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Hybridization Method for Injection Moulding Process, Optimization with Melting Temperature Parameters

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Abstract

Due to the production of plastic products with complex shapes, the plastic injection moulding manufacturing method has recently received a lot of attention. In order to improve manufacturing performance, the cycle time for the injection moulding process has been reduced, the defect known as dimensional warpage that results from temperature differences inside the mould has been reduced, and the mechanical tensile strength of the material has been increased so that it cannot warp easily. The plastic injection molding manufacturing process has drawn a lot of attention lately since it produces plastic goods with intricate shapes. In order to enhance manufacturing performance, the injection molding process's cycle time has been shortened, the dimensional warpage defect which arises from temperature variations inside the mold has been lessened, and the material's mechanical tensile strength has been raised to prevent warping. Warpage is a dimensional flaw of the product; hence a longer cycle time is needed. We risk a decline in production if we do this. Additionally, a superior product should have a higher tensile strength. A suitable experimental design is prepared using the Taguchi Orthogonal array to determine the trade-off analysis between quality and productivity. The Taguchi orthogonal array is used to select an appropriate experimental design, and utilising the experimental data, the entropy measurement method is then used to look into the choice of response behaviour. The utility idea is then used to determine how the processing parameters connect to the various processes. The best process parameters that can improve plastic products' tensile strength that can be maximized were found at the end of the manuscript to reveal the optimized parameters.

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INTRODUCTION

The procedure of injection moulding is typically used to create identical polymer parts from a mould. This procedure involves injecting the molten polymer into the mould at a specific pressure and speed so that it can take on the shape of the mould [1]. When creating high-quality products, process variables and the material used to make the mould are both crucial. The process parameters must be optimised to generate high-quality product quickly [2]. The process conditions have an impact on the product's strength, warpage, durability, surface roughness, aesthetics, and other qualities [3]. The process conditions for injection moulding include the following: injection pressure, holding pressure, cooling time, injection speed, injection temperature, and mould temperature [4]. Process variables that have been optimised deliver high-quality products faster. However, obtaining optimised parameters is a challenging task that depends on the operator's experience [5]. Depending on the type of monomer used, the polymers used to create the products exhibit a variety of characteristics. Most of the time, the conditions for making the polymers are determined based on a literature review, and some of them are then picked using the trial-and-error method [6]. However, the trial-and-error approach is time-consuming and expensive. Numerous equations were developed for the analytical method of determining optimised process parameters, but due to the complexity of the injection moulding process, they were unable to provide a solid solution [7]. Researchers have worked hard to introduce various optimisation approaches because of this [8]. The research on the optimisation of process parameters for injection moulding using various materials has been summarised in the literature addressed in the next section [9]. The typical process parameters that need to be observed and/or managed at each cycle are shown in Table 1 [10]. You can categorise a variable into two types—controllable and consequential—to make it easier to pinpoint the one responsible for the static stability brought on by the principal interference [11].

Ramesh et al. (2015) [12] examined the sink marks, weld lines responses with the help of mold temperature, melt temperature, nozzle temperature and injection pressure as process parameters to study the headlight of the car as the product with the help of Taguchi's method. The study concludes that the clear light of the headlight can be control by nozzle temperature should be much less than the melt temperature to avoid the sink marks and vulnerability of the weld lines. Mathivanan et al. (2010) [13] present Sink marks depth as response study with the help of melt temperature, mold temperature, packing pressure, packing time, Rib to wall ratio, Rib to gate system and injection time with the help ofTaguchi's experimental method. Sink marks depth can be minimized by minimizing Rib distance from the feed point. Few researchers studied the Warpage and sink marks responses with the help of rib cross-section, rib layout angle, melt temperature, mold temperature and packing pressure with the help of Taguchi's method. The study aim is to compare the Warpage and sink marks depth effect on different plastic materials PolyCarbonate/ Acrylonitrile butadiene styrene, Polyoxymethylene, ylon-66. Based on the resulting warpage is found to be minimum in the PolyCarbonate/ Acrylonitrile butadiene styrene and sink index is found to be minimum ylon-66. OzceHk et al. (2010) [14] experimentally analyze tensile strength, Impact strength as the response of plastic material

Acrylonitrile-Butadiene-Styrene by considering melt temperature, injection pressure, packing pressure and packing time as the process parameters. In their study of the experiment, they found that as packing pressure increases the tensile strength of material increased. In their study of the experiment, they found that as packing pressure improved the tensile strength of a material is increased.

