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Effect of SiC, graphite and marble dust on mechanical properties of Al6063 hybrid metal matrix composite

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Abstract

This paper focuses on the optimization of mechanical properties of AA6063 reinforced with SiC, graphite, and marble dust using the Taguchi method. Undoubtedly, metal matrix composites (MMCs) have recently become quite popular in various engineering applications due to their enhanced mechanical properties. The optimization of mechanical properties of MMCs requires careful consideration of various design parameters. In this study, the Taguchi method was used to design experiments and analyze the effect of SiC, graphite, and marble dust content on the mechanical properties of AA6063 [10]. The experiments were conducted using stir casting, and the composite samples were subjected to various mechanical tests, including hardness testing, tensile testing, and impact testing [7]. The results were analyzed using ANOVA to identify the optimal combination of design parameters. The study found that the addition of SiC and graphite significantly improved the mechanical properties of the composite, while marble dust had an undesirable effect due to its low strength and stiffness. It provides valuable insights for the design and development of high- performance composites for various engineering applications.

Keywords: Hybrid Metal Matrix Composites(HMMCs), Marble Dust (MD), Graphite (Gr), Silicon Carbide (SiC)

1. Introduction

The use of metal matrix composites (MMCs) inengineering applications has become increasingly popular due to their improved mechanical propertiescompared to conventional materials [2]. MMCs are composed of a metal matrix reinforced with ceramicor metallic particles, fibers, or whiskers. Among various types of MMCs, aluminum matrix composites are widely used due to their low density,high strength, and excellent wear resistance. However, the optimization of the mechanical properties of MMCs is a complex task that requires careful consideration of various design parameters. These parameters include the type and content ofthe reinforcement material, the size and shape of the reinforcement particles, and the manufacturing process used to fabricate the composite. The Taguchi method is a powerful statistical tool that has been used in various fields to optimize the performance of products and processes [20]. The Taguchi method involves the design of experiments based on orthogonal arrays, which allows for the evaluation of multiple design parameters simultaneously while minimizing the number of experiments required. The method also uses signal-to-noise ratios to evaluate the effect of each design parameter on the performance of the product or process.

2. Materials

The materials employed in this study are SiC, graphite, and marble dust as reinforcementmaterials, with AA6063 as the metal matrix. The high strength and good castability of the AA6063 alloy, which are important qualities for the stir casting process, led to its selection. The high strength and stiffness of the SiC particles were chosen [17], and the superior lubricity and thermal conductivity of the graphite were also chosen [18]. In order to look into how the inclusion of marble dust as a filler ingredient can affect the composite's mechanical qualities [15,16].

Base matrix alloy properties

Aluminum alloy AA 6063 is frequently employed inextrusion and architectural applications. It is a corrosion-resistant alloy with a medium strength that is simple to weld and construct. Magnesium and silicon are the main alloying components of the alloy, which add to its strength and workability. It has a melting point of around 655°C and is known for its excellent extrudability and weldability. It is a light substance because of its relatively low density of 2.7 g/cm3.Due to its high extrudability and capacity to create complex designs, AA 6063 is frequently used in the building sector for window frames, door frames, and curtain walls. Additionally, it is employed in the creation of different automobile components and heat sinks for electrical gadgets. AA 6063 is commonly used as a matrix material in the production of metal matrix composites due to its favorable mechanical properties and ease of processing In terms of mechanical properties, AA6063 exhibits good strength and toughness, with a tensile strength of approximately 145 MPa and a yield strength of around 65 MPa. It also has a high resistance to corrosion and a good surface finish, making it a popular choice for architectural applications. Its chemical composition (in weight percent) is given in Table 1.

Table 1: Chemical Composition of AA 6063 Alloy

Elements	Al	Mg	Si	Fe	Mn	Ti	Zn	Ni	Cu	Sn
Wt.%	98.65	0.499	0.466	0.343	0.0015	0.0011	0.007	0.006	0.002	0.001

Fig. 1 Commercially available AA6063 alloy plates

3. Design of Experiment

The Taguchi method was used to design the experiments. The L9 orthogonal array was selected as it can accommodate three factors, each at three levels. This design allows the effect of each factor to be analyzed individually and in combination withthe other factors, thus reducing the number of experiments required. The factors selected for this study were SiC wt. %, graphite wt. %, and marble dust wt.%. The levels are shown in Table 2.

