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Interaction and Optimization of Machine Parameter towards Mechanical Properties of New Composed Composite: Dynaglass PPG3637

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ABSTRACT

This study reveals the interaction and optimization of machine parameter towards mechanical properties of new composed composite. The new composed composite is polypropylene reinforced with fiber glass composite. Injection molding machine was utilized in this study. The processing parameters involved in the experimental were melting temperature (MeT) (250 – 280°C), injection pressure (IP) (22 – 28 MPa) and cooling time (Ct) (60 – 90s). The optimum processing parameters value that gave the highest tensile strength, highest tensile modulus and shortest elongation were studied. From the result analysis, it was found that the injection pressure was the most significant parameter that affected tensile strength and percentage of elongation. Meanwhile, melting temperature showed the most significant parameter affected on the tensile modulus. The optimum parameters effecting the tensile strength were 250°C for MeT, 22 MPa for IP and 77.97s for Ct. Furthermore, optimum parameters affecting the tensile modulus were 262.4°C for MeT, 27.0 MPa for IP and 60s for Ct. Finally, optimum parameters affecting the percentage of elongation were 250°C for MeT, 28 MPa for IP and 90s for Ct.

1. Introduction

There is very competitive production of composite material based on polypropylene (PP) and fiber glass. Due to low cost, flexible processability, high abundance and recyclability justify their use in a wide range of application, mostly in automotive industry. Polypropylene (PP) is one of the most commonly thermoplastic polymers used in a wide variety of application worldwide. In general, PP offers a good balance of properties and cost unachieved by most thermoplastics. It is lightweight yet stronger in such high flexural strength due to its semi-crystalline nature and has good impact strength. Meanwhile, fiber glass is the most commonly used fiber to reinforce thermoset and thermoplastic resins across a wide variety of applications and processes. Glass reinforcements in which added or molded with other materials, help improve the surface aspect as it allows a uniform impregnation (with resins) and are not subject to cracking, breaking or splitting. It has a greater specific resistance in such higher tensile strength compared to steel. This characteristic is the primary

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reason for the use of glass strand in the production of high-performance composites. Injection molding machine is one of the most commonly used methods of producing plastic product in high volumes due to its ability to fast production and highly efficient.

Thus, this study investigates the interaction and optimization of the injection molding machine parameter such as melting temperature, injection time and cooling time towards mechanical properties such as tensile strength, tensile Young's modulus and the percentage elongation of composite PP with fiber glass type PPG 3637 using response surface method.

Many plastic injection molding companies having problem to setting injection molding optimum parameters during the production run especially for new mold and new plastic materials are introduced. Application of design of experiment (DOE) becomes more essential in optimization parameters. Therefore, trial and error practice in industry can be replaced by using systematical approach. One of DOE method is using response surface method (RSM). RSM is statistical method that uses quantitative data from appropriate experiments in order to determine and simultaneously solve multivariant equations. RSM is useful for the modeling and analysis of programs in which a response of interest is influenced by several variables and the objective is to optimize this response. Therefore by using RSM, the optimum factor of the machine parameter can be identified towards tensile strength, tensile Young's modulus and the elongation of composite PP with fiber glass. The objectives of the current study are as follow:

i. To determine the interaction of process parameters on tensile strength, tensile modulus and percentage of composite PP with fiber glass type PPG 3637.
ii. To optimize machine parameter that related to the tensile strength, tensile Young's modulus and the elongation of the composite PP with fiber glass type PPG 3637 using single and multiple objective optimizations.

2. Literature Review

2.1 Properties of Polypropylene Reinforced with Fiber Glass

Polypropylene (PP) is one of the fastest growing polymers today. The glass fiber reinforced PP is used in a variety of applications such as building construction, marine, automotive industries and others. According to Harutun [10], the main advantages of glass fiber reinforced PP over the other engineering plastics are low cost and low specific gravity. In response to Harutun [10], Maria *et al.,* added that PP filled with particulate fillers will improve the hardness and modulus. High particle loadings result in products with much higher weight than that of the pure polymers. Hence a composite with improved properties at low particle concentration is always the optimum choice. A research has been conducted by Sinto [30], PP reinforced with short glass fiber was modified with precipitated nanosilica by using melt mixing method. The study found that the amount of the glass fiber required for a particular modulus could be reduced by the addition of nanosilica. This is due to the hydrophobic nature of polypropylene, which limits its adhesion to the 'hydrophilic' filler. The problem has been overcome by tailoring the affinity between the inorganic material and the organic polymer by in-situ polymerization, employment of coupling agents and other strategies. Such modifications have shown improvement in mechanical properties.

On the other hand, Azuddin *et al.*, [4] conducted a study on fiberglass reinforced polypropylenes (PP) with various glass fiber percentage. The study commenced with the fabrication of micro tensile specimens at three different injection temperatures which is 260°C, 270°C and 280°C for different percentage by weight of fiberglass reinforced PP. It was found that 20 % fiberglass reinforced PP possessed the greatest percentage increase of tensile strength with increasing temperatures.

In similar with Azuddin *et al.*, [4], Ota [35] investigated the study on the combined effect of injection temperature and fiber content on the properties of polypropylene-glass fiber composites. The study focuses on correlations between physical and mechanical properties of PP and PP reinforced with glass fiber molded at different injection temperatures and fiber weight fractions (20% and 30%). The result from the experiment shows that the melting flow index (MFI) of the composites was dependent on fiber content, fiber length distributions, a slight additional thermal protection due to the fibers and PP chain scission. Besides, the finding from the experiment shows that tensile strength and elastic modulus of the PP composites increased linearly with fiber content. In addition, the other outcome from the research reveals that the injection temperature can decrease elastic modulus to a point that the different composites showed statistically comparable rigidities.

