EXPERIMENTAL INVESTIGATION ON THE RECYCLED HDPE AND OPTIMIZATION OF INJECTION MOULDING PROCESS PARAMETERS VIA TAGUCHI METHOD

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ABSTRACT

Present paper investigates the feasibility of the substitution of recycled plastic with virgin plastic. A plastic tray was made by injection moulding, using virgin and recycled High Density Polyethylene (HDPE), and the process parameters were optimized to yield optimum tensile, compressive and flexural strengths. The effect of selected injection moulding process parameters and their optimal settings have been obtained using Taguchi method. The estimated optimal values of mechanical properties e.g. tensile, compressive and flexural strengths for recycled HDPE are 19.900 MPa, 1.228 MPa and 75.127 MPa respectively. These properties differ only by less than 3% from those for the virgin HDPE. Results of investigation, establish that the recycled HDPE can be feasibly substituted for the virgin HDPE as the mechanical properties of recycled HDPE were found close to the virgin HDPE.

Keywords: Recycled plastics, Taguchi method, ANOVA, Optimization, Injection moulding

1. INTRODUCTION

Plastics are polymeric materials that have large chain like molecules. The invention of plastic in 19th century has, arguably, touched more lives than any other technological breakthrough. Due to the ease of manufacturing, durability and low cost of plastics (Fortelný et. al., 2004) they find increasing use in the manufacture of several types of consumer and industrial product such as in packaging, house hold consumer durables, electrical appliances, shipping containers, pipe sidings, toys and etc.

The world's annual consumption of plastic materials has experienced a spectacular growth from five million tonnes in the 1950s to nearly 100 million tonnes in 2004 (Takoungsakdakun and Pongstabodee, 2007). However, with the escalating consumption of plastic products the pressure to recycle has increased significantly because the production and use of plastics contribute significantly to the environmental pollution and reduction of raw material from renewable resources (Santana and Gondim, 2009; Saidur et al., 2007). Plastics pose increasing threat to environment as they are non-bio-degradable. More waste disposal problems arise due to the legislation being introduced to limit the landfill disposal method (Aurrekoetxea et al., 2001). On the other hand, strict legislation also makes incineration difficult to be implemented as well due to issues such as emission of gaseous pollutants. The dioxins that are produced from the incineration can cause acid rain which destroys vegetation, wildlife, rivers, soils and even architecture. Plastic recycling can start in a production process itself or during or after the product's life. Thus, the process scrap parts that are not contributing into the production usage, i.e., runners, sprues and defective parts should be given high recycling priority as 70% less energy is consumed to recycle plastic products compared to the production of virgin resins (Santos and Pezzin, 2003). Consequently, by recycling thermoplastic polymers damage to environment can be limited.

Injection moulding is one of the most common methods for the manufacturing of plastics. More than 1/3 of all thermoplastic materials are injection moulded and more than half of all polymer processing equipments are for injection moulding (Shen et al., 2007) Studies made by researchers in the past have shown that the quality of injection molded plastics products is greatly influenced by the process parameter. Shen et al (2007) carried out the research on the process variables of distance to gate and part thickness to minimize the sinkmarks and the results revealed that the part thickness is the most crucial factor because increased part thickness eases the flow to compensate for the shrinkage which produces less sinkmarks. The effect of three process parameters (melting temperature, injection speed ratio and injection pressure ratio) for three strokes on contour distortion (Yang et al, 2006) was investigated, as well as tensile and wears properties (Lin et al, 2008) of the polypropylene parts. Deng et al. (2008) used four process parameters (injection time, velocity pressure switch, packing pressure and injection velocity) to discuss the effects of process parameters on plastic product weight. Therefore, determination of an optimum setting of injection molding process is of great concern for the plastics industry because it critically affects the productivity, quality, and cost of production (Chen el. al., 2009).

Generally, the processing parameters of injection moulding are determined by experienced moulding personnel in industry based on trial and error method (Shie, 2008). Indeed, the parameter setting is a highly skilled job based on a long-term experience rather than through a theoretical and analytical approach. To start up a new moulding process, the moulding personnel will determine the processing parameters with intuitive adjustments and modifications by recalling the previous work which is similar to the current one. The tuning operation is usually exercised by using trial and error method and it is repeated until the quality of the moulded parts is found satisfactory in industry. Length of the time for the parameter setting is dependent on the experience of the moulding personnel and it can be very time consuming and unproductive.

