact of contour plot observations every mixing recycled ABS material. The results of the determination of the optimum point in auto summary in table 5 as follows:

**Table 5. Optimal Level Factor Model of Second Order.**

| Experiment | Parameters | Level | Impact Test | Tensile Test |
|------------|------------|-------|-------------|--------------|
| Impact Test| 10%        |       | 45.87       | 34.08        |
| Melting temperature | -1 ~ -0.5 | 0.5 ~ 1 |              |              |
| Injection Pressure    | 0 ~ 1      |      |              |              |
| Holding Pressure      | -1 ~ -1    |      |              |              |
| Tensile Test          | -1 ~ 0     |      |              |              |
Melting temperature and injection pressure of the most determining factors of becoming simultaneously affect the mechanical properties of pure material mixing with recycle material, according to experiments conducted by Mohd Alias [7]. The pressure also affects the value of the power of arrest of mechanical material. Although it is not significant when compared to the melting temperature and the pressure of the injection, but the results showed the presence of a low level of increase to the middle level (optimal values) [8].

4. Conclusion
The results of the study of pure ABS recycling with recycle stated that the parameters of the melting temperature, injection pressure and holding pressure affect the optimal value of a result, here are the optimal parameters of each mixing combination:

1. The value of the optimal composition of pure ABS with 10% recycling in melting temperature is 210 ºC, the injection pressure 60 bar and holding pressure 35% yield strength of impact 45.87 [J] and 34.08 tensile strength [N/mm²].
2. The value of the optimal composition of pure ABS with 20% recycling in melting temperature is 240 ºC, the injection pressure 60 bar and holding pressure 25% yield strength of impact 45.40 [J] and 34.04 tensile strength [N/mm²].
3. The value of the optimal composition of pure ABS with 30% recycling in melting temperature is 225 ºC, the injection pressure 50 bar and holding pressure 45% yield strength of impact 45.17 [J] and 34.80 tensile strength [N/mm²].

Conclusions from the results obtained from impact test and tensile tests for each combination of composition mixing the same relative that is generating the impact 45 [J] and tensile strength 34 [N/mm²].

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