Table 2: Reinforcements wt. % and their levels forL9 Taguchi's Orthogonal Array Design of Experiment

		Levels		
Reinforcements	**Units**	1	2	3
SiC	Wt. %	2.5	5	7.5
Gr	Wt.%	2	4	6
MD	Wt.%	0.5	1	1.5

The Taguchi L-9 orthogonal array can be given by Table 3 shown below.

Table 3: Design matrix based on Taguchi's L9array design of experiment

Reinforcements			
S.No.	**SiC (wt. %)**	**Gr (wt.%)**	**MD (wt. %)**
1	2.5	2	0.5
2	2.5	4	1
3	2.5	6	1.5
4	5	2	1
5	5	4	1.5
6	5	6	0.5
7	7.5	2	1.5
8	7.5	4	0.5
9	7.5	6	1

4. Method of Fabrication

Stir casting

Stir casting is a widely used method for fabricating metal matrix composites (MMCs) due to its simplicity, versatility, and cost-effectiveness [1],[2]. In this study, the AA6063 matrix was prepared using the stir casting technique, which involves melting the matrix material in a furnace at high temperature and adding the reinforcement materials to the melt while stirring at a constant speed. This process ensures uniform distribution of the reinforcement materials in the matrix and enhances the mechanical properties of the resulting composite [8]. Bottom tapping stir casting furnace as shown in Fig.2 with crucible capacity of 2 kg and maximum melting temperature of 1000 °C was used [5]. The mechanical stirrer was operated in the range of 100–2000 rpm and controlled by limit switches. The furnace has bottom tapping valve through which molten metal can be poured into the moulds.

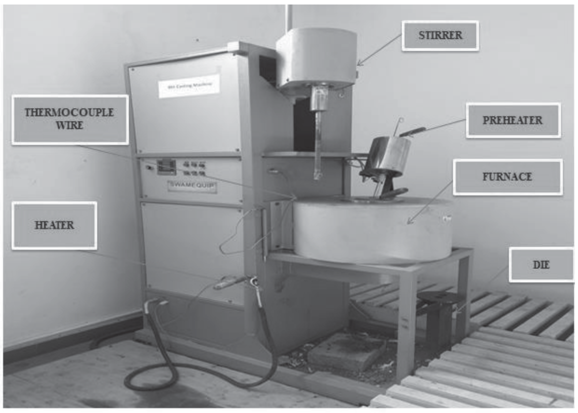


Fig. 2 Bottom tapping stir casting machine Setupat Anand ICE, Jaipur

Procedure for preparation of composites

The various steps involved in making the AA6063/SiC composites by stir casting process are as follows:

Encapsulation Technique

To prevent agglomeration and uneven particle dispersion [4], and to manufacture high-quality AMCs, the stir casting method employs a revolutionary, creative encapsulation feeding methodology [6]. The order of events is as follows. In this feeding method, an Aluminium Alloy 6063 solid shaft with an initial 65 mm outer diameter (OD) was machined into a hollow cylindrical cup shape, with dimensions of 65 mm external diameter,45 mm internal diameter, 150 mm length, and 30 mm bottom thickness (as shown in Fig.3).

