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Research Article

Optimization of Tensile and Impact Strength for Injection Moulded Nylon 66/Sic/B_4c Composites

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The mechanical properties of different polymer matrix composites are discussed in this research study. These composites are multiphase materials in which reinforcing elements and a polymer matrix are suitably combined. The mechanical properties of 18 PMCs, including nylon 66 reinforced with 5, 15, and 25% wt% silicon carbide (SiC) and nylon 66 reinforced with 5, 15, and 25% wt% boron carbide (B_4C), were evaluated using an injection moulding technique at three different injection pressures in this study. The optimization of process parameters like reinforcement material, reinforcement quantity, and injection pressure to maximize the tensile and impact strength of nylon 66 composites are the main focus of this study. It is observed that the specimens 25% SiC with an injection pressure of 90 MPa has optimised tensile strength, while the specimen 5% B_4C with an injection pressure of 90 MPa has optimised impact strength.

1. Introduction

Factors including wear, vibrations, and noise influence the strength and reliability of the materials used to make the gears. The gears can be made out of metal or nonmetallic materials. Gears are made up of both metallic and nonmetallic materials. The most common metal gears are cast iron, carbon steel, stainless steel, cast steel, and alloy steels. For lighter load applications, aluminium alloys, brass alloys, bronze alloys, magnesium alloys, nickel alloys, and other nonmetallic materials are employed. Nonmetallic materials including wood, jute, compressed paper, and synthetic polymers like nylon are used in gears to reduce noise, wear, and other concerns. Because of their light weight and desirable qualities required in particular applications, composite materials have recently found applications in gears. Nylons, Teflon, and other composite materials are widely utilised in office equipment, textile machines, and other light-weight devices. Due to their superior mechanical qualities and light weight as compared to their base metal, many polymer and metal-based composites, such as Al-SiC composite, have lately found utility. Composite gears are a promising material for gear drive in the future, according to continuous research.

The importance of gearing in power transmission cannot be overstated, according to the author. Polymer gears are becoming more commonly used as a result of their advantages. When evaluating any gearbox that is used in a car, temperature is a crucial issue to consider. Nylon 66 gear's superior dampening and self-lubrication properties considerably reduce temperature. Experiments were undertaken to measure the temperature that occurs in the gear box of a moped when nylon 66 helical gear is used instead of metal gear [1]. For over 50 years, thermoplastic resins have been used in dentistry. Their applications are becoming more popular, as is public interest in nylon-based materials. Thermoplastic resins will almost certainly find new applications in the future to help patients with damaged or missing teeth as new properties emerge. Dentists must meet the increasing demand for prosthetic rehabilitation as the population ages and quality-of-life expectations rise. In this paper, we will go over the properties of nylon-based materials in detail, as well as their numerous dental implications [2]. The effects of theoretical and numerical approaches to stress at the tooth base were compared. They discovered that the outcomes were strikingly similar. In addition, they predicted how the tooth would respond to dynamic loading in terms of stress and displacement [3]. However, there is a significant disadvantage of nanoparticles; increasing the amount of reinforcement increases the amount of porosity, which is an important factor in strength reduction [4].

For strong, exact, and calm power transmission equips, a more precise examination of stuff attributes is required. The FEM helps analysts in foreseeing twisting and contact pressure and assists them with considering the pressure conveyance without playing out an actual test or testing. With the improvements in FEM innovation, it is currently conceivable to play out various tests by changing the stuff boundaries and materials significantly quicker and at a lower cost. On account of its accuracy in expectation, the FEM is regularly used to confirm test discoveries. Fatigue, crack, wear, and stress crack are the disappointment modes in diminishing request of recurrence [5]. Injection moulding is one of the most widely recognized polymer handling techniques, due to its high creation rate and capacity to make exceptionally perplexing calculations for a minimal price and surprisingly fast. Explore the impact of different infusion shaping boundaries on gear proficiency, including melt temperature, form temperature, pressing strain, pressing time, infusion time, and cooling time [6].

