

# Effect of Process Parameters on the Tensile Strength of the Developed Composite of Al 6065 in Stir Casting Process

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## Abstract

There are numerous techniques of producing metal matrix composites (MMC) like infiltration, stir casting process, sinter-forging, diffusion bonding etc. Stir casting process is amongst the most known technique to synthesize MMC. In current study an agro-based MMC is prepared by stir casting process using waste eggshell and rice husk as primary and secondary reinforcements and Al 6065 as base material. Process parameters (PP) have a major impact on tensile strength of finally prepared composite. The major factors also called as process parameters in stir casting process that is having a determining impact in tensile strength of hybrid MMC are temperature as well as speed of stirring, duration of stirring and temperature at which the reinforcement is allowed to be poured. The primary aim behind the current work is to evaluate the optimal values of process parameters in friction stir casting process. 9 separate samples have been prepared at different PP for analyzing tensile strength of composite and these samples were machined as per the ASTM standards for performing the test of tensile strength. It was concluded that maximum tensile strength value was found at a stirring speed of 320 rpm, optimal stirring temperature was 630°C and the time of stirring was 25 minutes. At these values of PP, the tensile strength of prepared composite was improved by 35% in contrast to that of the base material.

## 1. Introduction

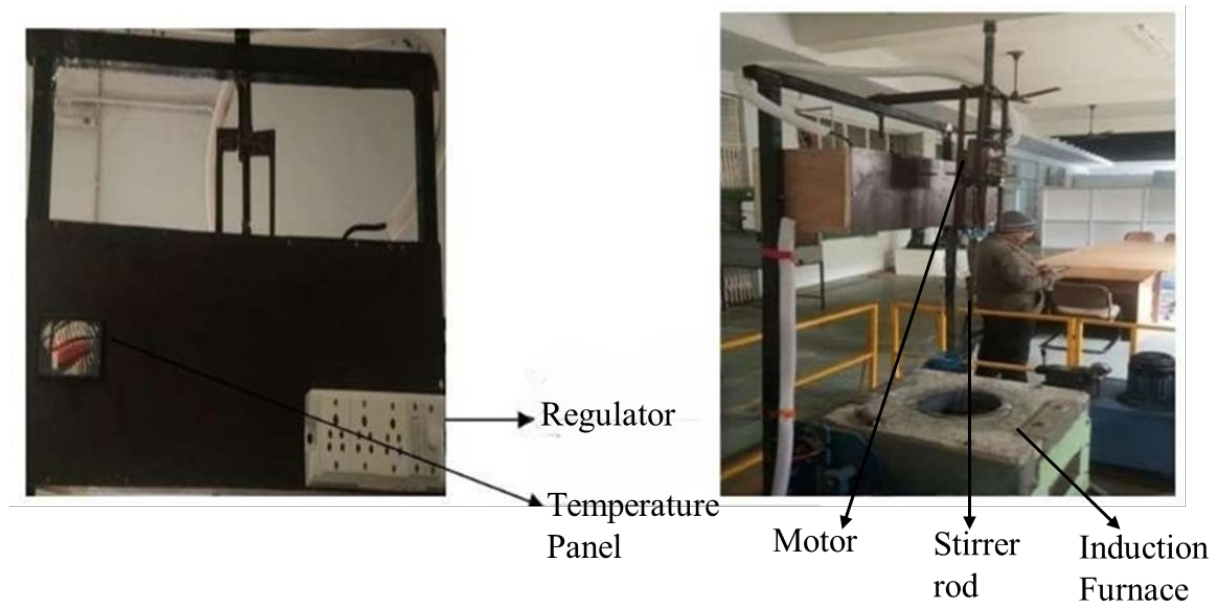
Pollution is damaging our environment at an exponential rate. Pollution is mainly generated from the wastes that are dumped in nature. Eggshell and rice husk ash is also one such kind of waste. In this work an aluminum-based composite has been developed using egg shell as primary and rice husk as secondary reinforcement with the help of stir casting process. The emerging sector for aviation and car industries is the creation of new range of materials and components [1]. A hybrid is developed by a mixture of two or more components that are chemically and physically distinct. Whenever the matrix material is metallic, the matrix composites composite (MMC) is generated and strengthening occurs shape in the presence of powder, earthenware, synthetic fibers and whiskers. Matrix composites reinforcing which consist of a metallic and perhaps other substance that could be ceramic or another organic compound [2]. Stir casting process is amongst the best suitable processing method for liquid state base material as it is simple, reliable, and economical [3].