The Taguchi method is an effective method targeted at quality improvement for product development as one of the distinctions in the experimental design of Taguchi method is attempted to test a small fraction of all possible combinations by using orthogonal arrays and comes out with the solution (Fowlkers and Creveling, 1995). Therefore, it requires shorter time to obtain the optimal parameter setting in injection moulding. Moreover, the form of experimentation does show the effects of a factor in relationship to varying levels of other factors. With sufficient statistical training and fundamental knowledge of injection moulding process, the moulding personnel can perform the optimization of processing parameters in injection moulding via Taguchi without having years of working experience and extensive training.

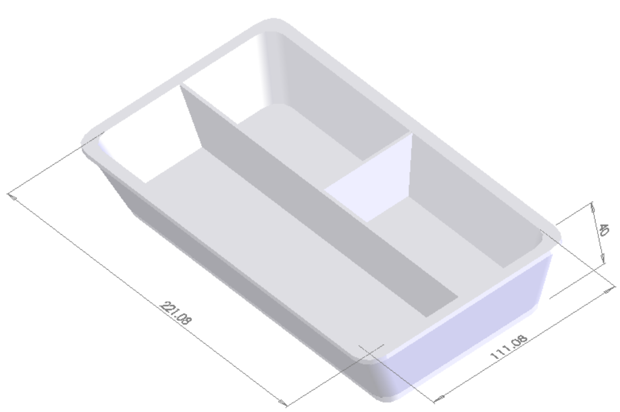

Figure 1: The plastic moulded tray

This paper presents a study on optimizing the injection moulding process parameters that maximizes the tensile, compressive and flexural strength of the plastic tray (as shown in Figure 1) made of virgin HDPE and recycled HDPE. The study was divided in two stages: At the first stage an experiment using virgin HDPE was carried out to identify the mechanical properties of HDPE. In the second stage the experiments were performed using recycled HDPE as raw material. Mechanical properties, e.g. tensile, compressive and flexural strength, of the tray made by recycled HDPE and virgin HDPE were compared to investigate the feasibility of using recycled plastic. Experimentation was performed as per the L_9 orthogonal array of Taguchi method. Finally, ANOVA was performed to further analyze the significance of factors as well as optimal injection moulding process parameters. The details of Taguchi method are discussed in following sections.

2. METHODOLOGY

2.1 Selection of the injection moulding parameters and their levels

A large number of process variable affect the quality of products made by injection moulding process. The process parameters that will influence the results of the experiments have to be recognized before starting the experiments to ease the further analysis in DOE as these parameters will contribute to the variations of results and influence the results due to the adjustments of parameters. All of the parameters involved during injection moulding process can be grouped into four basic categories: temperature, pressure, time and distance. Temperature is the most important of the process parameters, followed by pressure, time and distance. However, these parameters are mutually inter-dependent and changing one requires the adjustment of the other parameters as well.

To visualize the effect of process parameters on the tensile, compressive and flexural strengths of plastic tray, following parameters were selected:Melting Temperature; Holding Pressure; Injection Time; Holding Time. Other parameters such as mould temperature (32°C), injection pressure (50 bars), cooling time (10s) and stroke distance (140 mm) were kept constant during the experimentation. Keeping in view the importance of the main process parameters and their effect on the performance characteristics, working range of the each parameter was carefully chosen to produce the plastic tray of acceptable quality. Each parameter level was then selected carefully and the experiments were performed as per the Taguchi L_9 orthogonal array. Each parameter at levels 3 was considered. Table 1 shows the injection moulding parameters and their levels.

Table 1 Injection moulding parameters and their levels

Factor	Parameter	Unit	Level 1	Level 2	Level 3
A	Melting Temperature	°C	190	200	210
B	Holding Pressure	bar	35	40	43
C	Injection Time	s	0.2	0.6	1.0
D	Holding Time	s	20	25	30

2.2 Selection of orthogonal array

An L_9 OA with four columns and 9 rows was selected and the experiments were performed according to L_9. Table 2 shows the L_9 Orthogonal Array (OA) with the process parameter and their levels.

Table 2: L_9 orthogonal array with the parameters and their levels.

Trial	Melting Temperature	Holding Pressure	Injection Time	Holding Time
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

2.3 Experimentation

The quality of the injection moulded tray was assessed by testing three mechanical properties i.e. tensile test, compression test and flexural test. Each of these tests was performed on 9 plastic trays, which were produced with different parameter settings according to L_9 OA.