To improve the mechanical properties of nylon, which is widely used in science and engineering, various reinforcements were tried with pure nylon 6 and nylon 66. The ceramic microparticles have slightly increased the strength of these materials, which have reached a certain standard with the elements of the alloy. The most common of these ceramics are silicon carbide and boron carbide [7]. B_4C particles are suitable for use as strength enhancer materials due to their superior properties on a wide scale [8]. As a result, researchers set out to create high-strength composites by combining B4C with aluminium alloys in order to achieve synergistic and complementary behaviours between nylon and ceramic particles [9].

The impact of manufacturing methods on machine cut and injection moulded polymer gears was studied, as well as the wear rate behaviour of polymer composites, principally acetal, nylon, and polycarbonate. The author discovered that the manufacturing process had no effect on acetal or nylon gears [10]. On a twin-screw extruder, researchers created a composite of nylon 66 with varying quantities of Al_2O_3 nanoparticles. The research revealed that alumina reinforcement improves tensile, flexural, and impact strength, and various new composite applications were proposed [11]. CNT-reinforced nylon 66 nanofibres electrically spun straight into normal Portland cement were used to create a cementitious material. Hardened cement's mechanical strength and microstructure were also greatly improved [12]. Electrospinning was used to make nylon 66 nanofibres, which were used to interleave mode II analysis of unidirectional glass and carbon fibre composites. The failure modes of nylon 66 spur gears of both unreinforced and fibre reinforced were investigated. Increased wear on the gear tooth surface, gear tooth deformation, and a skin crack at the tooth root part were all observed as major failures [13].

Figure 1: Silicon carbide.

Figure 2: Boron carbide.

Using moulding simulation software, they discovered that gate styles and positions have a significant impact on the polymer flow front filling pattern inside the mould cavity. The melt temperature and packing time have a greater effect on the quality characteristics of the moulded gear observed using the grey-based Taguchi optimization approach than the other examined parameters [14]. Infusion embellishment was used by researchers to create an example made of normal fibre and glass half breed composites for gear applications. They calculated the elastic, flexural, and impact strength of an example built to ASTM specifications.

Table 1: Properties of silicon carbide and boron carbide.

S. no.	Properties	Values		
		Nylon 66	Silicon carbide	Boron carbide
1	Chemical formula	(C12H22N2O2)n	SiC	B4C
2	Density (kg/m^3)	1140 kg/m^3	3210	2520
3	Melting point (K)	507 K	3000	3036
4	Young's modulus (GPa)	1.6 to 23	476	450-472
5	Flexural strength (MPa)	80-260	324	375
6	Ultimate tensile strength (MPa)	60-240	310	261-569
7	Thermal conductivity (W/km)	0.24	41	

They discovered that woven fibre glass mixture composites exhibit a significant increase in rigidity. Composites made with banana glass banana (BGB) and glass banana glass (GBG) overlays had more grounded mechanical properties [13].

The value of gearing in power transmission cannot be overstated. Polymer gears are being more commonly used as a result of their advantages. Temperature is a vital parameter in performance testing for any gearbox that is used in a car. Nylon 66 gears excellent damping and self-lubrication properties greatly reduce temperature. Experimentation has been carried out in this regard to assess the temperature that occurs in the gear box of a moped when nylon 66 helical gear is used instead of metal gear [1]. Through the analysis in polymer composite gear with reinforcement of E-Glass GSM in various proportions, detailed analysis concluded that polymer composite gears have less wear rate related with conventional cast iron gears [15]. Composite was made using nylon 66 with various percentages of silica fume particulates through injection moulding machine to examine tensile, compression, flexural, impact, and heat distortion temperature (HDT). The improvements in tensile and HDT properties of nylon 66-silica fume composites were concluded [16]. This study introduces the fractional effort of fostering a polymer composite gear utilizing nylon 66 with silicon carbide and boron carbide as reinforcement materials.