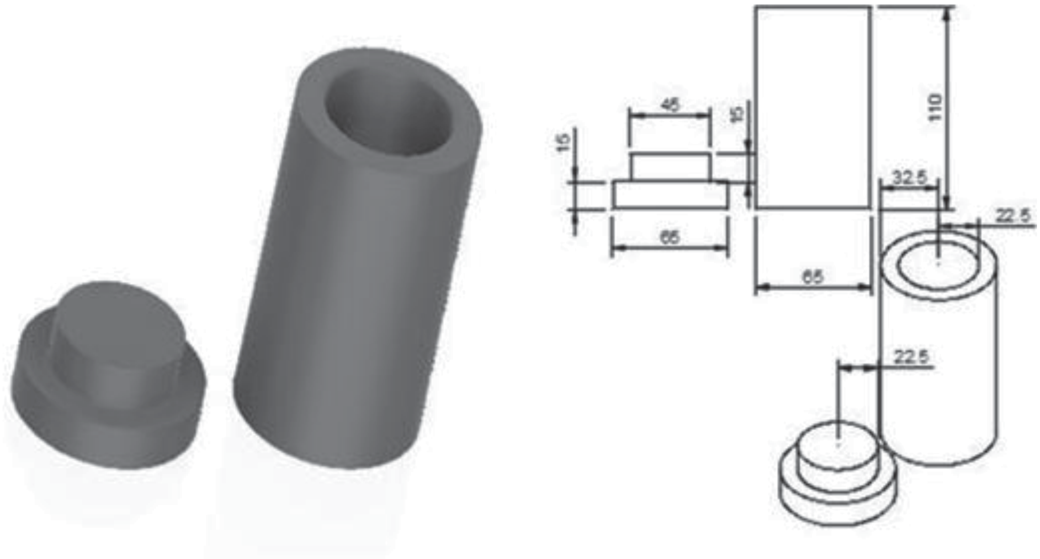


Fig. 3 Three-dimensional model and machinedcup with metal cap.

The reinforcement particles were then retained inside an aluminium foil sheet and contained at 2.5 % SiC, 2%Gr, and 0.5% MD. To improve the connection between the reinforcement particles and the base metal, two percent of magnesium was used as a wetting and binding agent. The wetting agent and wrapped ceramic powder are put into a hollow, cylindrical cup, and the cup is then sealed with a cup cap [9]. Despite base metal's relatively low melting temperature of 660–680 °C, the furnace warms up to 750 °C, and the molten slurry of base metal stops reinforcement particles in their tracks inall directions because of the gaseous layer that the base metal forms. The single-blade mechanical stirrer with a graphite coating then stirs to break up the mixing of the base metal and the gaseous region.For 10-15 minutes, the stirrer's speed steadily climbs to 400 rpm. Then, the stirrer speed was gradually lowered to zero before the composite slurry was put into a mould that had been preheated to 500°C. To shorten the time needed for fragments or molecules (particles) to settle, it is then swiftly air quenched. The aforementioned cycle is repeated with different fractions as a Taguchi L9 orthogonal array.

I. Mixing of the ingredients

The molten AA6063 aluminium matrix alloy is stirred continuously by the mechanical stirrer,rotating at 300 – 400 rpm for 10–15 min. The speed was increased gradually.

II. Casting of the composites

The molten slurry was then transferred with a pouring temperature at a range of 650℃ to 750℃ to a cleaned permanent metallic preformed die mould measuring 250 mm × ×60 mm ×10 mm. The molten composite mixture was allowed to solidify for approximately 8 h at room temperature. The cast composite material, as shown in Fig. 3, was then removed from the die mould and used as the input material for the preparation of specimens for further investigations.

5. Results and Discussion

The prepared samples were tested for tensilestrength and microhardness.

Tensile testing

The tensile testing of the specimen was done on a 30KN tensile testing machine [12]. The ASTM E8 standard was used for the preparation of the samplesas shown in Fig. 4.

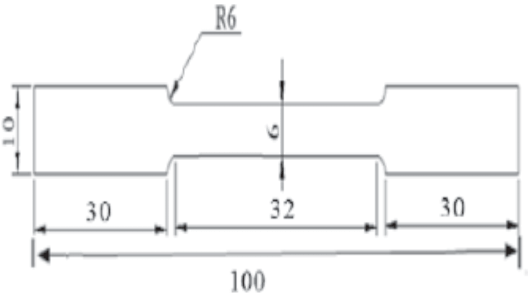


Fig 4: ASTM E8 Standard specimen

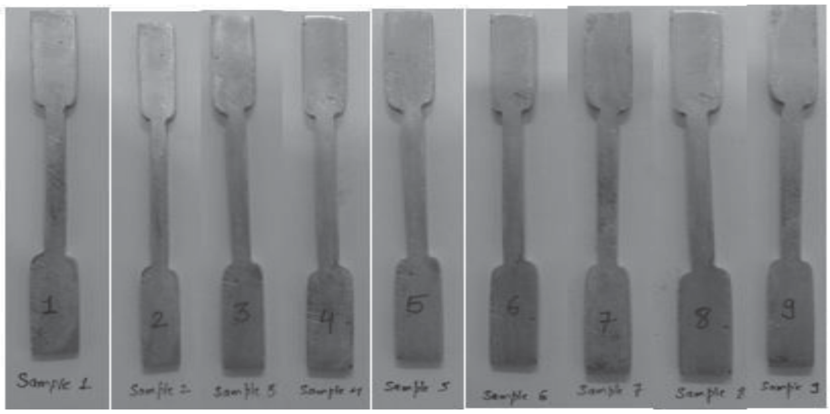


Fig. 5 Tensile Testing samples as preparedaccording to Taguchi L9 orthogonal array

The result of the tensile testing of the specimens is shown in Table 4 below.

