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Optimization of Tensile Strength and Shrinkage on R-Abs and Abs Blend using Taguchi and Pcr-Topsis Method

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The growing focus on ecological balance has led to the exploration of alternative materials and recycling methods, such as blending recycled ABS with virgin ABS. This approach not only reduces plastic waste but also enhances the composite's mechanical properties and overall quality. Tensile strength is crucial for the performance and quality of the final product. The Taguchi method, a statistical technique for designing experiments, has been successfully applied to optimize injection molding processes. This study uses Taguchi and PCR-TOPSIS techniques to maximize the tensile strength of a mixture of recycled and virgin ABS and minimize shrinkage. The research findings indicated that the ideal parameters were achieved by combining a mixing proportion of 70:30, a mold temperature of 60°C, a melt temperature of 230°C, and a packing pressure of 150 Bar. Among the four criteria, the packing pressure is the most essential factor.

Keywords: alternative material, recycle, taguchi method, PCR-TOPSIS, optimization.

1. Introduction

The world's increasing focus on preserving ecological equilibrium has spurred numerous industries to explore alternative materials and recycling methods [1], [2]. Acrylonitrile butadiene styrene (ABS), a thermoplastic polymer renowned for its versatility and durability, stands out as one material that has garnered significant acknowledgement [3]–[5]. By blending recycled ABS (r-ABS) with virgin ABS, we not only contribute towards tackling environmental concerns by decreasing plastic waste but also unlock the potential for enhancing the resulting composite's mechanical properties and overall quality.

The tensile strength of a material is a fundamental mechanical property that determines its ability to resist axial force without undergoing distortion. The tensile strength of the materials used in injection molding has a substantial impact on the performance and quality of the finished product. Reference [6] and [7]emphasize the importance of optimizing the processing parameters in order to achieve the required tensile strength. Reference [6] employs the Six Sigma methodology, whereas [7] adopts the Taguchi approach. Reference [8] and [9] conducted a study to investigate how various processing parameters affect the weld line tensile strength of injection molded items. The parameters encompassed variables such as melt and mold temperature, injection speed, and cross-sectional form.

The shrinkage in injection molding is influenced by various factors, including material properties, processing conditions, and mold and product design. As stated in reference [10], microstructures have the ability to reduce shrinkage, especially when the packing pressures are kept at a low level. The significance of melt temperature is acknowledged by [11], who also identified holding pressure as a critical variable. [12] revealed the impact of processing variables, specifically packing pressure and melt temperature, on the shrinkage of thin-wall parts. Gas counter pressure and holding pressure are two techniques that can be employed to reduce shrinkage. This topic has been investigated by both [13] and [11]. [14] and [15] provided a summary of the factors that affect shrinkage, including material properties, processing conditions, and mold and specimen design. The study conducted by reference [16] assessed the influence of process factors on the occurrence of shrinkage and warpage.

To achieve the needed mechanical qualities and reduce shrinkage defects, these investigations underlined the important role of tensile strength and shrinkage minimization in injection molding. They additionally highlighted the necessity of carefully considering processing parameters.

Enhancing the tensile strength of recycled and virgin ABS blends is crucial to broaden their use in multiple sectors, such as automotive, electronics, and consumer goods. Achieving exceptional tensile strength in these blends necessitates adopting a methodical methodology that examines several factors affecting the material's mechanical properties.

The Taguchi method, a dependable statistical tool for designing experiments (DOE), has demonstrated its utility in optimizing various engineering applications [17]–[21]. The capacity of this method to simultaneously analyze multiple parameters and their interactions has made it a popular choice for optimizing materials in the field of material science and polymer blends. As a result, this leads to experimentation that is more efficient and cost-effective. The Taguchi approach has been effectively utilized in numerous research to optimize injection molding operations. Both studies cited in references [6] and [22] utilized the Taguchi method to improve the tensile strength and reduce shrinkage, respectively. References [23] and [24] also employed the Taguchi approach to decrease shrinkage and minimize faults. References [25] and [26] built upon this research by integrating fuzzy quality assessment with PCR-TOPSIS to enhance the optimization of the procedure. Finally, researchers [27] and [28] utilized the Taguchi method to minimize shrinkage and warpage in plastic injection molding. These studies collectively show that the Taguchi approach is useful in optimizing injection molding operations.

This study systematically use the Taguchi and PCR-TOPSIS approaches to optimize the tensile strength of a composite material made from a blend of recycled and virgin ABS, while simultaneously minimizing shrinking. This study aims to comprehensively examine the impact of process parameters, including blend composition, mold temperature, melt temperature, and packing pressure, in order to determine the conditions that maximize tensile strength and minimize shrinkage. The research findings enhance our comprehension of the mechanical properties of blended ABS made from recycled and virgin materials, and offer valuable recommendations for the advancement and manufacturing of high-performance polymeric composites.