2. Materials and Methods

2.1. Matrix Material—Nylon 66. The word "nylon" refers to a group of synthetic polymers. Polyamides that are aliphatic or semiaromatic are used. It is a thermoplastic substance that can be formed into fibers, films, or fibers. It is a synthetic fiber that comes in a number of grades, including nylon 6, nylon 66, nylon 11, and nylon 12. Nylon 66 is a common term for a group of synthetic polymers referred to as aliphatic polyamides. It is one of the most widely used plastics. The materials used to produce gears, sprocket wheels, chains, and other rotating spares are determined by their strength and service conditions such as wear, tear, and noise, among other factors [9]. In general, improved mechanical properties with weight reduction can be achieved primarily by introducing reinforcement materials in nylon polymer matrix, design optimization, and use of better manufacturing processes.

Table 2: Moulding machine parameters.

Sl. no	Parameter	Value
1	Oven preheating time	1 hour
2	Oven preheating temperature	40 to 60°C
3	Injection pressure machine maximum	200 bar
4	Holding pressure	70 bar
5	Clamping pressure	110 bar
6	Injection pressure	80bar
7	Holding time	8 sec
8	Sample cooling time	75 sec
9	Mould open time	5 sec
10	Setting time	40 sec
11	Moulding time	20 sec
12	Bottom or nozzle zone temperature	275 to 295°C
13	Top zone temperature (thermostat controller)	80°C

2.2. Reinforcement Materials—SiC and B_4C. SiC is a chemical compound made up of carbon and silicon. It is created through a high-temperature electrochemical reaction between sand and carbon. SiC is a fantastic abrasive material that has been used to make grinding wheels and other abrasive products for over a century. SiC has progressed to become one of the highest-quality professional ceramics with superior mechanical properties. In a range of high-performance applications, it is used as abrasives, refractory materials, and ceramics. Figure 1 depicts the SiC powder.

Boron carbide (B_4C) is a hard material that ranks third in terms of hardness after diamond and cubic boron nitride (CBN). Carbon is reacted with B_2O_3 in an electric arc furnace; carbo-thermal reduction or gas phase methods are used to produce B_4C powder. B_4C powders are frequently treated and filtered to remove metallic impurities before being utilised commercially. Figure 2 depicts B_4C in granular and powder form. Table 1 lists the properties of nylon 66, SiC, and B_4C.

2.3. Composite Fabrication. Because of its high crystalline nature, nylon has exceptional physical and mechanical qualities, according to the literature. It has a broader range of uses for gears used in office machines, textile machines,

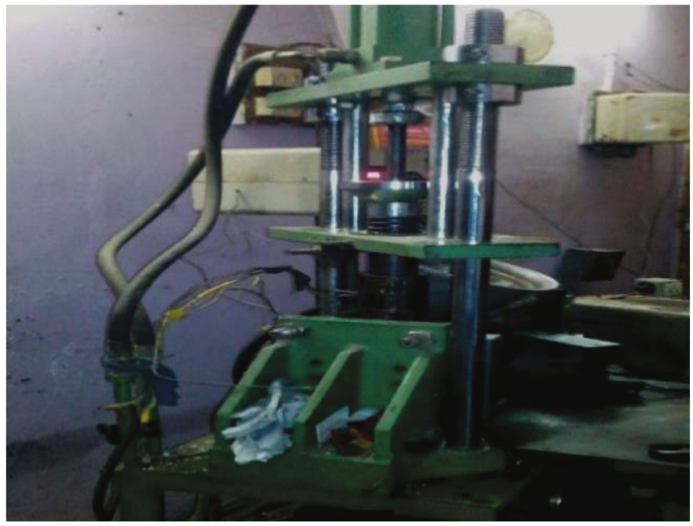

Figure 3: Semiautomatic moulding machine.

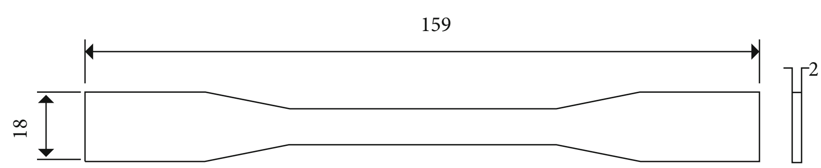

Figure 4: Schematic diagram of tensile test specimen.

Figure 5: Tensile test specimen.