Some researchers investigated light transmission, surface waviness and surface finish on the optical quality of lenses as the response by considering melt temperature, mold temperature, injection pressure, packing pressure as process parameters. In their studies, they found that injection pressure influenced responses. Warpage dimensional defect was analyzed as a response of plastic products with the help of process parameters melt temperature, packing pressure and injection time by Taguchi's method. In their studies, they conclude that as the melt temperature rises, the warpage is less in plastic products. Karasu et al. (2014) [15] investigated Warpage as the response by considering melt temperature, mold temperature and packing time. Their study shows that Taguchi's method has advantages over other methods by considering the time and cost of the product manufacturing process. Ghazali et al. (2011) [16] investigated the warpage as response with the help of melt temperature, packing pressure, packing time, filling time by Taguchi's method on ylon 66 plastic material production process manufacturing. In their study, they found that as melt temperature and packing time increases warpage get minimized in nylon 66 plastic products. It was experimentally analyzed warpage response with the help of Short-shot size, water pressure, water temperature, and water injection delay time, melt temperature, mold temperature and holding time as process parameters with the help of Taguchi 's method on Glass-fiber filled polypropylene composites. In their study, they note that as the melting temperature increases,

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warpage is minimized in polypropylene composite products. Ahmad et al. (2009) [17] investigated warpage as the response by considering melt temperature, mold temperature, packing pressure, packing time on Acrylonitrile butadiene styrene plastic material product with the help of Taguchi's method. In their study, they find that melt temperature and mold temperature influential factor for control warpage of Acrylonitrile butadiene styrene plastic products.

Hazwan et al. (2017) [18] examine the Warpage as the response by considering melt temperature, packing pressure, cooling time, coolant temperature as process parameters with the help of rotatable central composite design response surface method. In their analysis, they find that cooling temperature is the most effective factor, which affects the dimensional defect warpage. They also investigate shrinkage and cycle time as response with the help of melt temperature, packing pressure with the help of Center composite design and Latin Hypercube design of response surface method. In their analysis, they find that melt temperature contribute significantly in cycle time and shrinkage. Yin et al. (2011) [19] inspect Warpage and clamp force as the combined response by considering melt temperature, mold temperature, packing pressure, packing time, cooling time as process parameters with the help of Backpropagation and Genetic algorithm method. In their research, they find that as packing pressure increases, the Warpage gets reduced and the clamping force needs more to keep the material in the mold. Mebat et al. (2012) [20] evaluate the shrinkage defect with the help of melt temperature, packing pressure, packing time, cooling time as process parameters with the help of Taguchi's method coupled with GRA. The melt temperature in their sh1dy is the most effective processing parameter. A few authors surveyed on the product weight as response with the help of injection velocity, injection time, packing pressure as process parameters. In their studies, they find that packing pressure is a critical contributing factor to the increase in product weight. Various researchers [21] used worked on optimization of parameters and reported that at optimum parameters better results are obtained.After extensive study of the literature, there are many gaps have been found out in the field of processing of injection molding process are:-

1. The optimization of process responses cycle time of Injection molding process and Tensile strength of plastic components materials have been studied in the selected parameters range based on literature review with the help of Taguchi and advanced optimization techniques such as Desirability Function etc..
2. Since there are many studies have been done in the polypropylene plastic components materials, but a majority of researchers focused on the limited number of process parameters on the responses of an injection molding process, but none of them represented an optimization of input process parameters and factors with the advance hybridization techniques.
3. The research on polypropylene plastic components manufacturing has never been attempted by the researchers with the help of advanced hybridization techniques like Taguchi with desirability function.
4. Multi-response optimization of the injection molding process is also much focused which has been given less consideration in the previous studies.
5. Design of experiment (Taguchi's method) is used very rarely is used by the researches for experimentation and then optimization by advance hybridization methods.

Table 1. Process variables of the Injection molding process.

Pressures	Temperature	Times	Speeds	Strokes
Holding	Melt	Ejection	Injection	Melt cushion
Injection	Mold surface	Mold close	Screw	Serve stroke
Hyd. back	Barrel	Mold open	Mold close	Mold open
Ejection	Component	Cooling	Mold open	Change over
Mold safety	Material	Cycle	Screw return	Position
Nozzle	Environment	Screw recovery	Ejection	Decompress.
Oil	Oil	Hold press.		

MATERIAL AND METHODS

The actual image of experimental set up is shown in Figure 1.

However, the Machine Specification is listed in Table 2.