2.2 Injection Molding

Injection Molding is a type of manufacturing process that produce parts in large volume. It is typically used in almost across mass-production processes where the same part is being created in high repeatability with a good succession rates. According to Gurjeet Singha [12], most thermoplastic polymers can be processed by injection molding process. Over 30 % of all the plastic parts are manufactured by the injection molding process [19]. This is one of the process that are greatly preferred in manufacturing industry because it can produce complex-shape plastic products and having good dimensional accuracy with short cycle times typical examples are automobile industry, casings and housings of products such as computer monitor, mobile phone and which has a thin shell feature [12]. Injection molding is also used to produce daily routine items such as toothbrushes or small plastic toys. Many medical devices, including valves and syringes, are manufactured using injection molding as well.

Many studies and researches have been conducted in order to find the appropriate parameter of injection molding machine. Ozcelik [22] considered the melt temperature, packing time, cooling time, and injection pressure as the parameter in order to examine mechanical properties of material using Taguchi method. In addition, Liu [17] conducted an experiment of the manufacturing of thermoplastic composites with the help of injection-molding technology. They study injection molding condition by process parameter water pressure, water temperature, water injection delay time, melt temperature, mold temperature and hold time with the help of Taguchi method. The proper injection capacity in the injection unit is found that shot weight of 70 to 80% of the injection capacity. This is due to at the side where the capacity is small, plasticizing time and injection time become long, and it is used at the narrow capacity of the molding machine. That is, the filling shortage is caused due to the extension of molding cycle and slow filling rate. On the other hand, at the side where the capacity is large, dwell time of the resin inside the cylinder becomes long, and the resin thermally decomposes.

2.3 Response Surface Methodology

Response surface methodology is a set of mathematical techniques that describe the relation between several independent variables and one or more responses [3]. Research surface method was developed by Box and Wilson and since then it has been widely used as a technique for designing experiments. Montgomery [7] defined response surface methodology (RSM) as a collection of statistical and mathematical techniques useful for developing, improving, and optimizing processes. The crucial applications of RSM are in the particular situations where there are several input variables that potentially influence some performance measure or quality characteristic of the process. The response is related to performance measure or quality characteristic. In general, the input variables are called independent variables, and are subject to the control of the researchers. Finding from Montgomery [7] indicated that the field of response surface methodology consists of the experimental strategy for exploring the space of the process or independent variables, empirical statistical modeling to develop an appropriate approximating relationship between the yield and the process variables, and optimization methods for finding the values of the process variables that produce desirable values of the response. In similar with Douglas [7] he defined that RSM is a collection of mathematical and statistical techniques for empirical model building, in which a response of interest is influenced by several variables and the objective is to optimize this response.

One of the main objectives of RSM is the determination of the optimum settings of the control variables that result in a maximum (or a minimum) response over a certain region of interest R [1]. This method requires having a 'good' fitting model that provides an adequate representation of the mean response because such a model is to be utilized to determine the value of the optimum. Optimization techniques used in RSM depend on the nature of the fitted model.

For first-degree models, the method of steepest ascent is a viable technique for sequentially moving toward the optimum response. Khuri [32] developed certain improvements regarding the stopping rule used in the execution of this method. The first-degree model is usually used at the preliminary stage of a response surface investigation. Second-degree models are used after a series of experiments have been sequentially carried out leading up to a region that is believed to contain the location of the optimum response [32].

In general, second factorial design is often used to fit linear and non-linear (second order) response surface models for some number of input variables. Meanwhile experimental designs for first-order models such as factorial designs can be used when the data set does not present curvature. On the other hand, the experimental designs for quadratic response surfaces should be used, such as three- level factorial, Box–Behnken, central composite, and Doehlert designs [18].

3. Methodology

The overall process flow throughout the experimental work is as follow. At initial stage of the study, the data were collected from the experimental procedure. Next the data acquired was consumed in Design Expert software in order to achieve the optimization. The method used in Design Expert is Response Surface Methodology (RSM) particularly using Box–Behnken design. Then the analysis of variance can be done by ANOVA. Hence the optimization achieved.

At initial stage of the study, the data were collected from the experimental procedure. Next the data acquired was consumed in Design Expert software (*Minitab*) in order to achieve the optimization. The method used in Design Expert is Response Surface Methodology (RSM) particularly using Box–Behnken design. Then the analysis of variance can be done by ANOVA. Hence the optimization is achieved.

RSM is suggested as a standard procedure for optimizing any process parameters. This study is planned to use Response Surface Methodology (RSM) particularly using Box–Behnken design. In general, Box–Behnken developed a 3-level incomplete factorial design as an alternative to the labour extensive full factorial design. The steps involved in Box–Behnken:

1. Define the independent input variables (material melting temperature, injection pressure, cooling time).
2. Adopting the Box–Behnken design to plan the experimental design.
3. Performed the experiments according to Box–Behnken design matrix. Experiment matrices are

built by means of two level factorial designs (+1(high), -1(low)) with incomplete block designs.

4. The final matrix is completed with several replications of the central point, what improves precision. There are no experimental points in this design, where all factors have extreme values. This feature might be beneficial in experiments where undesired phenomena might occur in extreme conditions.
5. Perform the regression analysis with the quadratic model response.
6. Carry out the statistical analysis.
7. Obtain the optimal design parameters for the desired output.
8. Conduct the confirmation to verify the optimal design parameter settings.