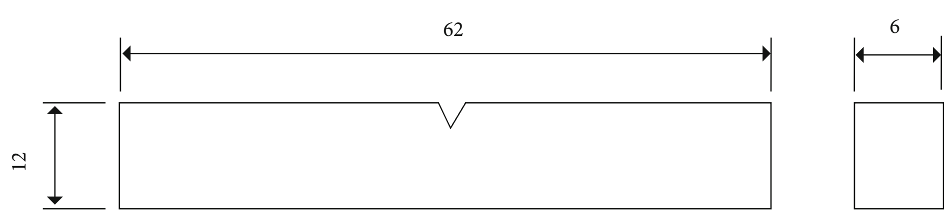

Figure 6: Schematic diagram of impact test specimen.

Figure 7: Impact test specimen.

Table 3: Process parameters and their levels.

Terms	Factors/parameters	Level 1	Level 2	Level 3
A	Type of RM	SiC	B4C	—
B	wt% of RM content (%)	5	15	25
C	Injection pressure (MPa)	80	90	100

Table 4: Experimental results.

Sl. no.	Type of RM	wt% of RM content (%)	Injection pressure (MPa)	Tensile strength (MPa)	Impact strength (J)	S/N ratio	
						Tensile strength	Impact strength
1	SiC	5	80	54.66	1.96	34.75	31.73
2	SiC	5	90	50.66	1.97	34.09	32.59
3	SiC	5	100	48.45	2.00	33.71	33.40
4	SiC	15	80	45.33	1.88	33.13	33.56
5	SiC	15	90	46.33	1.82	33.32	32.79
6	SiC	15	100	46.33	1.85	33.32	32.80
7	SiC	25	80	53.85	1.87	34.62	33.17
8	SiC	25	90	55.85	1.96	34.94	34.58
9	SiC	25	100	49.85	1.96	33.95	34.58
10	B4C	5	80	45.65	4.0	33.19	30.53
11	B4C	5	90	44.65	4.0	33.00	31.03
12	B4C	5	100	43.65	4.1	32.80	31.55
13	B4C	15	80	41.33	3.2	32.33	31.28
14	B4C	15	90	43.33	3.33	32.74	31.73
15	B4C	15	100	42.33	3.0	32.53	32.80
16	B4C	25	80	46.85	2.2	33.41	32.78
17	B4C	25	90	47.85	2.1	33.60	32.82
18	B4C	25	100	41.85	2.0	32.43	32.58

and even large equipment for noise/vibration reduction, among other things. Particles are put to nylon polymers to improve their qualities and minimise the over cost of composite products. In general, reinforced nylon polymers outperform base nylon in terms of characteristics. In this study, nylon was utilised as the basis material for the composites preparation. As foundation ingredients, two grades of nylon are used: nylon 6 and nylon 66. The particles of SiC and B_4C are used as reinforcing materials. SiC and B_4C are thought to have good thermal conductivity, a stable crystal structure, low toxicity, high hardness, and a low price. The addition of reinforcement improves the mechanical properties of these nylon composites, making them excellent for gear applications.

Injection moulding is a widespread method of making products out of thermoplastic and thermosetting polymers. The materials are mixed in a heated barrel before being forced into a mould cavity, where they cool and harden to the shape of the mould cavity. Injection moulding is used to make a wide range of parts, from minor components to whole car body panels. The injection moulding process comprises four stages: clamping, injection, cooling, and ejection. It takes between 2 seconds and 2 minutes to complete.

Table 5: Response table for signal to noise ratios of tensile strength.

Level	Type of RM	% of RM content	Inj. pressure
1	33.98	33.59	33.57
2	32.89	32.89	33.61
3		33.83	33.12
Delta	1.09	0.93	0.49
Rank	1	2	3

After enough time has passed, the cooled component can be evacuated from the mould by the ejection mechanism, which is attached to the back half of the mould. When the mould is opened, a mechanism is employed to force the part out. After the component is removed, the mould can be clamped shut, allowing the next shot to be injected. After the injection moulding cycle, any postprocessing is usually required. Granules, pellets, or powders can be used to compute the initial raw materials required. The following parameters are set in the unit to get good quality components from injection moulding shown in Table 2. The semiautomatic injection moulding machine is shown in Figure 3.