The use of the organization to carry out the experiments Taguchi orthogonal array and the process parameters are Melt temperature, packing pressure, injection pressure and packing time selected and three levels, in experiments are performed using the combination of virgin polypropylene as 100% each, which is shown in Table 3.

Multi-response optimization of 100% Virgin Polypropylene composition with hybridization of Taguchi with Desirability Function

Different Desirability index is calculated based on the type of quality characteristics for all reactions. In this study Tensile strength is Higher the better type characteristics and Cycle Time is Lower the better characteristics. The Optimized desirability value 100% Virgin Polypropylene composition is shown in Table 4. Further, the Eigenvectors and Weight Calculation is given in Table 5

Figure 1. Injection molding machine used for experiment (CIPET)

Table 2. Machine specification.

S N.	Specification	Units	Value
1	Injection capacity Maximum (GPPS)	gms	116
2.	Injection Pressure Maximum	bar	2360
3.	Injection rate into Air	cc/sec	80
4.	Injection Screw stroke	mm	159
5.	Screw diameter	mm	32
6.	Screw LID ratio	LID	20
7.	Screw speed	Rpm	266
8.	Shot Size (Theoretical)	cc	128

Table 3. Process Parameters and levels for Virgin polypropylene 100 %.

Process parameters	Abbreviation	Level 1	Level2	Level3
Packing pressure MPa	Pp	40	50	60
Injection pressure MPa	IP	20	25	30
Melt temperahlfe ^{0}c	MT	220	230	240
Packing time in Sec	PT	4	8	12

Table 4. Optimized desirability value 100% Virgin Polypropylene composition.

S N.	MT (^{0}C)	IP (Mpa)	PP (Mpa)	PT (Sec)	Desirability for tensile strength (d_1)	Desirability for cycle time(d_2)
1.	220	20	40	4	0.928571	0.112819
2.	220	25	50	8	0.785714	0
3.	220	30	60	12	0.571429	0.148197
4.	230	20	50	12	0	0.073098
5.	230	25	60	4	0.928571	0.043265
6.	230	30	40	8	0.714286	1
7.	240	20	60	8	0.714286	0.148197
8.	240	25	40	12	0.5	0
9.	240	30	50	4	1	0.060125

Table 5. Eigenvectors and Weight Calculation for 100%Virgin Polypropylene composition.

Responses	Eigenvectors		
	First principal component	***Second principal component***	***Weight determination***
Cycle time	0.707	0.707	0.5
Tensile Strength	0.707	-0.707	0.5

Table 6. Weightage Desirability value of 100% Virgin Polypropylene composition

S N.	Weightage desirability value for cycle time	Weightage desirabilityvalue for tensile stremi:th	Overall desirability value
I.	0.963624	0.335886	0.568918
2.	0.886405	0	0
3.	0.755929	0.384963	0.539449
4.	0	0.270367	0
5.	0.963624	0.208001	0.4477
6.	0.845154	1	0.919323
7.	0.845154	0.384963	0.570398
8.	0.707107	0	0
9.	1	0.245203	0.495 I 8

Based on data, after determining the weight, the utility value of the responses is calculated by the product of the desirability value and weight. The value of Overall Desirability is listed in Table 6.

RESULT AND DISCUSSION

The effect of each processing parameter has been discussed with the surface and contour plot on the response like Tensile strength and Cycle time, etc.

Polypropylene is 100%

Figure 2 (a) represents the contour plot, and Fig.2 (b) represents the surface plot of Tensile Strength in relation to the processing parameters IP and MT. From this figure, it can be observed that maximum Tensile Strength can be achieved at Injection Pressure, at a high level and Melt Temperature at, medium level for thin shell semi-crystalline plastic materials

Figure 3 (a) represents the contour plot and Figure 3 (b) represents the surface plot of Tensile Strength in relation to the processing parameters PP and MT. From this figure, it can be observed that maximum Tensile Strength can be achieved at Packing Pressure, at a low level and Melt Temperature, at the median level for thin shell semi-crystalline plastic materials.

