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Effect of Injection Molding Parameters on Recycled ABS (r-ABS) Mechanical Properties

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Abstract

Background/Objectives: Recycled plastic resins are considered as low performance materials because of their properties decreased with the recycling process due to the loss of its chemical properties. This study aims to determine the strength and shrinkage of Recycled Acrylonitrile-Butadiene-Sytrene (r-ABS) and virgin ABS when mixed according to the loading ratio. **Methods/Statistical Analysis:** The two-plate test mold was used to inject the specimen according to ASTM D638 using 50 tons an injection molding machine. By adopting the L9 Taguchi orthogonal array, three controllable factors at three levels are tested to determine the optimal combination of factors and levels in the injection molding process. The STATISTICA software applies for further analysis. **Findings:**The resultrevealed that at a high melting temperature and high injection pressure produceless shrinkage. The cooling time also affect the strength and shrinkage of r-ABS .**Conclusion/ Application:** The performance of recycled plastic resin mixed with a virgin can be effectively enhanced to desire requirement using the Taguchi optimization approach.

Keywords: Recycled Acrylonitrile-Butadiene-Sytrene (r-ABS), Shrinkage, Taguchi Methods, Tensile Strength

1. Introduction

One of the fastest growing major industries in the world is plastic industry. Every year, the amounts of the plastic products used are increasing. The injection molding process is the predominant method for producing plastic parts. The product quality of injection molded plastic parts is the result of a complex combination of the material used, the part and mold designs and the process conditions used to manufacture them. Recycling at larger scales of plastic resin with virgin for consumer commodities such as soft drink bottles to industrial applications such as automotive parts requires a comprehensive study to meet the requirement of the end product[1,2].

Shrinkage is an important quality among others in determining the injection parts. It is commonly accepted that semi-crystalline plastics shrink more than amorphous ones because of a closer packing of the crystalline structure. Increasing melt temperature was found to reduce shrinkage because of better pressure transmission, which is affected to mold filling[3]. However, the increasing mold temperature wasreported to increase shrinkage while others concluded differently[4].

The Taguchi method uses an Orthogonal Array (OA) as the basic rudiment of this experiment. The benefit of using an Orthogonal Array is that a large amount of information about the effects of many processing parameters can be obtained from very few experiments[5]. In addition, the method is systematically to investigate the process conditions on the shrinkage and strength of RecycledAcrylonitrile-Butadiene-Sytrene (r-ABS). Those parameters include melting temperatures, injection pressures and cooling times.

The surface plot graph for the dependent and independent variables of each molded material was developed and the result of the experiment was generated using STATISTICA software. The aims of this study are to determine the strength r-ABS resin and virgin ABS resin when mixed according to the ratio selected and to optimize the best process parameter setting used for injection molding process.

The effects of several process parameters based

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on Taguchi's orthogonal design could be determined effectively from matrix experiments[6]. It is the suitable method to determine the best levels of control factors. In order to find optimum levels, fractional factorial designs using Orthogonal Arrays are used. In this way, an optimal set of process conditions can be obtained from very few experiments[7]. The method invented by Dr. Genichi Taguchi is a unique engineering process that unifies the optimization of cost, quality and product development cycle time[8]. Process optimization is found to have a decisive effect on the quality improvement of injection-molded parts[9]. Numerousstudies were conducted to investigate the influence of injection molding parameters on the mechanical properties of molded parts and on the occurrence of moldingdefects[10–14].

2. Experimental Works

2.1 Materials

The materials used for these studies were r-ABS resin and virgin ABS. The ABS material were prepared and mixing according to the ratio selected such as 100:0, 90:10, 80:20 and 70:30. The specimens for tensile test and shrinkage measurement were molded using injection molding machine Toyo Ti-150Gx at injection temperature varying from 200°C to 260°C.

The three heating zones were set at 200°C, 230°C and 260°C respectively. All processing was done with the same equipment by the same setting parameters and level as shown in Table 1. The properties of ABS compound were shown in Table 2.