Miskovic et al. have stir casted Aluminium A356 as a base material and reinforced 1, 2 and 3 wt. % of Al<sub>2</sub>O<sub>3</sub> [4]. Metin Kok has performed experimentations on the particles of Al<sub>2</sub>O<sub>3</sub> composite and he studied the life of tool, tool wearing, surface roughness and life of tool in turning operations by using TiN coatings and uncoated HX tools of carbide in various cutting conditions [4]. In another investigation conducted that typically in the stir casting

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technique matrix material is heated until the melting point inside a vessel to produce MMC followed by the continuous stirring of liquid/molten metal to develop a vortex. Subsequently the reinforcing particles are added to the vortex [5,6]. The process parameters that influence the tensile strength of the developed composite are stirring speed, stirring temperature, duration of stirring and pouring temperature [7-9]. Out of the available methods to synthesize these AMC, stir casting is most commonly practiced [10]. Stir casting method is very economical, flexible, simple and it is having wide range of applications [11-13]. Also, the billets of AMC that are prepared through this technique could be shaped by incorporating secondary process such as rolling, extrusion etc [14-20]. Fused deposition modelling (FDM) is indeed one of the additive manufacturing methods that can produce multi-material parts [21]. A very close watch on these process parameters is very necessary while synthesizing any composite material. A setup has been designed inside the laboratory of GLA University Mathura for preparing the composite, the novelty of this setup is the height of the stirrer [22] stirring speed can be changed very easily as per the optimized results. A clear picture of the current set up has been shown by Figure 1.



**Fig. 1** Shows the developed stirring casting process setup

The process of stir casting is widely agreed as a highly useful path, commonly understood economically, amongst discrete composite materials. The significance lies in its versatility, efficiency and potential applications for the processing of large quantities. It is desirable as it facilitates use of a traditional metal manufacturing method, and thus minimizes the eventual cost of production. The expense of manufacturing composite using a casting technique is around one-third to half of what it is in other methods, and it is estimated that expense could drop to one-tenth in large scale production. In light of the reviewer's suggestion, we have introduced a dedicated section that elaborates on the diverse manufacturing techniques employed to facilitate the replacement process. By exploring methods such as powder metallurgy, stir casting, and infiltration, we offer a comprehensive understanding of how MMCs are integrated into the manufacturing process. This discussion now encompasses the step-by-step procedure, from material preparation to the final production of components, shedding light on the intricate mechanics of this replacement. The crystallization development of composite materials typically facilitates the establishment of a melting of the chosen matrix material, preceded by injection of some reinforcing agent in melted metal, resulting in a sufficient distribution.

In current work at various values of different process parameters and the corresponding value of tensile strength has been measured thus the optimal value of process parameters has been noted at which the tensile strength comes out to be maximum.

## 2. Material and Methods

### 2.1 Primary Reinforcement as Eggshell (ES)

The hard shell of an egg, primarily composed of calcium carbonate ( $\text{CaCO}_3$ ), constitutes a significant industrial waste product. Within this shell, calcium particles are prevalent, accompanied by protein and a diverse array of minerals. The eggshell predominantly comprises  $\text{CaCO}_3$ , accounting for approximately 90% of its composition. This readily available eggshell (ES) material is typically discarded as waste but holds untapped economic

potential. The eggshell possesses remarkable compressive strength and exhibits favorable electrical properties, making it a preferred composite alongside polyamide, especially in the automotive sector. Microscopic analysis reveals the ES's internal structure, highlighting its porosity and matrix. This discarded byproduct from the food industry contributes significantly to air and soil pollution, adversely affecting the environment. Improper disposal of eggshells can also degrade agricultural land. The eggshell's composition consists of roughly 95% calcium carbonate, primarily in the form of calcite, and the remaining 5% comprises organic substances such as  $Al_2O_3$ ,  $SiO_2$ , S, P, Cl,  $Cr_2O_3$ , MnO, and various proteins. Chemical composition of ES in Table 1.