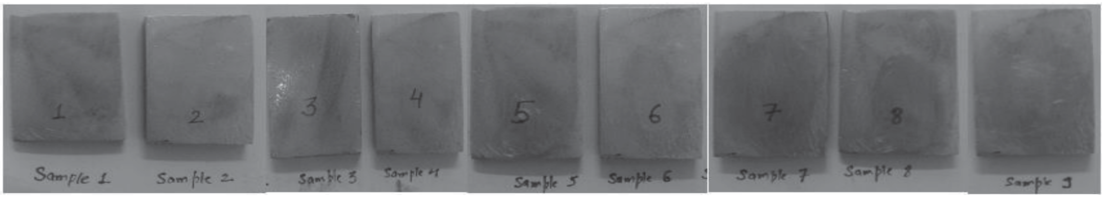
Table 4: Tensile testing results of samples prepared according to Taguchi's L9 array design of experiments

Reinforcements				
S.No.	**SiC (wt. %)**	**Gr (wt.%)**	**MD (wt. %)**	**UTS (MPa)**
1	2.5	2	0.5	160
2	2.5	4	1	165
3	2.5	6	1.5	161
4	5	2	1	170
5	5	4	1.5	175
6	5	6	0.5	173
7	7.5	2	1.5	182
8	7.5	4	0.5	192
9	7.5	6	1	190

Micro hardness testing

The test specimens were prepared from the samples by cutting in the middle portion of the samples, and then polished by using grinding machine for 5 min, and further polished on a disc polishing machine with various grades of emery sheets for 5-6 min for rotational speed of 800 rpm and then finally polished on a velvet disc polishing machine with alumina paste for 5 min, and then etched with Keller's reagent to remove the projecting burrs.The size of the sample was 35mm×25mm×5mm as shown in fig.6 below.

Fig. 6 Micro hardness testing samples as prepared



The test results of the micro hardness testing are shown in Table 5 below.

Table 5: Tensile testing results of samples prepared according to Taguchi's L9 array design of experiments.

Reinforcements				
S.No.	**SiC (wt %)**	**Gr (wt%)**	**MD (wt %)**	**(Hv)**
1	2.5	1.5	1	63.2
2	2.5	3	2	68.4
3	2.5	4.5	3	64.6
4	5	1.5	2	86.2
5	5	3	3	91.2
6	5	4.5	1	87.2
7	7.5	1.5	3	94.5
8	7.5	3	1	101.0
9	7.5	4.5	2	99.4

Analysis of variance for tensile testing

ANOVA is a statistical tool which helps in analyzing differences among group means. ANOVA is a handy tool when it is required to find the significant parameters which can affect the experiment. Through ANOVA it is easier to obtain the contribution of each parameter in percentagewhich gives the optimal result and also the errors [13],[14].

Calculation of S/N ratio

S/N ratio was calculated from the software MINITAB by UTS values. The Taguchi's L9 orthogonal array was used for taking the input factor. i.e. the tensile strength values which obtained from different parameters values [19]. UTS value was taken as the response factor. The larger is better concept was used for calculating S/Nratio.

$$\text{S/N (larger is better)} = -10\log\ [1/\sum_{i=0}^{n} \frac{1}{y2}\ ]$$

where y = Represents the responses for the factor level grouping,

n = Represents the number of responses in the factor level grouping.