Table 1. The process parameters and levels

ProcessParameter	Denoted	Level 1	Level 2	Level 3
Melt temp. (°C)	P1	200	230	260
Cooling time (s)	P2	16	19	22
Injectionpressure (MPa)	P3	90	120	150

Table 2. Physical and mechanical properties ABS

Physical Properties			
Melt flow index	ASTM D1238	200 C/5 kg	1.8 g/10 min
Mechanical Properties			
Tensile strength	ASTM D638	5 mm/min	47 MPa
Flexural strength	ASTM D790	2.8 mm/min	66 MPa
Flexural modules	ASTM D790	2.8 mm/min	2200 MPa
Izod impact strength	ASTM D256	¼ in.	235 J/m

Therefore, a good interaction and combination among the variables are important in order to produce a high quality and economical plastic part due to not require secondary and assembly process. Table 3 shows the L_9 Taguchi Orthogonal Array to conduct the experiment.

Table 3. Experimental layout using L9 (33) Taguchi Orthogonal Array

Experiments	Injection Molding Parameters		
	A	B	C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Several injection trials were run according to the Taguchi method which then served as a reference to set the Orthogonal Array for the Taguchi method. The factors used in the experiments were melting temperature (A)Cooling time (B) and Injection pressure (C). The levels and assigned values for each resin are shown in Table4.In the experiments, each processing condition was allowed to stabilize for at least half an hour. For each run, 10 samples were taken out and 5 parts were taken as a sample for tensile testing and shrinkage measurement.

Table 4. Experimental layout using L9 (33) Taguchi Orthogonal Array

Experiments	Injection Molding Parameters		
	A	B	C
1	200	16	90
2	200	19	120
3	200	22	150
4	230	16	120
5	230	19	150
6	230	22	90
7	260	16	150
8	260	19	90
9	260	22	120

2.2 Tensile Testing

Testing machine is of hydraulic type (Universal Testing Machine Instron 3369).Tension test is widely used to provide basic design information on the strength of materials and is an acceptance test for the specification of materials. The machinewas certified byInternational, British and American Society for Testing and Materials standards.

Tensile testing was carried out according to ASTM D638 standard on five dumbbell-shaped samples of dimensions 160 mm length × 13 mm width ×3.5 mm thickness which obtained by injection molding process. The distances between the ends of the gage section and the shoulders should be great enough so that the larger ends do not constrain deformation within the gage section and the gage length should be greater relative to its diameter.

Otherwise, the stress state will be more complex than simple tension. Average values of 5 samples were calculated. Test parts are shown in Figure 1.

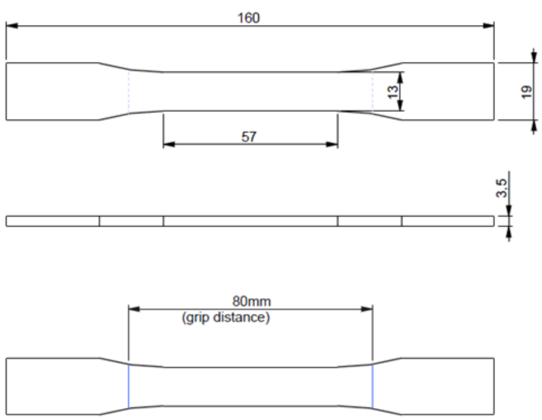


Figure 1. Specimen dimensions for tensile strength (ASTM D638).

2.3 Shrinkage Measurement

Figure 2 illustrates how the shrinkage is measured from a rectangular bar. Five measurements along the flow were taken for each specimen using a digital calliper with an accuracy of +0.001inches.

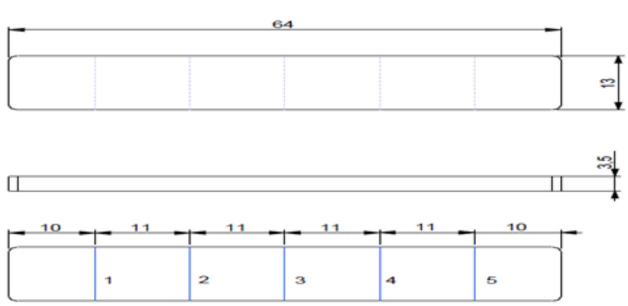


Figure 2. Specimen dimensions for shrinkage (ASTM D638).