The study aims to facilitate the development of sustainable materials and processes that correspond to global standards for being resource-efficient, economical, and environmentally friendly. Significant new information from this study may enhance the sustainability of manufacturing processes. The research discusses the optimal method for integrating recyclable materials and enhancing the mechanical properties associated with their application, delivering them valuable for numerous applications.

2. Methods and Methodology

As seen in **Error! Reference source not found.**, virgin ABS and r-ABS resin were the materials used in these studies. The 90:10, 80:20, and 70:30 ratios were chosen, and the ABS material was put together and mixed accordingly. The specimens for the tensile test were made using a Fanuc Roboshot S-2000i injection molding machine, which operates within a temperature range of 200°C to 260°C.

Furthermore, the melt temperatures were set at 200°C, 230°C, and 260°C, while the mold temperature was modified to 50°C, 65°C, and 80°C. The packing pressure was set to 100, 150, and 200 Bar. The processing was carried out using identical equipment, utilizing the same configuration settings and level, as specified in **Error! Reference source not found.**. **Error! Reference source not found.** presents the attributes of the ABS material.

Table 1 Control Factor and Level

Code	Control Factor	Level		
		1	2	3
A	Mixing Proportion	70% : 30%	80% : 20%	90% : 10%
B	Mold Temperature	50˚C	65˚C	80˚C
C	Melt Temperature	200˚C	230˚C	260˚C
D	Packing Pressure	100 Bar	150 Bar	200 Bar

Table 2 Properties of ABS

ABS Properties			
Tensile Strength (at break)	31 Mpa	-	43 Mpa
Shrinkage Rate	0,7%	-	1,6%

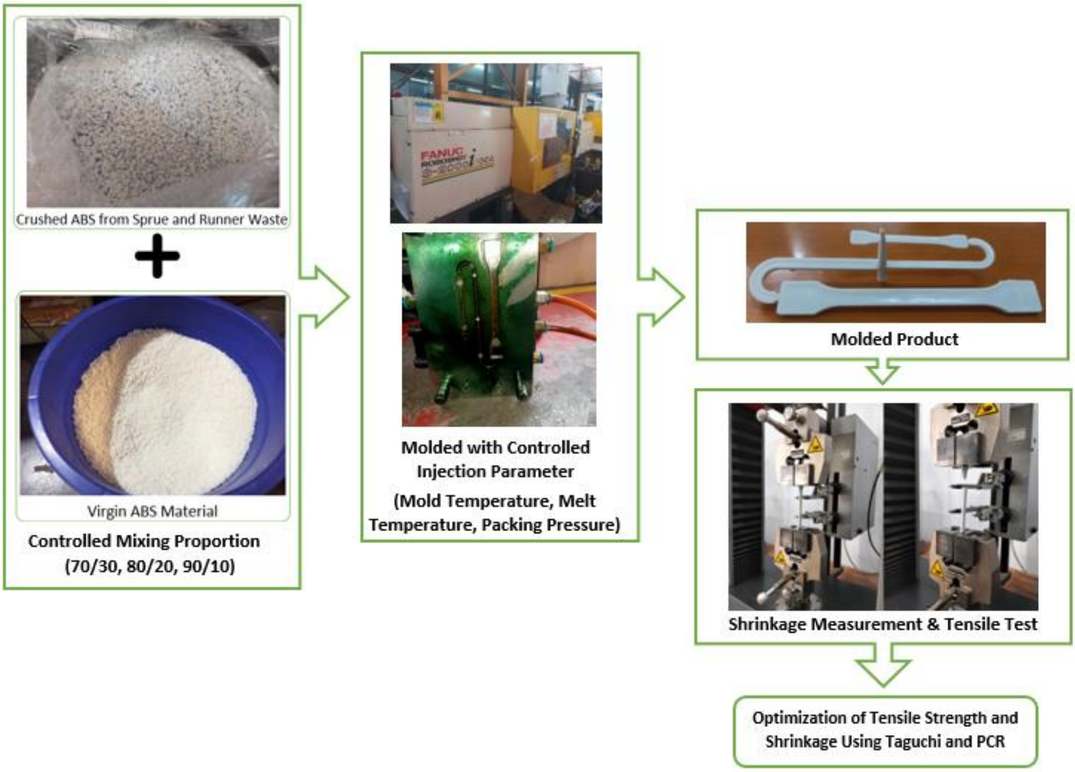

Figure 1 Experiment Flow

As a result, developing an optimal relationship and combination between variables is critical when producing a top-notch and cost-effective plastic part that lacks secondary or finishing operations.