3.1 Materials

PP reinforced with constant fiber glass contents; type DYNAGLASS PPG3637 that appears in black granule was used in the study. Figure 1 shows the PP reinforced with 20 % fiber glass type DYNAGLASS PPG3637 used during experimental work.

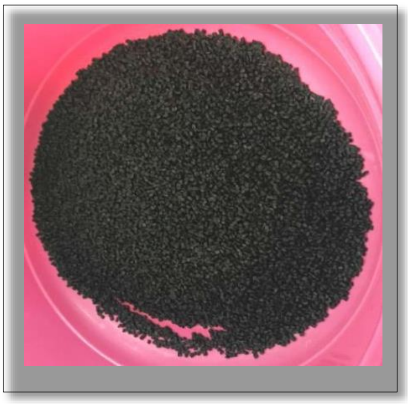

Fig. 1. Composite PP Reinforced with 20 % Fiber Glass DYNAGLASS PPG3637

The composed composite has heat stability up to 280ºC, while the molding temperature is between 190 - 210°C. Table 1 shows the characteristic of PP reinforced with fiber glass.

Table 1
The characteristic of PP reinforced with fiber glass DYNAGLASS PPG3637

Characteristic	Value
Glass fiber content	20 %
Heat stability	280°C
Drying temperature	80° C/ 2 hours
Molding temperature	190 - 210 ° C

3.2 Experimental Plan and Procedure

3.2.1 Selection of process parameters and level

For the experimental work, the three process parameter each at two level have been decided. It is desirable to have two level of process parameters to reflect the actual behavior of the measured output parameter. The process parameters are named as factors and they are located in the adjacent column. The level of the individual process parameters or factors are given in Table 2. PP reinforced with constant 20 % glass fiber contents is processed by using different combination of processing parameter at different combinations of material melting temperature, injection pressure and mold cooling time.

Table 2
The level of individual process parameter

Parameter	Level Low	Level High
Melting temperature, (MeT) (°C)	250	280
Injection pressure, (IP) (MPa)	22	28
Cooling time, (Ct)(s)	60	90

As per experimental design (Box-Behken), a set of two levels assigned to each process parameter. The matrix is completed with five replications of the central point, in order to improve precision. Hence the final matrix comprised of 17 runs as per Table 3.

Table 3
The experimental plan using BB design

No. of experiment	Melting Temperature, (°C)	Injection Pressure,(MPa)	Cooling time, (s)
1	250	22	75
2	280	22	75
3	250	28	75
4	280	28	75
5	250	25	60
6	280	25	60
7	250	25	90
8	280	25	90
9	265	22	60
10	265	28	60
11	265	22	90
12	265	28	90
13	265	25	75
14	265	25	75
15	265	25	75
16	265	25	75
17	265	25	75

3.2.2 Injection molding machine

In this experiment, PP reinforced with fiber glass, type DYNAGLASS PPG3637 used. A series of experiment were conducted using an injection molding machine model Arburg 420C 800 - 250 as shown in Figure 2.

Fig. 2. Injection molding machine used in the experiment

PP reinforced with glass fiber contents is processed by using different combination of processing parameter, material melting temperature, injection pressure and mold cooling time. Table 4 shows the capabilities of the injection molding machine used in the experimental work.

Table 4
Capabilities of the injection molding machine

Parameter	Value
Maximum injection pressure (MPa)	180
Maximum injection rate (cm^3/s)	5000
Maximum clamping force (tonne)	7000

3.3. Mechanical Testing

The mechanical properties of all specimens is tested by using universal testing machine as per Figure 3. The universal testing machine is supported by electro- mechanical or hydraulic system. The system is equipped with the suitable specimen grips, an extensometer and with software capable of strain rate control and recording stress-strain data.

Fig. 3. Universal testing machine used during experiment

4. Results and Discussion

4.1 Interaction Machine Parameter on Tensile Strength

Figure 4 and 5 show the contour plot relationship between MeT, IP and Ct towards the tensile strength. While, Figure 5 and 6 show the 3D plot of relationship between MeT, IP and Ct with respect to the tensile strength. From Figure 4, it shows that the highest tensile strength is achieved when both MeT and IP at the lowest value. The contour plot from Figure 5 indicates the highest tensile strength is attained at certain range value of Ct.

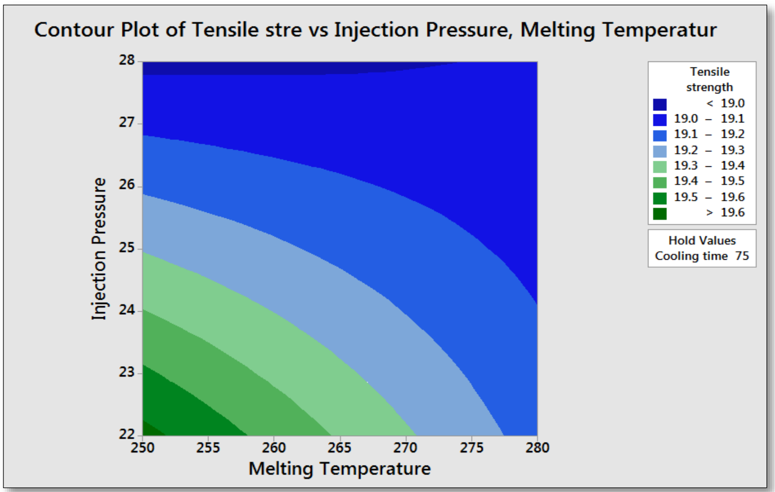

Fig. 4. Contour plot of tensile strength vs IP, MeT

From Figure 5, it displays the combination of low IP and high MeT contribute towards highest value of tensile strength. Meanwhile, surface Plot of tensile strength vs Ct, MeT in Figure 6 shows that interaction of mid-range value of Ct and low IP towards highest value of tensile strength.