**Table 1** Chemical composition of ES

Element available in ES	Value%
(Aluminum oxide) $Al_2O_3$	0.03
(Calcium oxide) CaO	50.70
(Chlorine) Cl	0.08
(Ferric oxide) $Fe_2O_3$	0.02
(Magnesium oxide) MgO	0.01
(Nickel oxide) NiO	0.001
(Phosphorus oxide) $P_2O_5$	0.24
(Silicon dioxide) $SiO_2$	0.09
(Sodium oxide) $Na_2O$	0.19
(Strontium oxide) SrO	0.13
(Sulphur oxide) $SO_3$	0.55
(Loss of ignition) LOI	47.80

## 2.2 Secondary Reinforcement as Rice Husk Ash (RHA)

Rice hulls, also known as rice husks, serve as the protective outer coverings of rice grains. They fulfill the role of safeguarding rice during its growth cycle. Rice hulls find multiple applications, such as building materials, soil enrichment, insulation, and even as a source of fuel. These hulls are derived from the straw of the rice plant. Their composition is primarily indigestible for humans, largely due to their tough and fibrous nature, leading to a high fiber content. To separate rice from its hulls, a traditional method called winnowing is employed. In this technique, the entire mixture of rice and hulls is tossed into the air, allowing the lighter hulls to be carried away by the wind while the heavier rice grains fall back into the container.

Rice hull ash (RHA) contains a significant presence of  $SiO_2$  (silicon dioxide). This element constitutes a higher percentage compared to other constituents like graphite, calcium oxide, magnesium oxide, potassium oxide, and ferrous oxide within RHA. Originating as agricultural waste, rice hulls are often burned by farmers, inadvertently contributing to air pollution in the form of smog. The material possesses a Si-content of over 85%, granting it the label "Super-Pozzolans." To enhance toughness and strength, RHA particles are uniformly blended with an aluminum matrix. This amalgamation yields a cost-effective composite material exhibiting pozzolanic reactivity. Chemical composition of RHA in Table 2. The pozzolanic reaction is a prolonged chemical process involving dissolved silicic acid, water, and either CaO or  $Ca(OH)_2$  or alternative pozzolanic agents. These elements combine to form a sturdy matrix.

**Table 2** Chemical composition of RHA

S. No.	Constituent	value%
1.	$SiO_2$	90.23
2.	Graphite	4.77
3.	CaO	1.58
4.	MgO	0.53
5.	$K_2O$	0.39
6.	$Fe_2O_3$	0.39

### 2.3 Sieve Test

The ES and RHA powder were sieved using IS Sieve multiplier factor 200 (75μ), and the powder passing the sieve was used. This sieve was selected in order to achieve a uniform powdery. And the ball-milled ES and RHA are fine grain particle mixing with AA3105 in stir casting process to form a better composite material. Table 3 shows grain fineness number.

**Table 3** Grain fineness number

Sl.	Sieve series no.	Sand remained on each sieve (gm)	% of retained on each sieve	Multiplier factor	Product
1.	4.75	0	0	2	0
2.	2.36	0	0	7	0
3.	1.18	2	0.93	14	13.02
4.	600	6	2.79	25	69.75
5.	300	100	46.51	52	2418.52
6.	150	44	20.46	100	2046
7.	75	63	29.30	200	5860
		Total	99.99		10407.29

Grain fineness Number=Total product/Total % of retained on each sieve

$$=10407.29/99.99=104.0833$$

$$=1.0408 * 10^{17} \text{ particle size}$$



Sieve test m/c



500 particle size carbonized ES



300 particle size carbonized ES



100 particle size carbonized ES



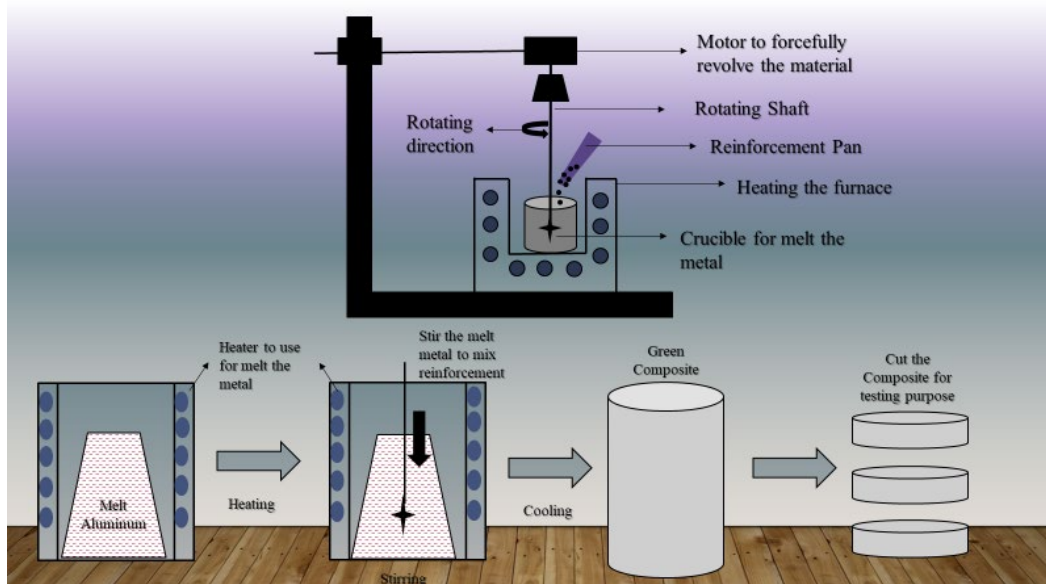
1.04 x 10<sup>17</sup> particle size carbonized ES