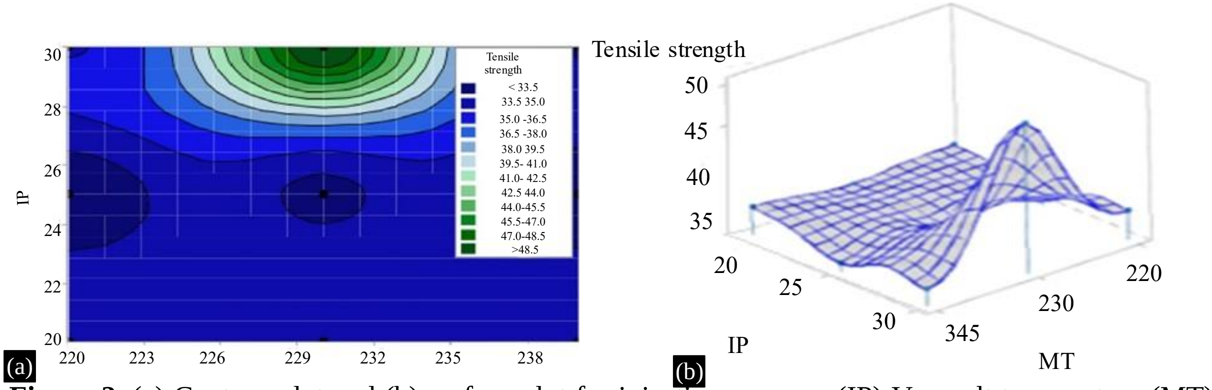

Figure 2. (a) Contour plot and (b) surface plot for injection pressure (IP) Vs. melt temperature (MT) for tensile strength of virgin polypropylene.

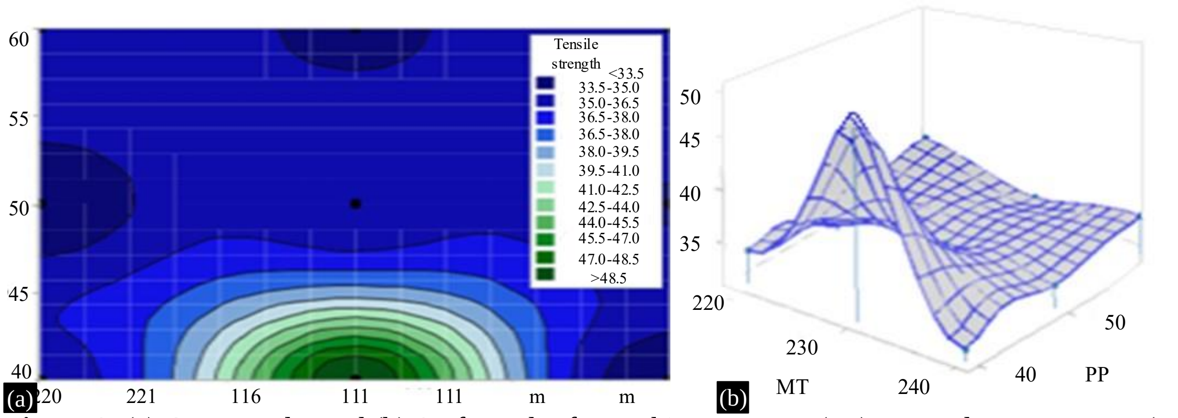

Figure 3. (a) Contour Plot and (b) Surface Plot for Packing Pressure (PP) Vs. Melt Temperature (MT) for Tensile strength of Virgin Polypropylene.

Figure 4 (a) represents the contour plot and Figure 4 (b) represents the surface plot of Tensile Strength in relation to the processing parameters PT and MT. From this figure, it can be observed that maximum Tensile Strength can be achieved at Packing Temperature, at medium level and Melt Temperature at the medium level for thin shell semi-crystalline plastic materials.

Figure 5 (a) represents the contour plot and Figure 5 (b) represents the surface plot of Tensile Strength in relation to the processing parameters PP and 'IP. From this figure, it can be observed that maximum Tensile strength can be achieved at Injection Pressure, at a high level and Packing Pressure, at a low level for thin shell semi-crystalline plastic materials.