The relative shrinkage was calculated by the following equation:

$S_{Flow} = 100 * (L_M - L_S) / L_M$

Where L_M is the length of the test section of the mold cavity and L_S is the corresponding length of the test specimen after it has cooled.

For each injection cycle, the switchover from the injection phase to the holding phase happened when the injection pressure reached the setting. Since ABS is an amorphous plastic, all of the samples were allowed to relax after experiments for at least 24 hours or 48 hours before measurements were taken.

3. Results and Discussion

From STATISTICA, the surface plot for dependent variable against all independent variables can be generated. By referring to the general model equation for the 3^k factorial design:

$Y = B_0 + B_1x_1 + B_2x_2 + B_3x_3 + \in$

Substitute the value of the regression coefficient into the model. In this case, x_1 is the melting temperature, x_2 is the cooling time and x_3 is the injection pressure.

The results of shrinkage and tensile strength at different loading ratio were shown inTables 5 and 6.

Table 5. Shrinkage value for ABS resin at different loading ratio

Exp No.	P1	P2	P3	Shrinkage (%)			
				100:0	90:10	80:20	70:30
1	200	16	90	0.363	0.181	0.294	0.593
2	200	19	120	0.341	0.206	0.223	0.421
3	200	22	150	0.590	0.220	0.318	0.261
4	230	19	90	0.301	0.286	0.547	0.426
5	230	22	120	0.274	0.347	0.607	0.458
6	230	16	150	0.246	0.357	0.407	0.440
7	260	22	90	0.224	0.283	0.252	0.984
8	260	16	120	0.517	0.332	0.546	0.661
9	260	19	150	0.363	0.434	0.209	0.680

Table 6. Strength value for ABS resin at different loading ratio

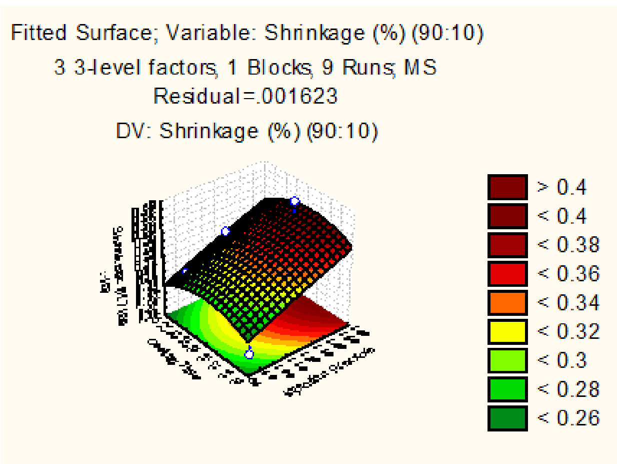
Exp No.	P1	P2	P3	Tensile Strength (MPa)			
				100:0	90:10	80:20	70:30
1	200	16	90	37.59	36.39	38.67	36.35
2	200	19	120	38.43	36.95	38.84	35.85
3	200	22	150	38.53	35.58	39.24	37.07
4	230	19	90	40.56	35.94	37.36	38.93
5	230	22	120	38.96	38.21	35.45	39.01
6	230	16	150	40.91	37.69	37.53	39.15
7	260	22	90	37.07	34.75	35.18	38.70
8	260	16	120	40.42	37.84	35.31	36.96
9	260	19	150	36.99	37.08	33.10	37.40