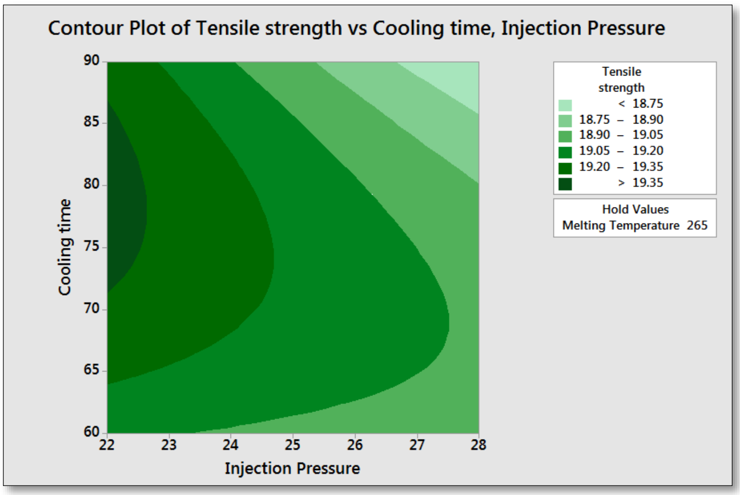

Fig. 5. Contour plot of tensile strength vs IP, Ct

The highest tensile strength occurred when the value of Ct is between 70 - 85s and when the IP at the lowest value (22MPa).

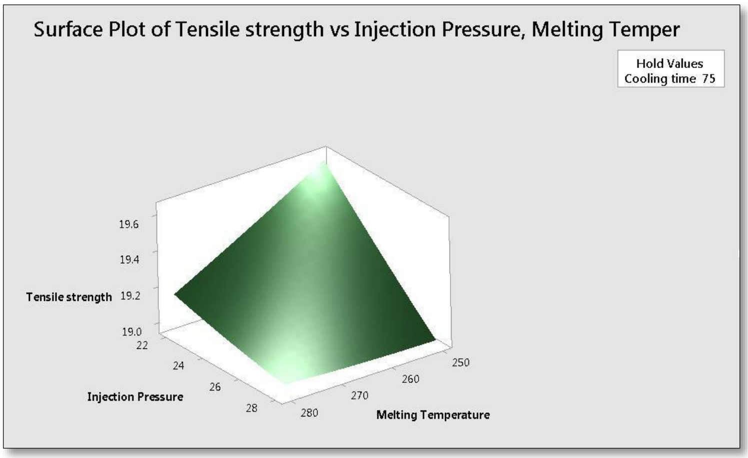

Fig. 6. Surface plot of tensile strength vs IP, MeT

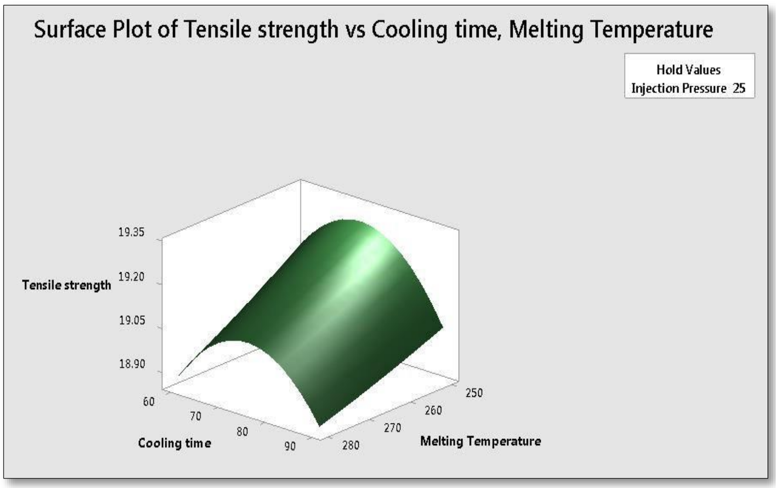

Fig. 7. Surface plot of tensile strength vs Ct, MeT

4.2 Interaction Machine Parameter on Tensile Modulus

Figure 8 and 9 show the contour plot relationship between MeT, IP and Ct towards the tensile modulus. While, Figure 10 and 11 and shows the 3D plot of relationship between MeT, IP and Ct with respect to the tensile modulus. The highest tensile modulus is achieved at certain range value of MeT and IP, which is the value of MeT from 235°C to 275°C and IP from value 23MPa to 28 MPa. The contour plot from Figure 9 indicates the highest tensile modulus is attained significantly at both highest and lowest value of Ct together with certain range value of IP. The highest tensile strength occurred at two conditions. First, when the value of Ct at the lowest value: 60 seconds and the value of IP is between 25 MPa to 28 MPa. Next the highest tensile modulus is achieved when the Ct is 90 seconds and the value of IP is in between 23 MPa to 26 MPa.