Table 6: Calculation of S/N Ratio

Reinforcements					
S. No.	**SiC (wt.%)**	**Gr (wt.%)**	**MD (wt.%)**	**UTS (Mpa)**	**S/N Ratio**
1	2.5	2	0.5	160	44.0824
2	2.5	4	1	165	44.3497
3	2.5	6	1.5	161	44.1365
4	5	2	1	170	44.6090
5	5	4	1.5	175	44.8608
6	5	6	0.5	173	44.7609
7	7.5	2	1.5	182	45.2014
8	7.5	4	0.5	192	45.6660
9	7.5	6	1	190	45.5751

Response table for means

From the delta and rank values obtained by the response Table 7 given below for means, it is clear that wt. % of SiC has an enormous impact on the response characteristics. The tensile strength. From the response table for means it can be seen that wt. % of SiC has maximum influence on the response characteristics so is given rank 1 followed by wt. % of Gr which is given rank 2 and wt. % of MD rate which is given rank 3.

Table 7: Response table for means

LEVEL	**SiC**	**Gr**	**MD**
1	162.7	172.0	175.7
2	172.3	178.3	176.0
3	191.3	176.0	174.7
DELTA	28.7	6.3	1.3
RANK	1	2	3

Main effect plot for means

The main effect plot shows a different level of factors in present work, i.e., wt. % of SiC, wt. % of Gr and wt. % of MD which are responsible for affecting the response factor here it is a tensile strength. The point represents the means of each parameter. Since the lines are not straight, this shows the existence of the main effect as shown in the figure7 below. The interpretation of the main effect plot is based on highest is the better criteria.

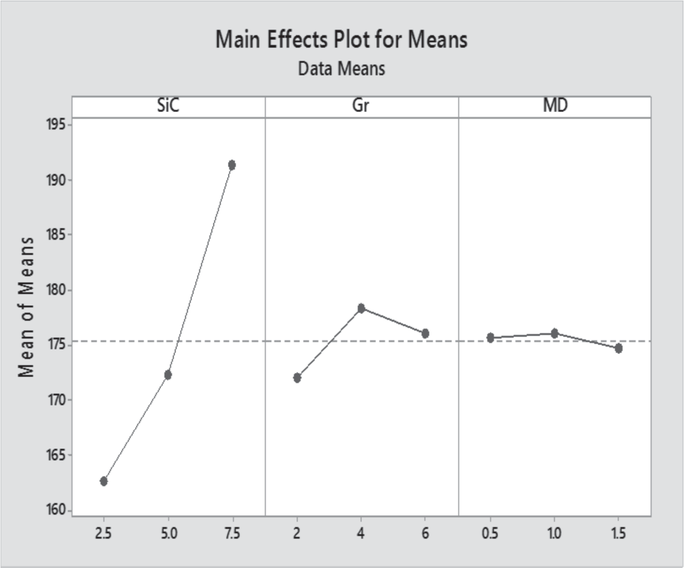


Fig 7 Main effect plot for means

Response table for S/N ratio (larger is better)

Table 8 shows different parameters with different levels along with the calculation of delta statics. The delta statics is obtained by subtracting lowest from the highest average for each factor. Moreover, the rank is assigned by Minitab by delta statics. From Table 8 we can conclude that wt. % of SiC has the enormous influence on the S/N ratio. The wt. % of Gr has the next greatest influence and wt. % of MD has the lowest influence on S/N ratio.

Table 8: Response table for S/N ratio larger isbetter

LEVEL	SiC	Gr	MD
1	44.23	44.69	44.86
2	44.73	45.0	44.89
3	45.63	44.89	44.83
DELTA	1.41	0.31	0.06
RANK	1	2	3

Main effect plot for S/N ratio

The main effect plot was plotted between the S/N ratio and the various process parameters in the present work the parameters are welding current, welding speed, and gas flow rate. The higher is better criteria was used for the interpretation of the main effect plot. From the figure 8, it can be seen that the 7.5 wt.% SiC, 4wt % Gr and 1 wt. % MD gives the higher values.