3.1 Shrinkage Analysis

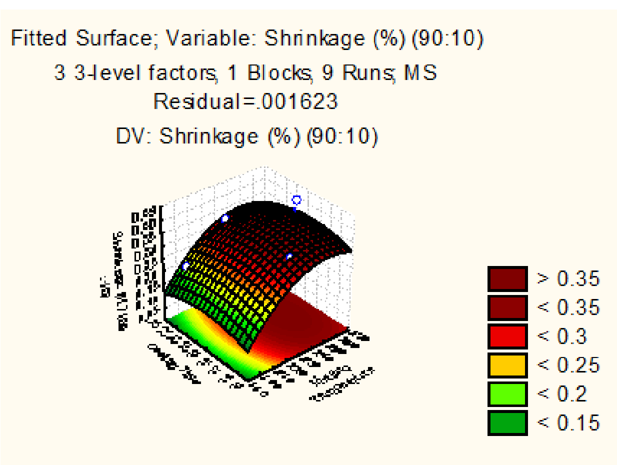
The correlations of shrinkage and injection pressure are shown in Figure 3 (a) and (b). The lowest shrinkage value was when applying lower injection pressure with maximum cooling time and at lower injection pressure with a lower melting temperature. In Figure 3 (c), it indicates a higher shrinkage value when applied with maximum melting temperature and medium cooling time.

Substitute the value of the regression coefficient into the model (2). The mathematical model for the shrinkage of r-ABS was established as:

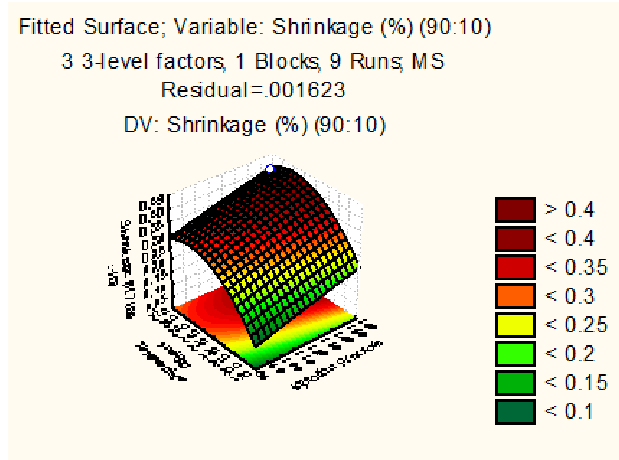
$S= -4.44997 + 0.03008T - 0.09084c + 0.001(3)$



(a)



(b)



(c)

Figure 3. (a) Injection pressure versus cooling time; (b) Melting temperature versus cooling time and (c) Injection pressure versus melting temperatur.

The results from measurements of shrinkage were presented in graph for each composition to determine the optimal setting parameters as tabulated in Table 7. The process variables affecting the shrinkage behavior and tensile strength of each plastic are identified.

Table 7. The shrinkage value at different loading ratio

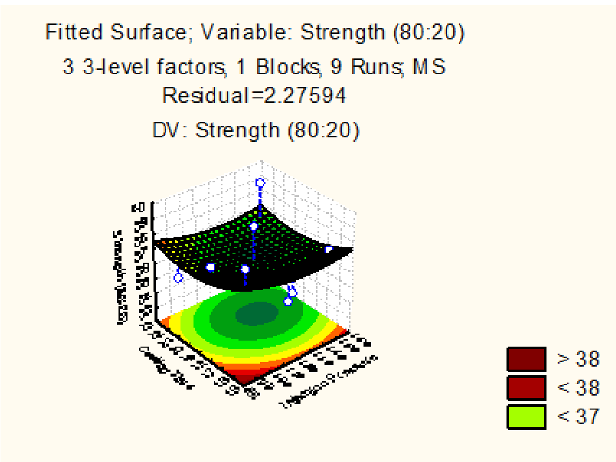
Ratio	Melt Temp. (°C)	Cooling Time (s)	Injection Pressure(MPa)	Shrinkage %
100:0	260	22	90	0.2244
90:10	200	16	90	0.1814
80:20	260	19	150	0.2091
70:30	200	22	150	0.2613

The result of shrinkage indicates that for a composition of 70:30 witha low melting temperature at 200°C and high injection pressure of 150MPa play very important rule in determining the injection tensile strength with less shrinkage of 0.2613%. For the composition of 90:10,itslow melting temperature at 200°C and low injection pressure of 90MPa where the shrinkage is 0.1814%. Meanwhile, the result indicates for the composition 100:0 with high melting temperature at 260°C and the low injection pressure of 90MPa is 0.2244%. For the composition of 80:20,its melting temperature at 260°C and high injection pressure of 150MPaby 0.2091%.