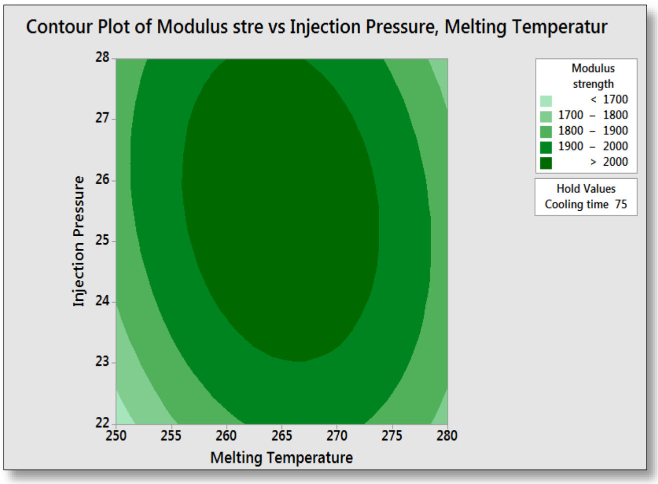

Fig. 8. Contour plot of tensile modulus vs IP, MeT

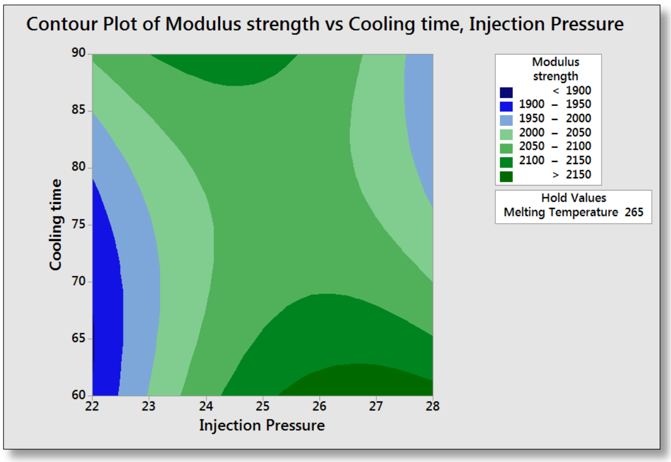

Fig. 9. Contour plot of tensile modulus vs IP, Ct

From Figure 10, it displays the combination of both mid-range value of IP and MeT contribute towards highest value of tensile modulus. Meanwhile, surface Plot of tensile modulus vs Ct and IP in Figure 11 shows that interaction of lowest and highest value of Ct and mid-range value of IP towards highest value of tensile modulus.

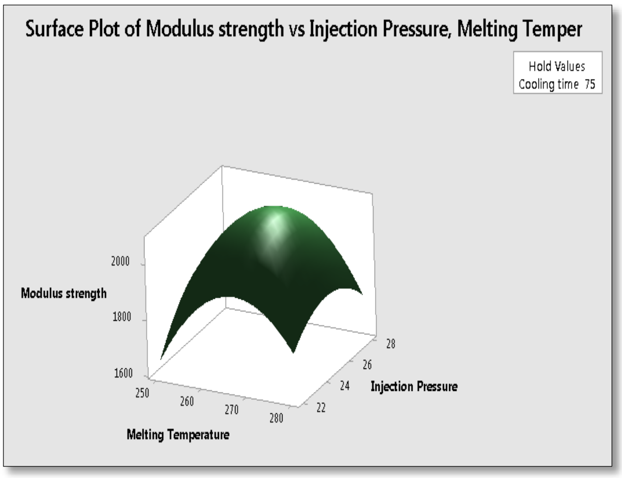

Fig. 10. Surface plot tensile modulus vs IP, MeT

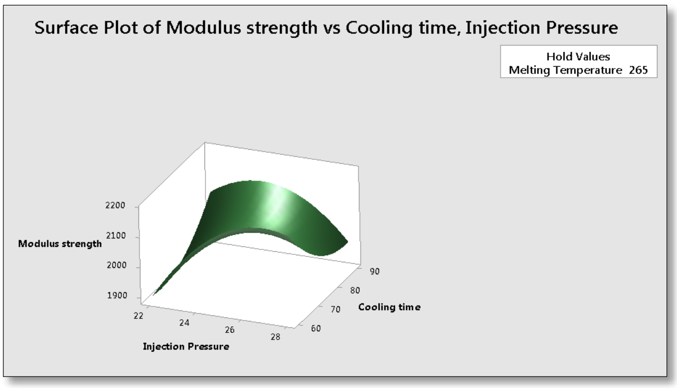

Fig. 11. Surface pplot of tensile modulus vs Ct, IP

4.3 Interaction Parameter on Elongation

Figure 12 - 14 show the contour plot relationship between MeT, IP and Ct towards the elongation. While, Figure 15 - 17 show the 3D plot of relationship between MeT, IP and Ct with respect to the elongation. The contour plot from Figure 12 indicates the highest elongation is attained significantly at both highest and lowest value of Ct together with certain range value of IP. Figure 15 - 17 display the combination surface plot of elongation vs MeT, Ct and IP.