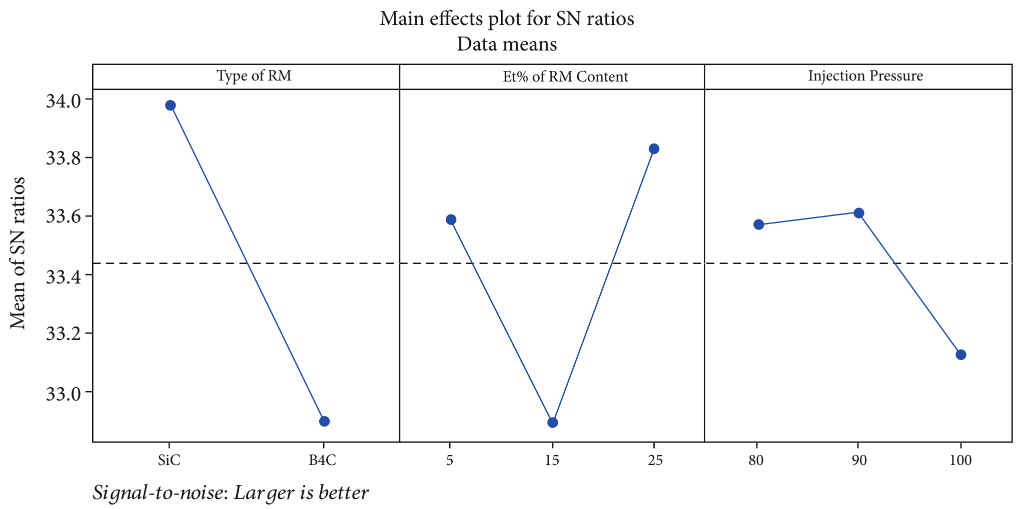

FIGURE 8: Effect of control factors on tensile strength of nylon 66 composites. Optimum levels: type of RM = SiC; wt% of RM content = 25%; Inj. pressure = 90 MPa.

TABLE 6: ANOVA table for tensile strength.

Source	DF	Adj SS	Adj MS	*F* value	*P* value	% of contribution
Type of RM	1	5.3438	5.3438	43.47	0	50.73
% of RM content	2	2.8308	1.4154	11.51	0.002	26.87
Inj. pressure	2	0.885	0.4425	3.6	0.06	8.40
Error	12	1.4753	0.1229			14.00
Total	17	10.5348				100.00

2.4. Mechanical Testing

2.4.1. Tensile Strength. Young's modulus, elastic limit, elongation, proportional limit, yield point, yield strength, tensile strength, percentage of reduction in area, and other tensile parameters are all determined via tensile testing. Specimens are frequently subjected to the tensile test [10]. The most common specimen geometries are the dog-bone shape and straight side type with end tabs. All of the specimens in this investigation were injection moulded in the shape of a dog bone with a dimension of $159 \times 18 \times 2$ mm as per ASTM D638. Figures 4 and 5 depict the schematic diagram specimen and injection moulded tensile test specimen, respectively.

2.4.2. Impact Strength. Material properties at greater deformation speeds are assessed through impact testing. The impact testing is used to assess the toughness and notch sensitivity of engineered materials. It is used to assess the toughness of metals, but polymers, ceramics, and composites are also subjected to similar testing. The impact of a heavy pendulum or hammer, descending at a predetermined velocity through a fixed distance, breaks the notched test specimen [11]. The energy absorbed by the fragmented specimen is measured in this test. Figure 6 shows a schematic representation of an Izod impact test specimen. Figure 7 depicts the notched impact test specimen. A notch was cut into the specimen before it was placed on the impact testing equipment.

TABLE 7: Response table for signal to noise ratios of impact strength.