Several injection trials were conducted following the Taguchi method, which was used to create the Orthogonal Array (OA). The experimental factors were the mixing percentage (A), mold temperature (B), melt temperature (C), and packing pressure (D). Table 3 presents the levels and their corresponding values. The trials ensured that every processing condition achieved a state of stability, which required at least thirty minutes. Each run involved the extraction of a total of 10 samples, out of which 5 were specifically chosen for the purpose of conducting tensile tests.

Table 1 Experimental Layout - L9 (3^4) OA

Experiment	Process Parameters			
	A	B	C	D
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

3. Result and Discussion

3.1 Result of Tensile Test

Several studies have investigated how The injection molding process settings have an impact on the mechanical qualities of ABS produced products. Reference [29] and [30] both concluded that higher material temperature and injection pressure could improve tensile strength, while [31] identified melt temperature, packing pressure, and cooling time as crucial factors. Reference [32]–[36] also explored various aspects such as melt and mold temperatures, injection speed, infill density for improving mechanical properties in either injection molding or 3D printing processes.

These studies demonstrate that optimizing process parameters is crucial for attaining the appropriate mechanical characteristics in molded ABS products. They provide valuable insights into the specific parameters that should be considered and manipulated to enhance the strength and reliability of ABS materials.

Zwick UTM Z020 serves as the testing machine used in this study. Tensile testing was performed on the ASTM D638 tensile standard using 5 dumbbell-shaped samples. The samples were acquired by the injection molding technique and had measurements of 160 mm in length, 13 mm in breadth, and the thickness is 3.5 mm. The gaps across the arms and the tip of the measurement section should be sufficiently large to ensure that the larger ends do not hinder the deformation of the measuring section. The gauge's span should exceed its diameter. Disregarding doing this will result in a stress state that is more intricate than mere tension. The average results of five separate experiments were evaluated. The experiment's pieces are depicted in Figure 1, while the outcome of the tensile test results is displayed in Table 2.

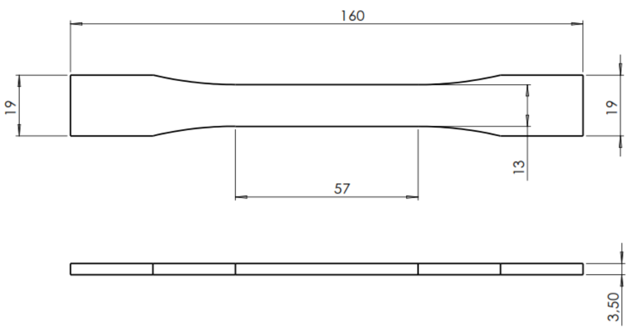

Figure 1 Tensile Test Part

Table 2 Result of Tensile Test

Run #	Injection Molding Parameters				Mean Tensile Strength (MPa)
	A	B	C	D	
1	70% : 30%	50˚C	200˚C	100 Bar	31.33
2	70% : 30%	65˚C	230˚C	150 Bar	31.96
3	70% : 30%	80˚C	260˚C	200 Bar	35.59
4	80% : 20%	50˚C	230˚C	200 Bar	29.48
5	80% : 20%	65˚C	260˚C	100 Bar	33.44
6	80% : 20%	80˚C	200˚C	150 Bar	31.4
7	90% : 10%	50˚C	260˚C	150 Bar	32.46
8	90% : 10%	65˚C	200˚C	200 Bar	30.49
9	90% : 10%	80˚C	230˚C	100 Bar	32.84

3.2 Shrinkage Measurement

Shrinkage analysis in injection molding is paramount in minimizing defects in the final product. By understanding the shrinkage behavior of a specific plastic material, manufacturers can optimize the process conditions to minimize defects such as warpages, sink marks, and dimensional inconsistencies. Shrinkage analysis helps manufacturers identify the factors contributing to shrinkage and allows them to make informed decisions regarding process parameters. By carefully analyzing the shrinkage characteristics of plastic material, manufacturers can determine the appropriate mold temperature, packing pressure, and cooling time to minimize shrinkage defects.

Figure 2 depicts the location at which a shrinkage measure is obtained. Every specimen was assessed utilizing a digital caliper having an accuracy of 0.01 mm, and five measurements were documented for each specimen.