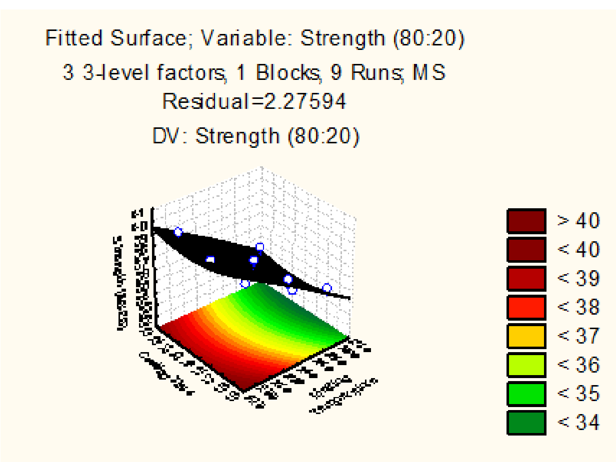
3.2 Tensile Strength Analysis

In Figure 4(a) and (c), higher strength value is achieved whenapplying lower injection pressure with lower cooling time and lower injection pressure with alower melting temperature. In Figure 4 (b), it indicates a lower strength value is obtained at higher melting temperature with medium cooling time. Substitute the value of the regression coefficient into the model (2). The model after the substitution is:

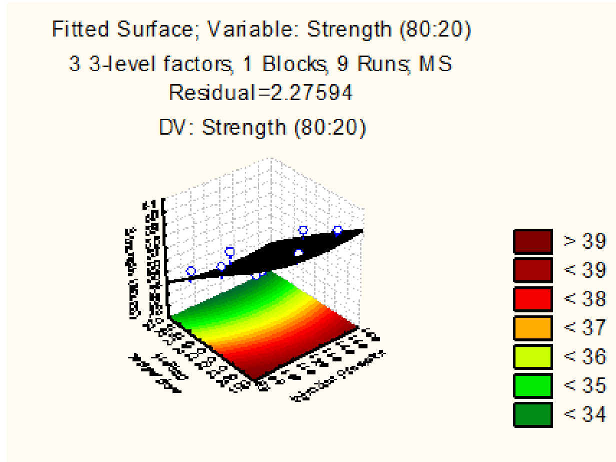
S_T=76.03232-0.04532T-2.03543c-0.09169p(4)



(a)



(b)



(c)

Figure 4. (a) Injection pressure versuscooling time; (b) Melting temperature versuscooling time and (c) Injection pressure versusmelting temperature.

Results from measurements of tensile strength were presented in a graph using Microsoft Excel for each composition to determine the optimal setting parametersas tabulated in Table 8.

Table 8. The tensile strength value at different loading ratio

Ratio	Melt Temp. (°C)	Cooling Time(s)	Injection Pressure (MPa)	Tensile StrengthMPa
100:0	230	16	150	40.9084
90:10	230	22	120	38.2074
80:20	200	22	150	39.2432
70:30	230	16	150	39.1456

It was found that for virgin ABS material with a medium melting temperature at 230°C and a high injection pressure 150MPa, the strength of virgin ABS is 40.9084MPa. But for the tensile strength composition of virgin ABS and r-ABS with a low melting temperature at 200°C and high injection pressure 150Mpa gives higher strength i.e. 39.2432MPa. Meanwhile, at medium melting temperature 230°C and medium injection pressure

120MPpagive low strength value 38.2074MPa compared with medium melting temperature 230^{o}C and high injection pressure 39.1456MPa.