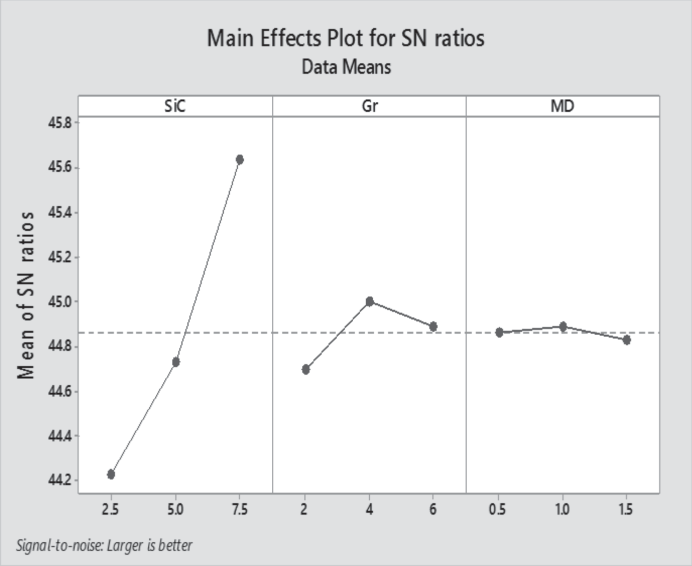


Fig. 8 Main effect plot for means

Result of analysis of variance for tensile strength

The percentage contribution is obtained from the analysis of variance. The percentage contribution shows the contribution of each significant parameterin percentage which affects the response factor here it is a tensile strength [10]. For obtaining the percentage contribution, various values are calculated which is shown in table 9. From table there are two values F-value and P-value. For the parameters to be significant, the P-value should be low, and F-value should be high. It can be observed from the table 9 that wt. % SiC affects the tensile strength maximum 94.80% followed by wt.% of Gr 4.57 % while wt. % MD has minimum affect only 0.21 %.

Table 9: Analysis of variance for tensile strength

Source	**DF**	**Adj.SS**	**Adj.MS**	**F-Value**	**P- Value**	**%Contribution**
SiC	2	1276.22	638.111	229.72	0.004	94.80 %
Gr	2	61.56	30.778	11.08	0.083	4.57 %
MD	2	2.89	1.444	052	0.658	0.21 %
Error	2	5.56	2.778			0.42 %
Total	8	1346.22				

Result of parametric optimization for tensile strength

Taguchi's optimization technique was successfully applied to find out the optimal parameters for maximizing the strength of the specimens. The optimized parameters for tensile strength are shown below in Table 10.

Table 10: Optimized results for tensile testing

SiC	Level 3	7.5
Gr	Level 2	4
MD	Level 2	1

Analysis of variance for microhardness testing

In the same way as the analysis of variance was done for the tensile testing for obtaining the significant parameters the ANOVA was done for microhardness values so that significant factors can be found out and the percentage contribution can be obtained.

Calculation of S/N Ratio

After the micro-hardness testing was done, the S/N ratio was calculated from the software MINITAB. Using Taguchi L9 orthogonal array the microhardness values for different levels of parameters were taken as the response factor for calculating the S/N ratio. The S/N ratio was calculated taking larger is better criteria given by the formula.

$$\text{S/N (larger is better)} = -10\log\left[1/\sum_{i=0}^{n}\frac{1}{y2}\right]$$

where y = Represents the responses for the factor level grouping,

n = Represents the number of responses in the factor level grouping.

Table 11: Calculation of S/N ratio formicrohardness

Reinforcements					
S. NO	**SiC(wt.%)**	**Gr(wt.%)**	**MD (wt %)**	**(Hv)**	**S/N Ratio**
1	2.5	1.5	1	63.2	36.0143
2	2.5	3	2	68.4	36.7011
3	2.5	4.5	3	64.6	36.2047
4	5	1.5	2	86.2	387101
5	5	3	3	91.2	39.1999
6	5	4.5	1	87.2	38.8153
7	7.5	1.5	3	94.5	39.5086
8	7.5	3	1	101.0	40.0864
9	7.5	4.5	2	99.4	39.9477

Response table for means

From the delta and rank values obtained by Table 12 for means, it is clear that the response characteristics, i.e., the microhardness value is greatly influenced by wt % of SiC after that wt % ofGr and wt % of MD. From the response table for means it can be seen that SiC has maximum influence on the response characteristics so is given rank 1 followed by Gr which is given rank 2 and MD which is given rank 3.

Table 12: Response table for means

LEVEL	**SiC**	**Gr**	**MD**
1	65.40	81.30	83.80
2	88.20	86.87	84.67
3	98.30	83.73	83.43
DELTA	32.90	5.57	1.23
RANK	1	2	3

Main effect plot for means

Figure 9 shows the main effect plot for means. The plot shows the various welding parameters and means values. The point represents the means of each parameter. Since the lines are not straight, this shows the presence of the main effect as shown in the figure below. The plot is based on higher the better criteria.