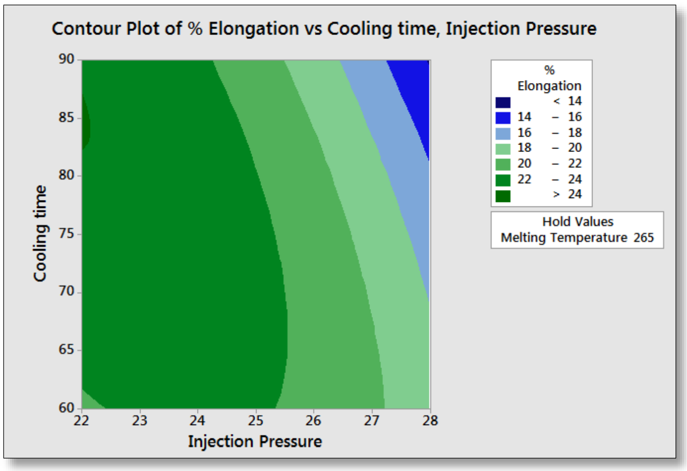

Fig. 12. Contour plot of elongation vs IP, Ct

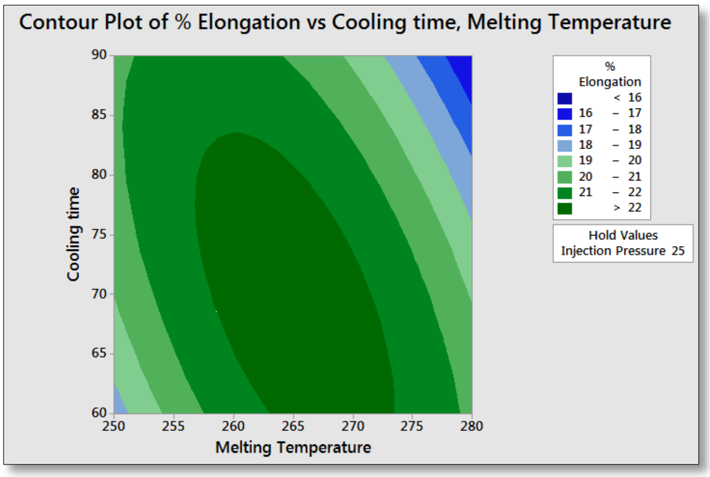

Fig. 13. Contour plot of elongation vs Ct, MeT

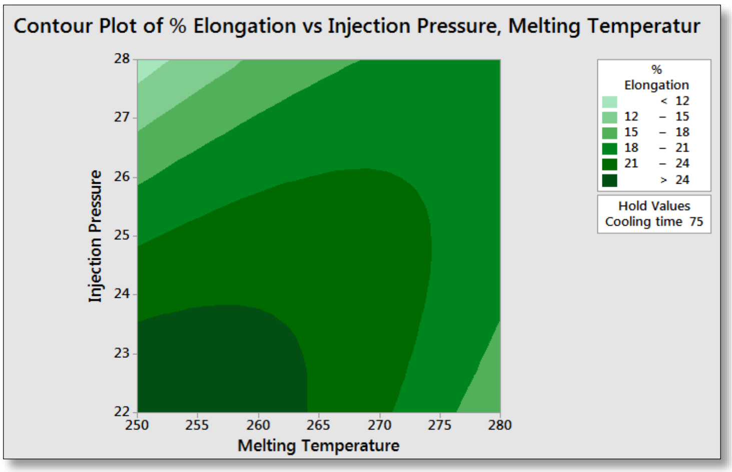

Fig. 14. Contour plot of elongation vs IP, MeT

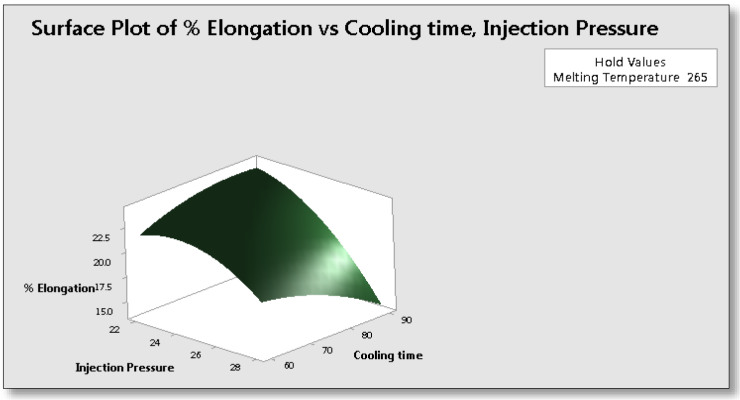

Fig. 15. Surface plot of elongation vs IP, Ct

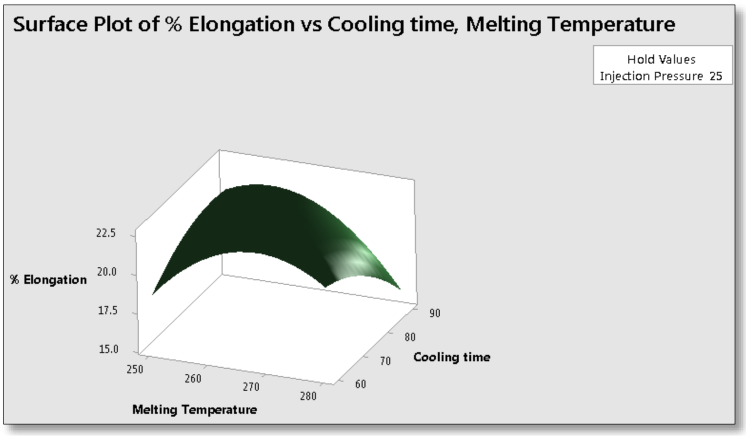

Fig. 16. Surface plot of elongation vs Ct, MeT

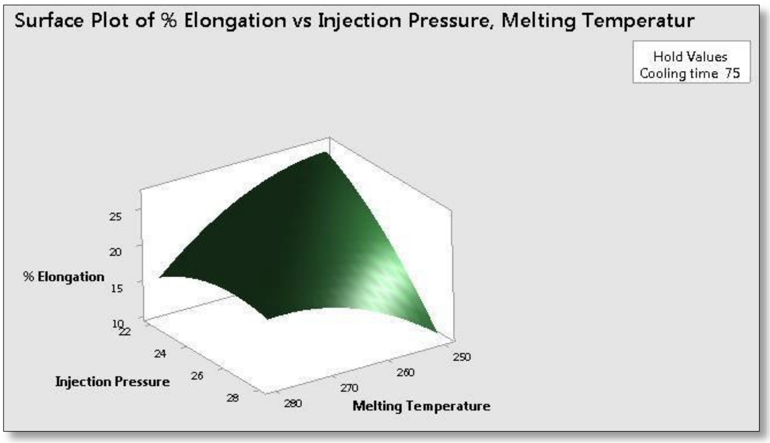

Fig. 17. Surface plot of elongation vs IP, MeT

4.4 Single Optimization of Tensile Strength, Tensile Modulus and Elongation

One of the advantages of RSM is able to determine the optimized parameters based on target setting. The target can be decided based on minimum, maximum or even specific target value of response. For the experimental work, the target is to find the highest tensile strength within the range value of varied parameters. Figure 18 shows the optimized parameters based on the target and parameters set.

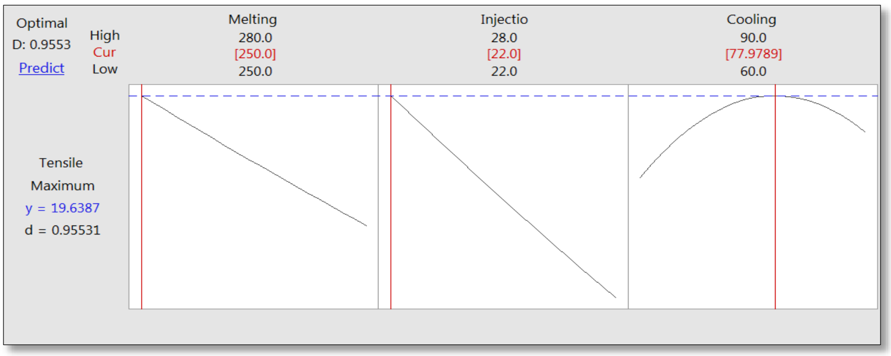

Fig. 18. Optimization plot of tensile strength