Level	Type of RM	% of RM content	Inj. pressure
1	5.657	9.016	7.639
2	9.536	7.687	7.645
3		6.087	7.505
Delta	3.879	2.929	0.14
Rank	1	2	3

2.5. Optimization—Taguchi Method. The application of the Taguchi methodology is highly desirable because it gives phase and analysis phase. The quality of the gears produced is influenced by injection moulding process parameters, type of the RM, and the content of the RM. As a result, determining the optimal parameters is critical [12]. The reinforcement materials SiC, B4C, wt. percent of reinforce materials content, and injection moulding pressure are considered influencing characteristics for this research effort since they affect the mechanical strength of the composite specimens created. Appropriate parameter level with a small number of experiments. It is a method for performing experiments and analysing the effect of many parameters on the response

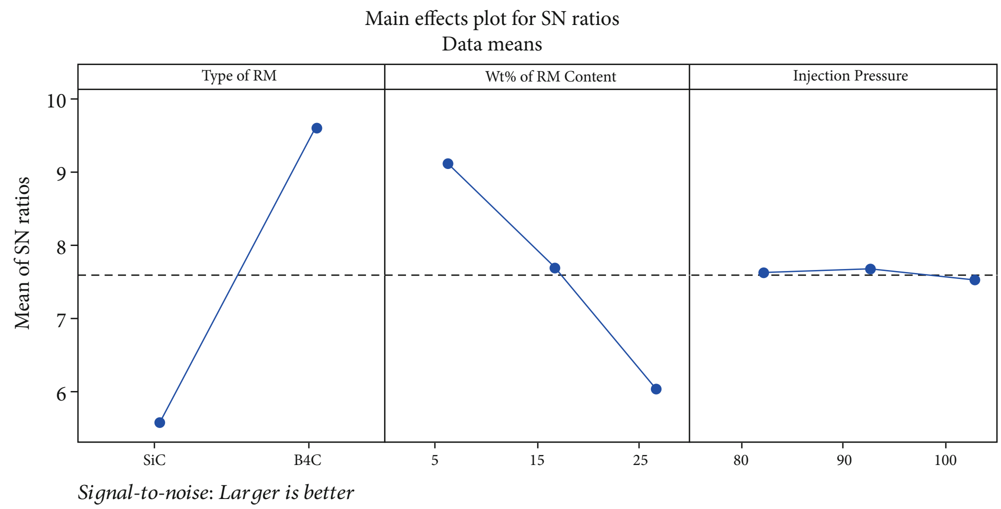

FIGURE 9: Effect of control factors on impact strength nylon 66 composites. Optimum levels: type of RM = B_4C; wt% of RM content = 5%; Inj. pressure = 90 MPa.

that is based on a systematic statistical approach [14]. The Taguchi approach is carried out in three stages in general. Planning, experimentation, and analysis are the three phases [13]. Composite specimens are constructed with two base materials, nylon 66 and nylon 6, as well as two RMs, SiC and B4C, which are added in weight percents of 5%, 15%, and 25%, respectively. Injection moulding is used to create nylon composite specimens at a specific pressure and temperature.

2.5.1. Planning Phase. The main goal of this research is to develop controllable aspects in order to improve mechanical strength qualities. At three stages, the type of reinforcing materials, the weight percent of support content, and the injection moulding pressure are all monitored [15]. In light of the writing overview, the reaches for the cycle boundaries are set. Because the collaborations are of minor importance, it was decided in this focus on that the primary impacts are the most important [16]. Table 3 lists the variables and their levels for nylon 6 composites. Minitab 17 is used to create the experimental arrangement.

2.5.2. Experimental Phase. In this stage, the analyses are directed according to Taguchi's test plan involving L18 symmetrical cluster for nylon 66 composites [17].

2.5.3. Analysis Phase. The investigation is carried out using Minitab 17 programming at this level. The product calculates the normal value of the S/N ratio of each border at a given level. The S/N ratio is important for achieving a higher boundary level. The product plots the S/N ratio in accordance with the quality brand selected [18].

3. Results and Discussion

Table 4 shows the results of the experiment.

3.1. Tensile Strength of Nylon 66. Response Table 5 can be used to see how different characteristics affect tensile strength. The response table shows the average response characteristics for each level of the individual element in the experimental design. Based on their delta values, the factors are ranked from most to least influential. Table 5 clearly indicates the importance and rank of the criteria studied, as seen in Figure 8.