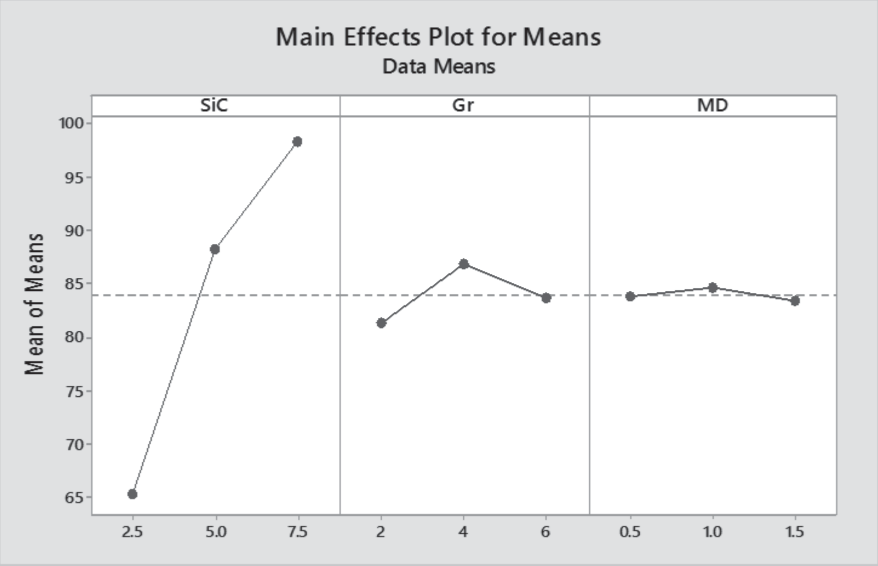


Fig. 9 Main effect plot for means

From the main effect plot, it can be seen that current 7.5 wt. % SiC, 4 wt. % Gr and 1 wt. % MD is associated with highest mean strength.

Response table for S/N ratio larger is better

For every level that has been selected., wt. % SiC wt. % Gr and wt. % MD levels it is required to find out the average of every response characteristicswhich is shown in table 13. The delta statics iscalculated by subtracting lowest from the highest average for each factor. Moreover, the rank is assigned by Minitab by delta statics. From Table, 13we can conclude that wt. % of SiC has the most considerable influence on the S/N ratio wt. % of Gr has the next highest influence and wt. % of MD has the lowest influence on S/N ratio.

Table 13: Response table for S/N ratio larger is better

LEVEL	SiC	Gr	MD
1	42.82	41.28	41.82
2	41.46	41.71	41.56
3	40.61	41.89	41.51
DELTA	2.21	0.62	0.31
RANK	1	2	3

Main effect plot for S/N ratio

The main effect plot for S/N ratio is plotted betweenthe various reinforcements wt.% .

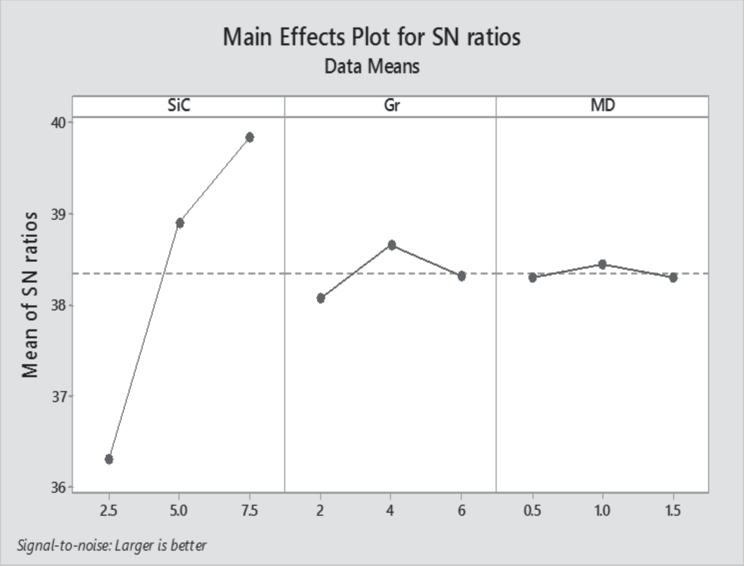


Fig. 10 Main effect plot for S/N ratio

The plot is based on higher the better criteria. Here 7.5 wt. % SiC, 4wt % Gr and 1 wt. % MD is associated with highest mean microhardness values.