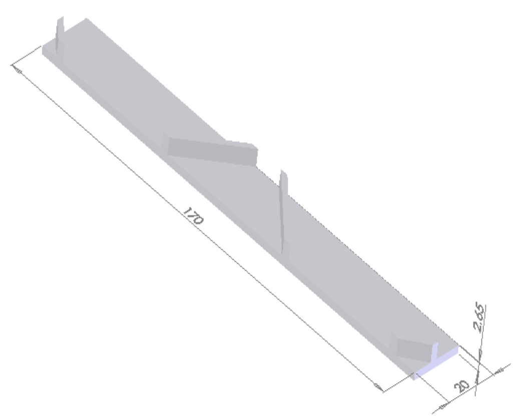

Figure 2 Schematic of the test specimen

High Density Polyethylene (HDPE) is selected as the raw material in which virgin HDPE resins (Etilinas HD5218AA) were manufactured from Polyethylene Malaysia Sdn. Bhd whereas the 100% recycled HDPE pellets were obtained by crushing the virgin HDPE plastic trays using a granulator. The basic physical properties of the virgin HDPE resins are listed as follows: melt flow rate of 18g/10 min, density of 952 kg/m^3, melting temperature of 130 °C, and glass temperature of -110 to -110 °C. Both, virgin and recycled, HDPE pellets were transferred into Battenfeld TM750/210 injection moulding to produce the plastic trays according to L_9 OA. The test specimen were obtained by removing the sides of the plastic tray and the base was cut, using band saw, into 4 specimens in dimension of length 170mm x width 20mm x thickness 2.65mm as shown in Figure 2. After the cutting the rough edges of the specimens were smoothened by sand paper.

2.4 Testing of mechanical properties

The tensile, compressive and flexural strengths of the virgin and recycled HDPE were measured on the INSTRON Table Mounted Universal Testing Machine Series 3367 at room temperature (23°C) and humidity (50%). The tensile strength test is conducted according to ASTM D-638 (ISO 527-1 and 2:1993) standards with a crosshead speed of 5 mm/min, sample rate of 2 points/s, specimen gauge length (G.L.) and extensometer G.L of 100 mm and 25 mm respectively. The compressive strength was measured according to ASTM D-695 with crosshead speed of 1.3 mm/min, sample rate of 2 points/s, both of specimens GL and extensometer GL are set as 100 mm. Finally, the flexural strength was measured according to ASTM D-790 (ISO 178:1993) with crosshead speed of 6.29 mm/min, sample rate of 2 points/s and full scale load range of 30kN.

3. RESULTS AND DISSCUSSION

The performance characteristics i.e. tensile strength, compressive strength and flexural strength of the test specimen were measured corresponding to nine trials of OA. The results were further analyzed by employing S/N ratio and main effects via MINITAB 15 meanwhile ANOVA analyses and the estimation of performance characteristic at the optimum condition were conducted via the pooling up strategy by Roy (1990) due to the limitation of MINITAB 15 which is unable to compute the percentage contribution of each process variable whenever the error degrees of freedom equal to zero. In this case, the percentage contributions are first calculated using sums of squares. Then, the pooling up strategy will be applied if there is any insignificant factor and the percentage contribution will be recalculated using the pure sum of squares. With the main effect and ANOVA analyses, possible combination of optimal parameters was predicted. Finally, a confirmation experiment was conducted to verify the optimal process parameters obtained from the process parameter design.

In addition, a comparison of the mechanical properties of the virgin and recycled HDPE was made to identify the feasibility of the substitution of recycled HDPE with the virgin HDPE. The tensile strength, compressive strength and flexural strength at optimum condition for both virgin and recycled HDPE were evaluated to measure the percentage difference between them to decide whether the recycled HDPE is a suitable substitution for virgin HDPE or not.

3.1 Analysis of S/N Ratio

The signal to noise (S/N) ratio was used to measure the sensitivity of the quality characteristic being investigated in a controlled manner. The S/N ratio was obtained as (Roy, 1990):

$$\eta = -10 \log (MSD) \quad (1)$$

where MSD = mean-square deviation of the quality characteristic.

Bigger-the-better quality characteristic for tensile strength, compressive strength and flexure strength of the plastic tray was considered for which MSD can be expressed as:

$$MSD = \frac{1}{n}\sum \frac{1}{y^2} \quad (2)$$

where n = number of observations and y = the observed data. The average S/N ratios of tensile, compressive and flexural strength of virgin and recycled HDPE were recorded and are given in Table 3.