4. Conclusion

The best parameter setting for each composition can be determined according to the composition ratio used. The result also indicates that the cooling time gives an effect to the strength and shrinkage of ABS material. Higher injection pressure can reduce shrinkage. In case for low shrinkage is required, the melting temperature at 200°C, cooling time and injection pressure 16s and 90MParespectively.The shrinkage values were recorded 0.1841% and 0.2936% at the loading ratio 90:10 and 80:20 respectively.

At melting temperature 200°C, cooling time and injection pressure 22s and 150MPa respectively. The highest strength value was recorded at 39.58MPa which is the loading ratio of 80:20.

Among the parameters selected in the optimization experiment, melt temperature and injection pressure were found to be the most decisive factor simultaneously affecting the mechanical properties of r-ABS.

All of the independent variables provide different effects to the products produced. The benefit of using orthogonal arrays is that a large amount of information from the effect of many processing parameters can be obtained from very little experiment, thus saves the time. Also, the recycled material can reduce the cost by reusing it again even after crushing, but only for certain application.

5. References

1. Chilton T, Burnley S, Nesaratnam S. A life cycle assessment of the closed-loop recycling and thermal recovery of post-consumer PET. Resources, Conservation and Recycling. 2010 Oct; 54(12):1241–9.
2. Froelich D, Maris E, Haoues N, Chemineau L, Renard H, Abraham F, Lassartesses R. State of the art of plastic sorting and recycling: Feedback to vehicle design. Minerals Engineering. 2007 Aug; 20(9):902–12.
3. Mohd A, Hindle C, Yusoff WA. Mould filling and pressure distribution for polymer resins. Advanced Materials Research. 2011 Jun; 264-265:771–6.
4. Chang TC, Faison E. Shrinkage behavior and optimization of injection molded parts studied by the Taguchi method. Polymer Engineering andScience. 2001 May; 41(5):703–10.
5. Park K, Ahn JH. Design of experiment considering two-way interactions and its application to injection molding processes with numerical analysis. Journal of Materials Processing Technology. 2004 Feb; 146(2):221–7.
6. Ozcelik B, Ozbay A, Demirbas E. Influence of injection parameters and mold materials on mechanical properties of ABS in plastic injection molding. International Communications in Heat and Mass Transfer. 2010 Nov; 37(9):1359–65.
7. Altan M. Reducing shrinkage in injection moldings via the Taguchi, ANOVA and neural network methods. Materials andDesign. 2010 Jan; 31(1):599–604.
8. Chang TC, Faison E. Shrinkage behavior and optimization of injection molded parts studied by the Taguchi method. Polymer Engineering and Science. 2001 May; 41(5):703–10.
9. Fei NC, Mehat NM, Kamaruddin S, MohamadAriff Z. Improving the performance of reprocessed ABS products from the manufacturing perspective via the Taguchi method. International Journal of Manufacturing Engineering. 2013. 2013; p. 1–9.
10. Shen YK, Liu JJ, Chang CT, Chiu CY. Comparison of the results for semisolid and plastic injection molding process. International Communications in Heat and Mass Transfer. 2002 Jan; 29(1):97–105.
11. Mehat NM, Kamaruddin S. Investigating the effects of injection molding parameters on the mechanical properties of recycled plastic parts using the Taguchi method. Materials and Manufacturing Processes. 2011; 26(2):202–9.
12. Bharti PK, Khan MI. Recent methods for optimization of plastic injection molding process-A retrospective and literature review. International Journal of Engineering Science andTechnology. 2010; 2(9):4540–54.
13. Seong-Ryoel H, Kye-Kwang C. Experimental study for mechanical properties of thermoplastic vulcanizates. Indian Journal of Science and Technology. 2015 Apr; 8(S8):139–43.
14. Manoharan N, Selvakumar V. Cryogenic mechanical properties of PP/MMT polymer nanocomposites. Indian Journal of Science and Technology. 2014 Nov; 7 (S7):16–23.