From Figure 18, it displays that the optimized parameters values are 250°C MeT, 22 MPa IP and Ct of 77.97 seconds. These optimized parameters have 0.95531 desirability to achieve the highest value of tensile strength. From the optimized set of parameters, the predicted value of achievable tensile strength is equal to 19.6387 N/m^2. Meanwhile, Figure 19 shows the optimized parameters based on the target and parameters set for tensile modulus.

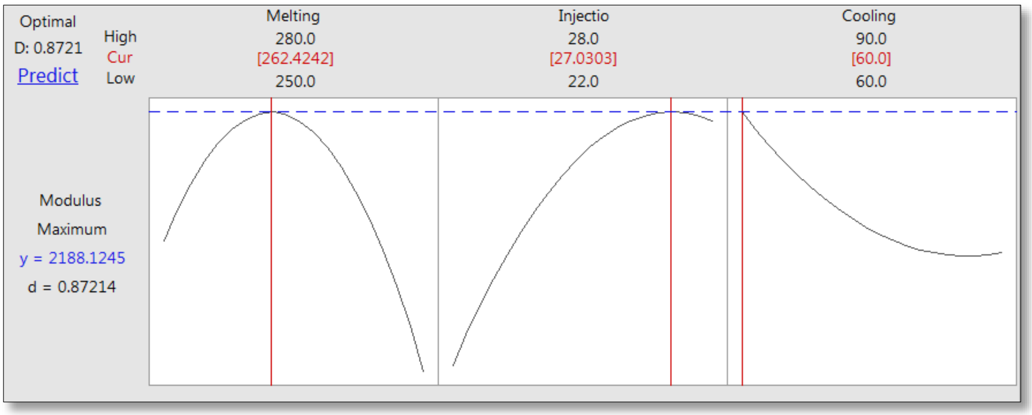

Fig. 19. Optimization plot of tensile modulus

From Figure 19, it displays that the optimized parameters values are 262.4°C MeT, 27.03 MPa IP and Ct of 60 seconds. These optimized parameters have 0.87214 desirability to achieve the highest value of tensile modulus. From the optimized set of parameters, the predicted value of achievable tensile modulus is equal to 2188.12 N/m^2. On the other hand, Figure 20 shows the optimized parameters based on the target and parameters set for elongation.

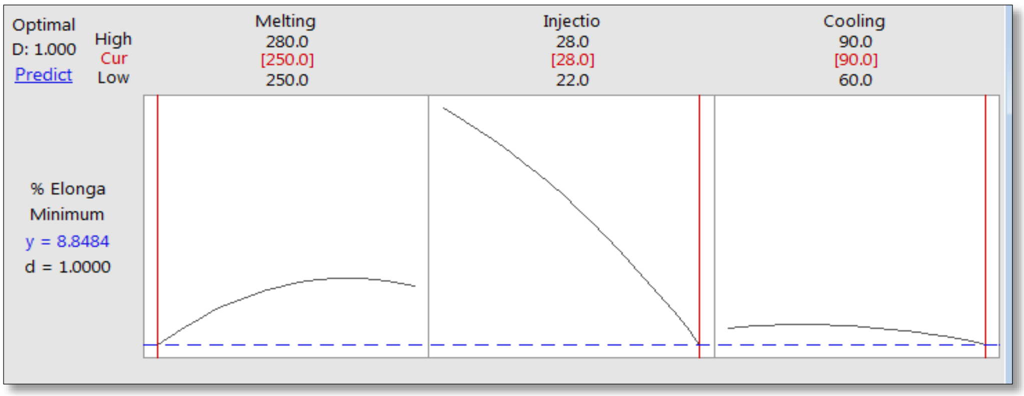

Fig. 20. Optimization plot of elongation

From Figure 20, it displays that the optimized parameters values are 250°C MeT, 28 MPa IP and Ct of 90 seconds. These optimized parameters have 1.0 desirability whereby it is 100 % success of achieving the shortest elongation. From the optimized set of parameters, the predicted value of achievable shortest elongation equal to 8.85 %.