The raw data are converted to S/N ratios. In the S/N analysis, the multiple results of a trial condition were first transformed into S/N ratios and then analyzed. The quality characteristics for tensile strength for both virgin and recycled HDPE are of bigger-the-better type. Therefore, higher value is desirable because greater S/N ratio will result in smaller product variance around the target value.

3.2 Main Effects

In order to figure out mean response at each level of the factors, the average value of the performance characteristic for each factor at different levels were computed and plotted into a graph as shown in Figure 3, 4 and 5 to provide a better picture of the comparison of the chosen control factors' effects between virgin and recycled HDPE on tensile and compressive strength as well as flexural strength. To compute the main effect of one factor at particular level, e.g. factor A at level 1, the OA has to be referred and sum of the results for trials including factor A at level 1 is obtained, and then the sum is divided by the number of such trials. Figure 3 shows that the most dominant factor for tensile strength for virgin HDPE is the injection time, followed by holding time, melting temperature and holding pressure. The Battenfeld TM750/210 injection moulding machine controls the injection moulding speed by controlling injection time. Higher injection moulding speed is achieved by lower injection time. The injection speed affects the polymer properties such as degree of polymerization, packing density, chain orientation and structure, which in turn affect the mechanical properties of the HDPE. Higher strength is obtained when the injection moulding speed is higher. Thus the injection moulding times has far greater effect on the mechanical properties of the recycled HDPE as compared to the virgin HDPE. The effect of all other parameters is not significant on the tensile strength of recycled HDPE. The influence order of factors for tensile strength of recycled HDPE is holding time, holding pressure, melting temperature and injection time. Figure 4 shows the main effect of process parameters on compressive strength for virgin HDPE and the influence order of for process parameters for the compressive strength of virgin HDPE is injection time, holding time, holding pressure and melting temperature respectively. Furthermore, the compressive strength of recycled HDPE is influenced, to a greater extent, by process parameters levels as compared to the compressive strength of virgin HDPE. Results for the flexural strength (Figure 5) shows the holding time has greater effect for virgin HDPE followed by melting temperature, injection time and holding pressure. On the other hand, melting temperature is the most influencing parameter which affects the flexural strength more than other factors for recycled HDPE. Injection time and holding pressure have turned out to be the second and third influencing factors on flexural strength whereas the holding time is the least significant factor.

3.3 Analysis of Variance (ANOVA)

Analysis of Variance (ANOVA) is a standard statistical technique which is routinely used to provide a measure of confidence. The purpose of the analysis of variance (ANOVA) was to find which parameters significantly affected the quality characteristic. The total sum of square deviation, S_T can be calculated using (Roy, 1990):

$$S_T = \sum_{i=1}^{n} y_i^2 - C.F. \quad (3)$$

where, n is the number of experiments in the orthogonal array, y_i is mean S/N ratio of ith experiment and C.F. is the correction factor. C.F was calculated as:

$$C.F. = \frac{T^2}{n} \quad (4)$$

where, T is the sum of mean S/N ratio.

Factor Sum of Squares, S is calculated as:

$$S_A = A_1^2 / N_{A1} + A_2^2 / N_{A2} - C.F \quad (5)$$

where N_{A1} , N_{A2} and N_{A3} are the number of trails with parameter A at levels 1, 2 and 3, respectively.

S_B, S_C and S_D are calculated in the similar way.

$$S_e = S_T - S_A - S_B - S_C - S_D \quad (6)$$

(Factor sum of squares involved in experiment)