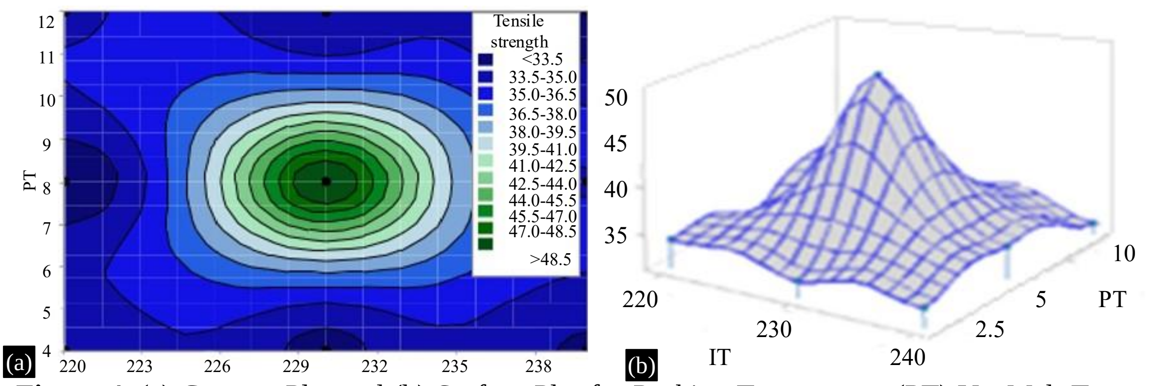

Figure 4. (a) Contour Plot and (b) Surface Plot for Packing Temperature (PT) Vs. Melt Temperature (MT) for Tensile strength of Virgin Polypropylene.

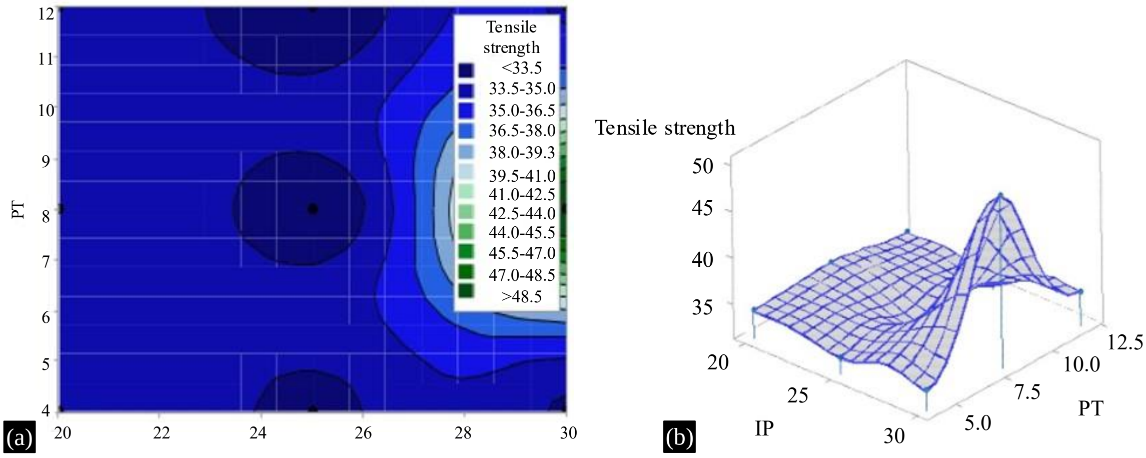

Figure 5. (a) Contour plot and (b) surface plot for packing time (PT) Vs. injection pressure (IP) for tensile strength of virgin polypropylene.

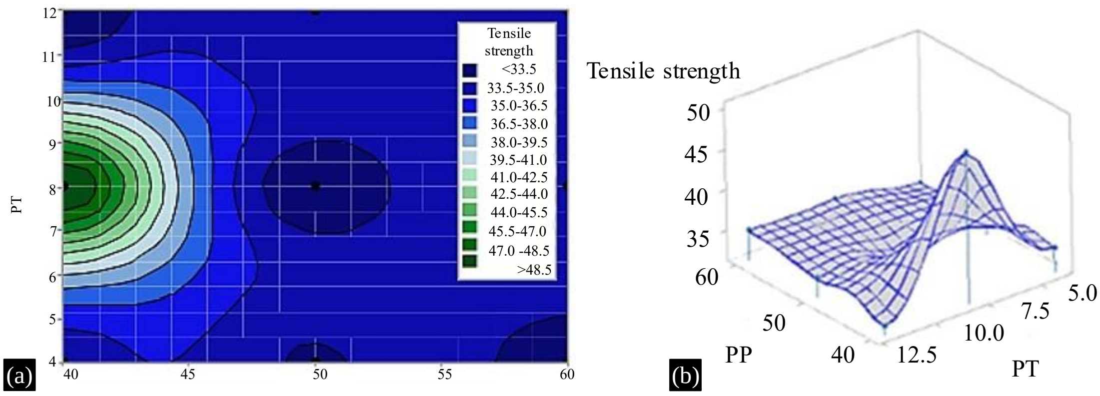

Figure 6. (a) Contour plot and (b) surface plot for packing time (PT) Vs. packing pressure (PP) for tensile strength of virgin polypropylene.