Figure 8 shows the principle impact plot for S/N proportions obtained from the product. The figure reveals that the variables, reinforcement material (A), and wt% of reinforcement material content (B) largely affect S/N proportion relating to rigidity of nylon 66 composite.

The analysis of variance (ANOVA) is used to investigate the model association between the response variable tensile strength and the independent factors (A, B, and C). The ANOVA findings for tensile strength are shown in Table 5. The P value can be used to verify the relevance of the components. At a 95% confidence level, the elements that are statistically significant are validated. The parameter makes a significant influence to the performance if the P value is less than 0.05 [10]. This indicates that the parameter has a stronger influence on the mechanical strength of the nylon 66 composite material. The kind of RM has the largest impact on tensile strength, as shown in Table 6. It is followed by factors B and C. The ANOVA table also shows the percentage influence of each parameter on mechanical strength.

3.2. Impact Strength of Nylon 66. Response Table 7 can be used to determine the effect of various parameters on impact strength. It also demonstrates the relevance of parameters in ranking, as shown in Figure 9.

The ANOVA result for impact strength is shown in Table 8. The importance of the components can be validated using a P value at a 95% confidence level.

3.3. Confirmation Experiment. The final stage is to look at the best interaction parameters after acquiring the ideal collaboration parameters through exploratory data analysis. Confirmation tests are performed to check if the Taguchi

Table 8: ANOVA table for impact strength.

Source	DF	Adj SS	Adj MS	F value	P value	% of contribution
Type of RM	1	67.723	67.7227	33.01	0	57.28
% of RM content	2	25.811	12.9056	6.29	0.014	21.83
Inj. pressure (MPa)	2	0.076	0.0379	0.02	0.982	0.06
Error	12	24.616	2.0514			20.82
Total	17	118.226				100.00

Table 9: Optimum factor levels for maximum properties of nylon 66 composites.

Properties	Type of RM	Weight % of RM content	Injection pressure (MPa)
Tensile strength (MPa)	SiC	25	90
Impact strength (J)	B_4C	5	90

upgrading process produces accurate finishes. According to the confirmatory study, the ideal level of boundaries derived will actually deliver closer quality features, with individual values being 15% closer to the certifiable ones. Table 9 demonstrates the improved properties of nylon 66 composites as a result of the response analysis.

4. Conclusion

The foremost goal of this research paper is to investigate the tensile and impact strength of polymer composites as a preliminary study for the development of polymer composite gears. In this study, the emphasis was solely on the optimization portion of analysing the role of RM type, RM content percentage, and injection pressure. In this study, 18 PMCs were made using nylon 66 reinforced with 5, 15, and 25% wt% SiC and B_4C using an injection moulding machine at 80, 90, and 100 MPa injection pressure in each case. The tensile and impact tests were carried out in accordance with ASTM guidelines. The Taguchi technique was used to establish the optimal value of tensile and impact strength with variations in wt% of RM content and injection pressure. It is believed that the load transfer mechanism and dislocations contribute the most positively, while porosity has the most negative effect, based on mechanical testing and morphological analysis. In mechanical strength analysis, the load transfer mechanism was shown to be the most important factor for both reinforcements. In addition, geometrically essential dislocations discovered in boron carbide particles significantly contributed to the increase in strength. As a result, the manufacturing process and volumetric content parameter for spur gear design can be claimed to be congruent with current studies and to be suggestions for future research.

Data Availability

The data used to support the findings of this study are included in the article. Should further data or information be required, these are available from the corresponding author upon request.

Disclosure

This study was performed as a part of the employment of Bule Hora University, Ethiopia.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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References

[1] A. N. Taywade and V. G. Arajpure, "Design and development of nylon 66 plastic helical gears in automobile application," *International Journal of Engineering Research & Technology*, vol. 3, no. 9, 2014.

[2] K. Shivani and B. Shekhar, "Polyamides in dentistry," *International Journal of Scientific Study*, vol. 1, no. 1, pp. 20–25, 2013.