where e = error in experiment

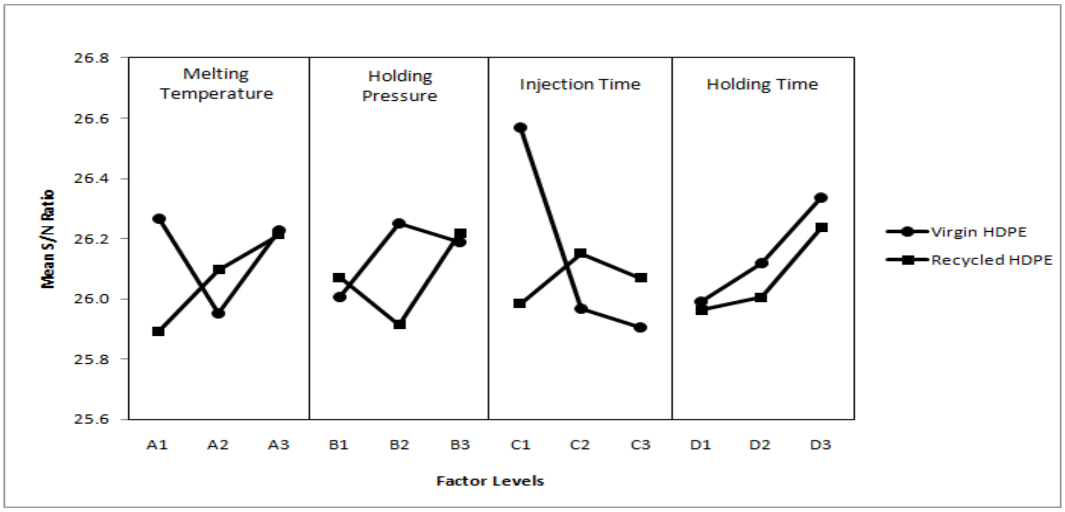

Figure 3: Main effects of tensile strength for virgin and recycled HDPE.

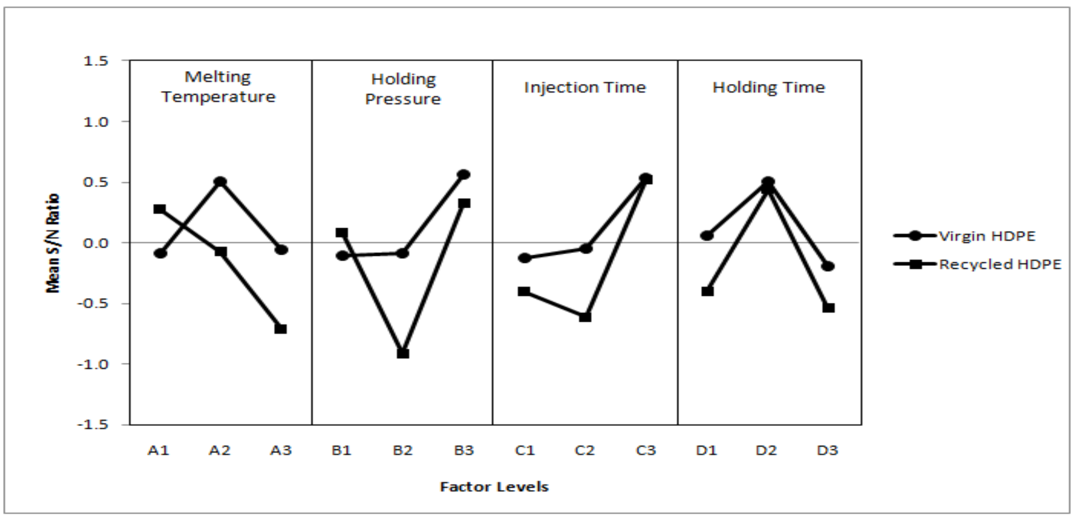

Figure 4: Main effects of compressive strength for virgin and recycled HDPE.