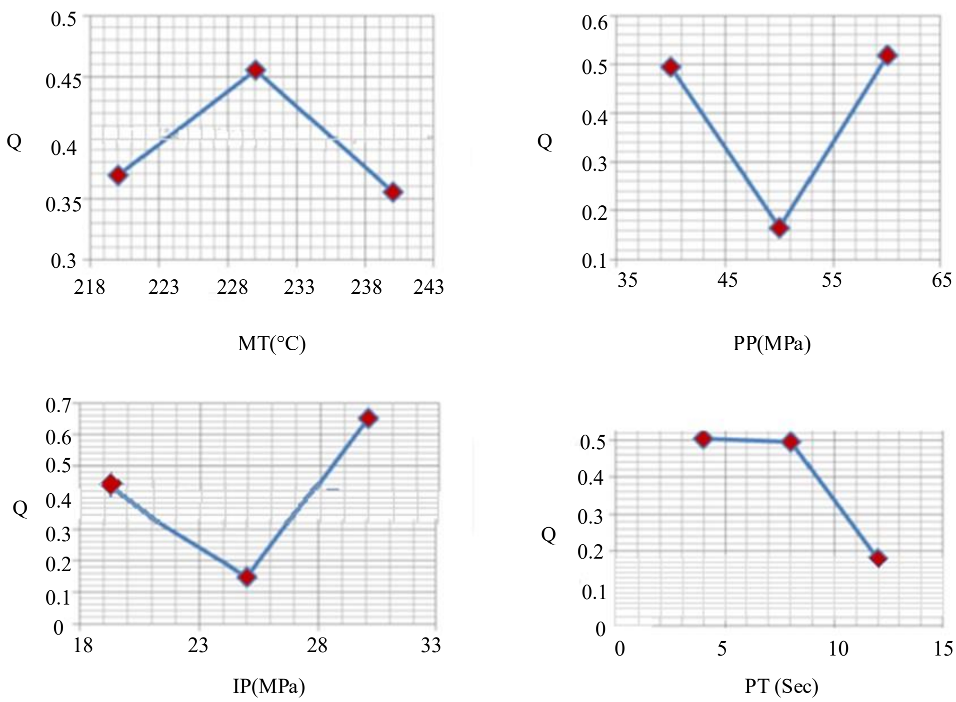

Figure 7. Evaluation of optimal setting for overall desirability value for virgin polypropylene.

Table 7. Optimal setting for the 100% Virgin Polypropylene Composition by Desirability Function.

Melt temperature (^{O}C)	Injection pressure (MPa)	Packing pressure (MPa)	Packing time (Sec)
230	30	60	4

Table 8. Optimal setting for the Tensile Strength and Cycle Time for Virgin Polypropylene.

Melt temperature (^{O}C)	Injection pressure (MPa)	Packing pressure (MPa)	Packing time (Sec)	Tensile strength (MPa)	Cycle time (Sec)
230	30	60	4	51.34	22

Figure 6 (a) represents the contour plot and Figure 6 (b) represents the surface plot of Tensile Strength in relation to the processing parameters PT and PP. From this figure, it can be observed that maximum Tensile Strength can be achieved at Packing Time, at medium level and Packing Pressure, at a low level for thin shell semi-crystalline plastic materials.

Figure 7 is presented on the basis of overall desirability value calculation. It has Melt Temperature at Level 2, Packing Pressure at Level 3, and Injection Pressure at Level 3, Packing Time at Level l has higher the better desirability value.

Table 7 depicts Optimal setting for the 100% Virgin Polypropylene Composition by Desirability Function, whereas Table 8 shows Optimal setting for the Tensile Strength and Cycle Time for Virgin Polypropylene. By test of an experimental run, the error of experiment is found out to be 3%, which shows that this method is suitable for the maximization of Tensile strength and minimization of Cycle time of the plastic products. Based on analysis both methods are suitable for the process.

CONCLUSIONS

The following conclusions have been drawn from the study. To obtain optimal process parameter that could provide better Tensile Strength of the plastic products

Tensile Strength can be maximum

- Melt temperature at 230°c and 30 MPa injection pressure
- Melt temperature at 230°c and packing Pressure at 40 MPa
- Melt temperature at 230°C and 7.5 sec .packing time
- Injection pressure 30 MPa and 40 MPa packing pressure
- Injection pressure 30 MPa and 7.5 sec. packing time

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