4.5 Multiple Optimization of Tensile Strength, Tensile Modulus and Elongation

In the first part of the optimization, the three responses are optimized individually; tensile strength, tensile modulus and elongation. Apart of single optimization, RSM is able to perform multiple optimizations whereby all three responses can be optimized simultaneously according to varied parameter. Therefore, all three responses; tensile strength, tensile modulus and elongation can be decided based on minimum, maximum or even specific target value of response. For the experimental work, the target is to find the highest tensile strength, highest tensile modulus and shortest elongation within the range value of varied parameters. Figure 21 shows the multiple optimized responses based on the target and parameters set. From Figure 21, it displays that the multiple optimized parameters values are 252.4°C MeT, 27.8 MPa IP and Ct of 60 seconds. These optimized parameters lead to 0.361 desirability to achieve the highest value of 18.99 N/m^2 tensile strength. Meanwhile, for tensile modulus, the desirability to achieve the highest value for tensile modulus is 0.716. This value of desirability results the highest tensile modulus of 2092.53 N/mm. The greatest desirability of the multiple optimization parameter belongs to elongation response. It contributes 0.9984 desirability in order to achieve the shortest elongation.

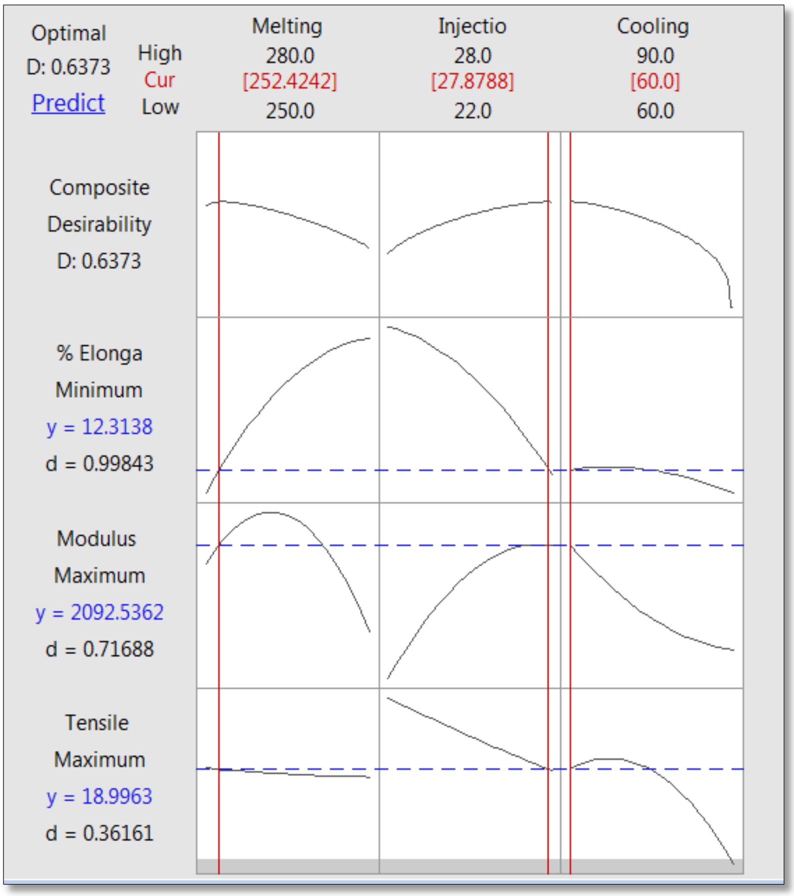

Fig. 21. Multiple optimization plot

5. Conclusions

Based on the analysis of results, the following conclusions are drawn. As for the interaction among parameter, it can be concluded that the highest tensile strength is achieved when the injection pressure (IP) is in the lowest value. The maximum tensile modulus is attained significantly during cooling time at both lowest and highest value. Besides, the longest elongation occurred ultimately at both lowest and highest value of cooling time.

For the single optimization is found that the optimized parameters values are 250°C MeT, 22 MPa IP and Ct of 77.97 seconds. These optimized parameters have 0.95531 desirability to achieve the highest value of tensile strength. Meanwhile for the in order to obtain the highest tensile modulus, the optimized parameters values are 262.4°C MeT, 27.0 MPa IP and Ct of 60 seconds. For the elongation, it displays that the optimized parameters values are 250°C MeT, 28 MPa IP and Ct of 90 seconds. These optimized parameters have 1.0 desirability whereby it is 100 % success of achieving the shortest elongation.

As for multiple optimizations, the multiple optimized parameters values are 252.4°C MeT, 27.8 MPa IP and Ct of 60 seconds. These optimized parameters lead to 0.361 desirability to achieve the highest value of 18.99 N/m^2 tensile strength. Meanwhile, for tensile modulus, the desirability to achieve the highest value for tensile modulus is 0.716. This value of desirability results the highest tensile modulus of 2092.53 N/mm. The greatest desirability of the multiple optimization parameter belongs to elongation response. It contributes 0.9984 desirability in order to achieve the shortest elongation.

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