[3] A. Shubham and N. Ajmera, "Static and dynamic analysis of spur gear," *International Journal of Mechanical Engineering and Technology*, vol. 7, no. 4, pp. 8–21, 2016.

[4] H. Porwal, P. Tatarko, S. Grasso, J. Khaliq, I. Dlouhy, and M. J. Reece, "Graphene reinforced alumina nano-composites," *Carbon*, vol. 64, pp. 359–369, 2013.

[5] A. Z. Ismail Ali, N. D. I. Daing Mohamad, and M. Wafiuddin, "Investigating bending strength of spur gear: a review," *MATEC Web of Conferences*, vol. 90, pp. 01037–01039, 2017.

[6] S. K. Lal and H. Vasudevan, "Optimization of injection moulding process parameters in the moulding of low-density polyethylene (LDPE)," *International Journal of Engineering Research and Development*, vol. 7, no. 5, pp. 35–39, 2013.

[7] T. Varol and A. Canakci, "Effect of particle size and ratio of B_4C reinforcement on properties and morphology of nanocrystalline Al2024-B_4C composite powders," *Powder Technology*, vol. 246, pp. 462–472, 2013.

[8] C. Wu, K. Ma, J. Wu et al., "Influence of particle size and spatial distribution of B_4C reinforcement on the microstructure and mechanical behavior of precipitation strengthened Al alloy matrix composites," *Materials Science and Engineering A*, vol. 675, pp. 421–430, 2016.

[9] H. Yang, T. D. Topping, K. Wehage, L. Jiang, E. J. Lavernia, and J. M. Schoenung, "Tensile behavior and strengthening mechanisms in a submicron B_4C-reinforced Al trimodal composite," *Materials Science and Engineering A*, vol. 616, pp. 35–43, 2014.

[10] K. A. Alharbi, "Wear and mechanical contact behavior of polymer gears," *Journal of Tribology*, vol. 141, no. 1, article 011101, 2019.

[11] L. Guglani and T. C. Gupta, "Wear and mechanical properties of nylon 66–Al2O3 microcomposite," *Journal of Reinforced Plastics and Composites*, vol. 36, no. 17, pp. 1254–1262, 2017.

[12] T. N. M. Nguyen, D. Y. Yoo, and J. J. Kim, "Cementitious material reinforced by carbon nanotube-nylon 66 hybrid nanofibers: mechanical strength and microstructure analysis," *Materials Today Communications*, vol. 23, p. 100845, 2020.

[13] R. Sakthivel and D. Rajendran, "Experimental investigation and analysis a mechanical properties of hybrid polymer composite plates," *International Journal of Engineering Trends and Technology*, vol. 9, no. 8, pp. 407–414, 2014.

[14] N. M. Mehat, K. Shahrul, and A. R. Othman, "Modeling and analysis of injection moulding process parameters for plastic gear industry application," *ISRN Industrial Engineering*, vol. 2013, Article ID 869736, 10 pages, 2013.

[15] S. S. Abdelhady, S. H. Zoalfakar, M. A. Agwa, and A. A. Ali, "Treated basalt fibers reinforced nylon 6, 6/epoxy hybrid nanofibril composites," *Journal of Thermoplastic Composite Materials*, vol. 35, no. 4, pp. 555–569, 2022.

[16] V. L. Raja and A. Kumaravel, "Studies on physical and mechanical properties of silica fume-filled nylon 66 polymer composites for mechanical components," *Polymers and Polymer Composites*, vol. 23, no. 6, pp. 427–434, 2015.

[17] G. Boopathy, K. Gurusami, M. Chinnapandian, and K. R. Vijayakumar, "Optimization of process parameters for injection moulding of nylon 6/SiC and nylon 6/B4C polymer matrix composites," *Fluid Dynamics & Materials Processing*, vol. 18, no. 2, pp. 223–232, 2022.

[18] K. Karthik, D. Rajamani, A. Manimaran, and J. Udaya Prakash, "Evaluation of tensile properties on glass/carbon/Kevlar fiber reinforced hybrid composites," *Materials Today: Proceedings*, vol. 39, no. 4, pp. 1655–1660, 2021.