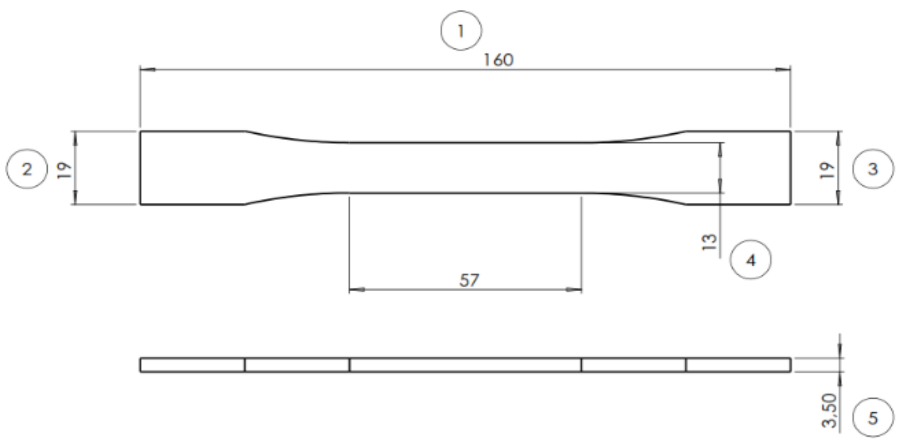

Figure 2 Shrinkage Measurement Point

The following equation calculated the relative shrinkage:

$$S_{flow} = \frac{100 \times (L_M - L_S)}{L_M}$$

LM refers to the measurement of the experimental portion within the mold, whereas LS represents the extent of the specimen after its temperature has cured.

At every injection period, a transition between the injecting stage to the hold phase takes place after the pressure used to inject reaches the preset threshold. Due to the amorphous nature of ABS, a relaxation period of no less than 48 hours was implemented for all samples following experiments before measurements. The finding of the shrinkage measure is displayed in Table 3.

Table 3 Result of Shrinkage Measurement

Run #	Injection Molding Parameters				Mean Shrinkage (%)
	A	B	C	D	
1	70% : 30%	50˚C	200˚C	100 Bar	-0.51
2	70% : 30%	65˚C	230˚C	150 Bar	0.08
3	70% : 30%	80˚C	260˚C	200 Bar	0.58
4	80% : 20%	50˚C	230˚C	200 Bar	0.49
5	80% : 20%	65˚C	260˚C	100 Bar	0.57
6	80% : 20%	80˚C	200˚C	150 Bar	0.56
7	90% : 10%	50˚C	260˚C	150 Bar	0.50
8	90% : 10%	65˚C	200˚C	200 Bar	0.58
9	90% : 10%	80˚C	230˚C	100 Bar	0.79

3.3 SNR (Signal to Noise Ratio) Calculation

Signal-to-noise ratio (SNR) serves as a reliable metric in a project's design process [37]–[39]. The emphasis is placed on objective judgments, with a clear distinction made for subjective assessments. One can assess the effect of various parameter modifications on product performance and thereafter optimize the performance exhibited by large values and small noise signals. Greater signal-to-noise ratio (SNR) values suggest the best performance for enhancing tensile strength. Several research [40]–[47] collectively indicate that higher signal-to-noise ratio (SNR) numbers are associated with optimal performance in optimizing tensile strength. These studies employed several techniques, such as Taguchi optimization, response surface method, and hybrid statistical instruments, to enhance the tensile strength of numerous materials and processes, including metal, stainless steel, paper, synthetic materials, and 3D printing. The consistent findings seen in these research emphasize the importance of SNR values in achieving the maximum strength of tensile. The equation for SNR “Larger is Better” is represented as:

$$SNR = -10\log\frac{1}{n}\left[\frac{1}{x_i(j)^2}\right]$$

Several research studies have investigated the optimization of shrinkage in injection molding, and some have proposed how lower SNR are indicative of optimal performance. The Taguchi approach and ANOVA were used by [23] and [48] to determine the optimal injection molding settings. Reference [23] observed a correlation between reduced signal-to-noise ratios (SNR) and decreased shrinkage. Similarly, to optimize shrinkage, [49] and [50] employed response surface methods and multistage testing, respectively. Both research found that smaller SNR ratios were a sign of better efficiency. The equation for SNR "Smaller is Better" is represented as:

$$SNR = -10\log\left[\frac{1}{n}\sum_{i=1}^{n} y_i^2\right]$$

The outcome of the SNR Calculation is presented in Table 4. The 3rd experiment indicates the most favorable setting for achieving maximum tensile strength. Simultaneously, the 9th experiment represents the optimal condition for shrinkage.