Analysis of variance result

Now from the table 14 which shows the ANOVA for hardness we have three significant parameters from the P-value obtained which shows that the three different parameters affected the result i.e., the microhardness.

Table 14: Analysis of variance for microhardness

Source	DF	Adj.SS	Adj.MS	F-Value	P- Value	% Contribution
SiC	2	1704.26	852.130	745.30	0.001	97.07%
Gr	2	46.73	23.363	20.43	0.047	2.66 %
MD	2	2.41	1.203	1.05	0.487	0.13 %
Error	2	2.29	1.143			0.14%
Total	8	1755.68				

From table 14 there are two values F-value and P- value. For the parameters to be significant, the P-value should be low, and F-value should be high. It can be observed from the table that wt% SiC affect the microhardness value maximum 97.07 % followed by wt% of Gr 2.66 % and wt% of MD 0.13 %.

Result of parametric optimization formicrohardness

Taguchi's optimization technique was successfully applied to find out the optimal parameters for microhardness of the specimens. The optimized parameters for hardness are as follows.

Table 15. Optimized results for microhardness testing

SiC	Level 3	7.5
Gr	Level 2	4
MD	Level 2	1

6. Conclusion

From the present work, it can be concluded that.

1. With the increase in the wt. % of SiC and Gr the tensile strength and microhardness was improved.
2. The optimum welding condition obtained by Taguchi method for tensile strength and microhardness was 7.5 wt. % of SiC , 4 wt. % Gr and 1 wt.% of MD.
3. It was seen that nearly equal amount of wt. % of SiC and Gr results in improvement of tensile strength.
4. Higher wt% of Gr with respect to SiC decreases the tensile strength.
5. Microhardness was greatly influenced by the wt. % of SiC as it can be seen from the ANOVA table for Microhardness in which wt.% of SiC with 97.07% contribution is significant as it rejects the null hypothesis.
6. MD showed lower contribution in improving the mechanical properties.

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Optimization analysis technique of plastic to fuel pyrolysis

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Abstract

The main objectives of this study were to understand and optimize the processes of plastic pyrolysis for maximizing the oil products, and to design a continuous pyrolysis apparatus as a semi-scale commercial plant. The materials to be tested in this study are (High Density Polyethylene) HDPE, (Low Density Polyethylene) LDPE, (Polypropylene) PP and (Polystyrene) PS which account for 70% of the plastics used in packaging. (Polyvinyl Chloride) PVC and (Polyethylene Terephthalate) PET are not studied due to health concerns. This study was divided into three stages following anextensive literature review on plastic pyrolysis. The first stage of the study focused on understanding of the thermal cracking process and identifying key factors that affect the pyrolysis process and the quality of the plastic pyrolysis products. From the literature review, reaction temperature was the most important factor that influenced the whole process, however, this study has also investigated the secondary cracking processand other significant factors such as temperature, heating rate, type of plastic, catalysts, interaction between different plastics, pyrolysis process, etc. The effects of secondary cracking were investigated.

This work has not been found in other researches. The second stage of the study was to optimize the operation conditions and the reactor design to produce high quality liquid fuel (diesel) from the pyrolysis of LDPE. Chemical analyses on the products were performed in this stage using gas chromatography (GC) and mass spectrometry (MS). Char content was also analyzed by using electron microscope. In the final stage, a continuous pyrolysis apparatus was designed and manufactured based on the results and the information collected from the work performed during the first two stages. The aim of this continuous apparatus was to convert LDPE and mixture of PE, PP and PS into gas and liquid fuels with maximizing the diesel range product. The apparatus consists of a feeding section, a pyrolysis reactor, and a separation section, which separated diesel, wax, petrol and non- condensable gases.

Keywords: Pyrolysis, Fuel, Optimization, (High Density Polyethylene) HDPE, (Low Density Polyethylene) LDPE, (Polypropylene) PP and (Polystyrene) PS (Polyvinyl Chloride) PVC and (Polyethylene Terephthalate) PET