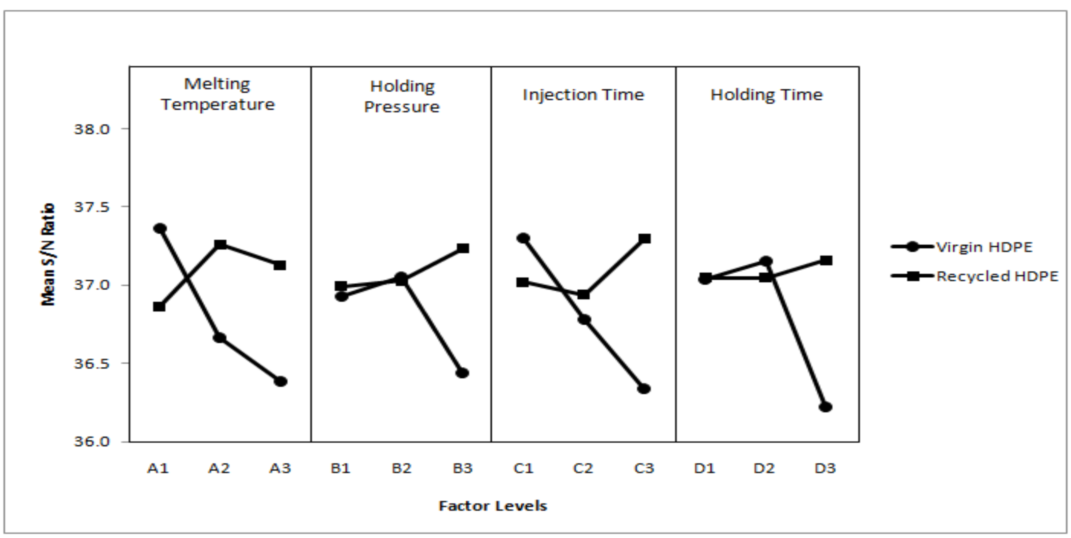

Figure 5: Main effects of flexural strength for virgin and recycled HDPE

Table 3: Average S/N ratio table for virgin and recycled HDPE

Exp. No.	Virgin HDPE						Recycled HDPE					
	Tensile Strength (MPa)		Compressive Strength (MPa)		Flexural Strength (MPa)		Tensile Strength (MPa)		Compressive Strength (MPa)		Flexural Strength (MPa)	
	Exp. Result	S/N	Exp. Result	S/N	Exp. Result	S/N	Exp. Result	S/N	Exp. Result	S/N	Exp. Result	S/N
1	20.859	26.39	0.931	-0.62	81.365	38.21	19.290	25.71	1.006	0.05	68.138	36.67
2	20.313	26.16	0.990	-0.09	78.811	37.93	19.408	25.76	0.965	-0.31	67.792	36.62
3	20.539	26.25	1.054	0.46	62.723	35.95	20.447	26.21	1.133	1.08	73.289	37.30
4	19.545	25.82	0.976	-0.21	64.377	36.17	20.778	26.35	0.929	-0.64	71.585	37.10
5	19.172	25.65	1.078	0.65	68.170	36.67	19.588	25.84	0.958	-0.37	73.956	37.38
6	20.859	26.39	1.133	1.08	71.931	37.14	20.182	26.10	1.096	0.79	73.314	37.30
7	19.522	25.81	1.060	0.51	66.038	36.40	20.312	26.16	1.100	0.83	72.528	37.21
8	22.226	26.94	0.908	-0.84	67.189	36.55	20.284	26.14	0.788	-2.07	71.472	37.08
9	19.791	25.93	1.018	0.15	64.755	36.23	20.753	26.34	0.903	-0.89	71.541	37.09

$$P_A = S_A / S_T \times 100\% \quad (7)$$

P_B, P_C, P_D and P_e are calculated in the similar way.
The total sum of square deviations, S_T was decomposed into two sources: the sum of squared deviation, S_A due to each process parameter and the sum of square error, S_e. The percentage contribution, P by each of the process parameter in the total sum of square deviation, S_T was a ratio of the sum of square deviation, S_A due to each process parameter to the total sum of square deviation, S_T.
Statistically, there is a test called F-ratios (variance ratio) to see which parameters have significant effects on the quality characteristic of plastic tray. For performing the F test, the variance, V_A due to each process parameter needs to be calculated. The variance V_A is equal to the sum of square deviation, S_A divided by the number of degree of freedom associated with the process parameters. Then, the F value for each process parameter is simply the ratio of the variance, V_A to the variance of error, V_e.

Pooling is recommended when a factor is determined to be insignificant by performing a test of significance against the error term at a desired confidence level. In this paper, a confidence level of 90% is proposed to determine the significance of the factors and any parameter with the contribution below than 5% is generally not considered significant. Besides that, the variance ratio, F which is smaller than the F-Table value of 90% confidence level should be pooled as well. Any pooled factor will not be further analyzed in the estimation of optimum performance characteristic and the contribution value will be neglected in the estimation of optimum performance. A review of the percentage contribution presents that there is no error term in ANOVA tables of virgin and recycled HDPE for tensile and compressive strength test (Table 4 – 7) because all error degrees of freedom is equal to zero. As a result, the variance ratio, F and pure sum of squares, S’ cannot be computed and this leads to the direct calculation of percentage contribution from the sum of squares. All factors which have contributed more than 5% to prove themselves are significant. Therefore, there is no pooling of insignificant factors with the error term and all factors are employed in the estimation of optimum performance characteristic to determine the expected performance at optimum condition.
Similar to Table 4 – 7, ANOVA table of virgin HDPE for flexural test (Table 8) has no error term because the error DOF is zero. However, ANOVA table of recycled HDPE consists of holding time factor with the computed percentage contribution of 4.45% which is lower than 5% contribution. Therefore, the one and only parameter, holding time is treated as insignificant factor and it is pooled. The initial ANOVA with zero error term is recalculated after the sum of squares for the factor of injection time is combined with the error term and come up to a pooled ANOVA as shown in Table 9. The variance ratio, F and pure sum of squares, S’ are calculated since the error degrees of freedom is no longer equal to zero. Therefore, the rest of 3 factors are having a value of the variance ratio, F and pure sum of squares, S’ is employed to recalculate the percentage contribution to come up with a new value for each factor, including error term.