Table 4 Result of SNR

Run #	SNR	
	Tensile Strength	Shrinkage (%)
1	43.9	5.61
2	44.11	18.11
3	45.1	4.62
4	43.39	6.06
5	44.47	4.84
6	43.93	4.91
7	44.23	5.94
8	43.7	4.68
9	44.32	1.98

3.4 PCR-SNR Calculation

PCR-SNR is utilized for assessing whether the technique falls inside the permitted range of parameters. A technique can be deemed acceptable if it falls within a range that is within three standard deviations of the mean. The PCR-SNR value is calculated by converting the SNR value of each response variable. The PCR-SNR is determined using a particular equation:

$$C_j^i = \frac{\eta_j^i - {}^x\eta_j}{3s_{\eta_j}}$$

The outcome of the PCR-SNR calculation is presented in Table 5. According to Table 5, the 3rd experiment demonstrates the most favorable condition for achieving high tensile strength, whereas the 2nd experiment is the most favorable for minimizing shrinkage.

Table 5 PCR-SNR Calculation Result

Run #	PCR-SNR	
	Tensile Strength	Shrinkage (%)
1	-0.04	-0.59
2	0	10.05
3	0.18	-1.43
4	-0.14	-0.21
5	0.06	-1.25
6	-0.04	-1.19
7	0.02	-0.31
8	-0.08	-1.38
9	0.04	-3.69

3.5 PCR-TOPSIS Calculation

The optimal outcomes for both responses can be found in separate parameter-level configurations. PCR-TOPSIS helps to concurrently ascertain the optimal parameter configurations for all responses. The calculation of PCR-TOPSIS is solved by the following equation:

$$d^{i+} = \sqrt{\sum_{j=1}^{n} \left(c_j^i - c_j^+\right)^2}$$ Equation 1

$$d^{i-} = \sqrt{\sum_{j=1}^{n} \left(c_j^i - c_j^-\right)^2}$$ Equation 2

$$s^i = \frac{d^{i-}}{d^{i+} + d^{i-}}$$ Equation 3

The result of the PCR-TOPSIS calculation is displayed in Table 6. The best condition for the parameter setting is ascertained using the PCR-TOPSIS result as a guide. Afterwards, the average value of every parameter is computed. The parameter with the highest mean value is then chosen.

Table 6 PCR-TOPSIS Calculated Outcome

Run #	PCR-SNR		di+	di-	PCR-TOPSIS
	Tensile Strength	Shrinkage (%)			
1	-0.04	-0.59	10.64	3.10	0.23
2	0.00	10.05	0.19	13.74	0.99
3	0.18	-1.43	11.48	2.28	0.17
4	-0.14	-0.21	10.27	3.48	0.25
5	0.06	-1.25	11.30	2.45	0.18
6	-0.04	-1.19	11.24	2.50	0.18
7	0.02	-0.31	10.36	3.38	0.25
8	-0.08	-1.38	11.44	2.31	0.17
9	0.04	-3.69	13.74	0.17	0.01

3.6 Optimum Parameter Setting Determination

The PCR-TOPSIS analysis result is displayed in Table 7. The optimal condition is obtained by combining parameter settings that yield a greater average value. Table 7 displays the "mixing proportion" at level 1, "mold temperature" at level 2, "melt temperature" at level 2, and "packing pressure" at level 2. The result indicates that the optimal condition is obtained by combining A1, B2, C2, and D2. The "packing pressure" is the primary characteristic, with "mold temperature", "mixing proportion", and "melt temperature" being secondary factors.

Table 7 Optimum Condition

	Mixing Proportion	Mold Temperature	Melt Temperature	Packing Pressure
Level 1	0.4592	0.2415	0.1918	0.1387
Level 2	0.2044	0.4442	0.4174	0.4716
Level 3	0.1421	0.1200	0.1965	0.1954
Difference	0.317	0.324	0.226	0.3329
Ranking	3	2	4	1
Optimal Level	A1	B2	C2	D2

4. Conclusion

The present investigation aims to optimize the injection molding process for a blend of r-ABS and virgin ABS material. The goal is to identify the most effective parameter settings that result in high-quality features, specifically tensile strength and shrinkage. The method was controlled by four parameters: "mixing proportion", "mold temperature", "melt temperature", and "packing pressure".

Taguchi approach was employed to ascertain the experimental design, The PCR-TOPSIS approach is used for assessing optimal results of all quality answers. The research findings indicated that the ideal parameters were achieved by combining a "mixing proportion" of 70:30, a "mold temperature" of 65°C, a "melt temperature" of 230°C, and a "packing pressure" of 150 Bar. Out of the four factors, the "packing pressure" is a particularly crucial feature.

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