Table 4 ANOVA table of virgin HDPE for tensile strength test

Symbol	Factors	DOF	Sum of Squares	Variance	F	Percent
A	Melting Temperature	2	0.1722	0.0861		13.67
B	Holding Pressure	2	0.0963	0.0482		7.64
C	Injection Time	2	0.8068	0.4034		64.02
D	Holding Time	2	0.1849	0.0924		14.67
All others/error		0				
	Total	8	1.2602	0.1575		100.00

Table 5 ANOVA table of recycled HDPE for tensile strength test

Symbol	Factors	DOF	Sum of Squares	Variance	F	Percent
A	Melting Temperature	2	0.1577	0.0788		33.66
B	Holding Pressure	2	0.1384	0.0692		29.55
C	Injection Time	2	0.0424	0.0212		9.06
D	Holding Time	2	0.1299	0.0650		27.74
All others/error		0				
	Total	8	0.4685	0.0586		100.00

Table 6 ANOVA table of virgin HDPE for compressive strength test

Symbol	Factors	DOF	Sum of Squares	Variance	F	Percent
A	Melting Temperature	2	0.6720	0.3360		21.73
B	Holding Pressure	2	0.8835	0.4417		28.57
C	Injection Time	2	0.7909	0.3954		25.57
D	Holding Time	2	0.7463	0.3731		24.13
All others/error		0				
	Total	8	3.0926	0.3866		100.00

Table 7 ANOVA table of eecycled HDPE for compressive strength test

Symbol	Factors	DOF	Sum of Squares	Variance	F	Percent
A	Melting Temperature	2	1.4932	0.7466		18.78
B	Holding Pressure	2	2.6069	1.3034		32.79
C	Injection Time	2	2.1688	1.0844		27.28
D	Holding Time	2	1.6804	0.8402		21.14
All others/error		0				
	Total	8	7.9494	0.9937		100.00

Table 8 ANOVA table of virgin HDPE for flexural strength test

Symbol	Factors	DOF	Sum of Squares	Variance	F	Percent
A	Melting Temperature	2	1.5149	0.7574		29.88
B	Holding Pressure	2	0.6294	0.3147		12.41
C	Injection Time	2	1.3826	0.6913		27.27
D	Holding Time	2	1.5433	0.7716		30.44
All others/error		0				
	Total	8	5.0701	0.6338		100.00

Table 9 ANOVA table of recycled HDPE for flexural strength test

Symbol	Factors	DOF	Sum of Squares	Variance	F	Pure Sum of Squares	Percent
A	Melting Temperature	2	0.2437	0.1218	9.379	0.2177	37.29
B	Holding Pressure	2	0.1005	0.0503	3.868	0.0745	12.77
C	Injection Time	2	0.2137	0.1068	8.223	0.1877	32.15
D	Holding Time	[2]	[0.0260]		Pooled		
All others/error		2	0.0260	0.0130			17.80
	Total	8	0.5839	0.0730			100.00

The next approach is to compare the computed value for F with the F-Table value of 90% confidence level. Since the degrees of freedom for the numerator is 2 and that for the denominator 2, from the F-Table at 0.10 level of significance (90% confidence), the obtained result $F_{0.1}$ (2, 2) = 9.000. Returning to Table 9, the computed F values for the factors of melting temperature, holding pressure and holding time are 9.379, 3.868 and 8.223 correspondingly. Out of three computed F values of the factors, there is only one F value is greater than the limiting values = 9.00 obtained from the F-Table, thus only the contributions of melting temperature is concluded in estimating the expected performance at optimum condition.

3.4 Estimation of performance characteristic at the optimum condition

The expected performance of tensile and compressive strengths, and also flexural strength for both virgin and recycled HDPE plastic tray at optimum condition is estimated through the addition of the contribution of the significant factors and the average performance as defined in (Roy, 1990):

$$y_{predicted}=y_{average}+(y_A-y_{average})+(y_B-y_{average}) +(y_C-y_{average})+(y_D-y_{average}) \quad (8)$$

where $y_{average}$ is the overall average response for the orthogonal array and y_A, y_B , y_C and y_D are the response average for parameters A, B, C and D respectively at optimal levels. After obtaining the optimal level of the injection moulding parameters the next step is to verify the improvement of the performance characteristics using this optimal combination. Table 10 and 11 compares the results of the confirmation experiments using the optimal injection moulding parameters for virgin and recycled HDPE. The verification experiments yield less than 10% errors indicating that the predicted and the experimental data were in unanimity and the Taguchi method is proved to be a very useful tool in performing the statistical experimental design to lessen the experiments which require horde of analysis to the optimization and is able to obtain the accurate prediction as well.

Table 10 Confirmation runs of mechanical properties test for virgin HDPE

Optimal Condition	Melting Temperature (°C)	Holding Pressure (bar)	Injection Time (s)	Holding Time (s)	Estimation/ Experiment
Tensile Strength (MPa)	190	40	0.2	30	22.33/20.48
Compressive Strength (MPa)	200	43	1.0	25	1.223/1.201
Flexural Strength (MPa)	190	40	0.2	25	83.68/81.67

Table 11 Confirmation runs of mechanical properties test for recycled HDPE

Optimal Condition	Melting Temperature (°C)	Holding Pressure (bar)	Injection Time (s)	Holding Time (s)	Estimation/ Experiment
Tensile Strength (MPa)	210	43	0.6	30	21.42/19.90
Compressive Strength (MPa)	190	43	1.0	25	1.268/1.228
Flexural Strength (MPa)	200	43	1.0	30	76.71/75.13

3.5 Comparison of Performance between Virgin and Recycled HDPE

The comparison of mechanical properties between virgin and recycled HDPE is done to assess the feasibility of using recycled HDPE as a substitute for virgin HDPE in plastic industry. It is evident from Table 12 that the tensile strength of virgin HDPE is very slightly better than that of the recycled HDPE, the difference of flexural strength for virgin and recycled HDPE is nearly 8%. However, the recycled HDPE has better compressive strength than virgin HDPE with the difference of 2.20%. Furthermore, the use of recycled HDPE reduces the adverse effect on the environment. Consequently, it is implied that the mechanical properties of the recycled HDPE tray are in very good agreement to mechanical properties of the virgin HDPE which reflected that the mechanical properties of recycled HDPE was not affected by the recycling process. It can be concluded that the use of recycled HDPE in place of virgin HDPE is economically and environmentally viable. The study reveals that the mechanical properties of virgin HDPE are slightly better than those of the recycled

HDPE, it may be because of impurities got in to the recycled HDPE during crushing and reheating process (Cruz et. al., 2004). To produce the recycled pellets the trays produced from virgin HDPE were recycled by crushing and granulating. During this recycling process some contaminants i.e. air bubbles and impurities might have crept in. This may be one of the reasons due to which the mechanical properties of the recycled HDPE are slightly lower than the virgin HDPE. The results show different optimal conditions for injection moulding of recycled and virgin HDPE. During recycling, the trays, which were made by virgin HDPE using different parameter setting as per the OA, were crushed and mixed together. The trays produce by different parameter settings have different structure. Due to the mixture of recycled HDPE pellets with different structure lead to the changes of the melt flow index (Cruz et al., 2004). This explains the reason for different optimum parameter settings for virgin and recycled HDPE.

Table 12 Comparison of Performance for Virgin and Recycled HDPE at Optimum Condition

Criteria	Virgin HDPE	Recycled HDPE
Tensile Strength (MPa)	20.48	19.90
Compressive Strength (MPa)	1.201	1.228
Flexural Strength (MPa)	81.67	75.13

4.0 CONCLUSION

An experimental design based on the Taguchi method was appropriate in enhancing the tensile, compressive and flexural strength of recycled HDPE by optimizing the processing variables with a minimum number of experiment trials. For the factors selected in the experiment, melt temperature was found to be the decisive factor affecting the tensile and flexural strength of recycled HDPE meanwhile holding pressure has the largest influence on the compressive strength. Through the experimental investigation of recycled HDPE has proved that it is a feasible to serve as an environmental friendly alternate material for virgin HDPE due to closeness of its mechanical properties at the optimum processing condition. Therefore, large-scale practice of plastic recycling is commercially viable and it is encouraged to establish the green industry not only for the reduction of raw material cost but also to preserving the environment.

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