**Fig. 2** Sieve test to used fine grain size reinforcement

### 2.4 Methods

In current experimentation, to prepare the AMMC firstly the base metal i.e., Al6065 is melted then at the melted surface vortex is formed by dynamically stirring the composite finally the reinforcing material (ES & RHA) are

added to vortex. Stir casting process is vortex and vigorous method to prepare the hybrid and green MMCs. Firstly, AA3105 is melted in the furnace when metal is in semi solid form. Eggshell and RHA (Rice Husk Ash) were chosen as reinforcements due to their abundant availability, cost-effectiveness, and desirable mechanical properties, enhancing the composite's sustainability and performance. Reinforcement i.e., ES and RHA are Preheated at temperature 300°C and 250°C respectively. Reinforcement incorporated in the melted AA3105 in uniformly distributed. Metal is introduced properly in AA3105 until MMCs are poured in the casting pattern. Figure 3 indicates the stir casting setup to prepare required composite.



**Fig. 3** Schematic procedure of stir casting method for preparing the MMC



**Fig. 4** Development process of composite material

### 3. Composite Material Synthesis

Figure 3 illustrates the composite procedure used in the stir-up method. Built up from AA 3105 and being used as a starting point. The powder of carbonized ES and RHA were preheated at 300°C and 250°C respectively before mixing in the matrix material. Whereas carbonized particles of ES and RHA that were taken out of ball milling represents as a single entity was preheated at 250°C. AA3105 was heated up to the melting point inside muffle furnace. Particles of reinforcement were added as soon as the matrix material temperature reached up to 690°C.

Squeeze, pressure was applied on the UTM machine in the mushy zone to eliminate the gaps or voids and uneven arrangement of reinforcing particles. Composition of developed composite material with weight % of the reinforcement is shown in Table 1. 10 sample specimens at changing process parameters have been prepared and the tensile strength was tested at each of the process parameters.

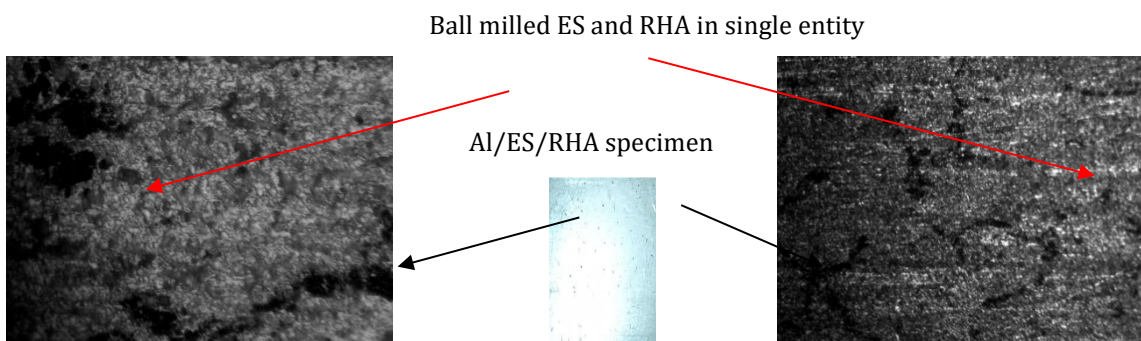
**Table 4 Composite preparation at different wt.% of reinforcements**

S. No.	Reinforcement (wt. %)	AA3105/(ES)	Heat-treated AA3105/ES/RHA Composition with ball milled	AA3105/RHA	AA3105/ES/RHA Composition without ball-milled	AA3105/ES/RHA Composition with ball milled
1.	3.0	Al/3 %ES	Al/1.5 % ES/1.5 % RHA	Al/3%RHA	Al/1.5 % ES/1.5 % RHA	Al/1.5 % ES/ 1.5 % RHA
2.	6.0	Al/6 % ES	Al/3 % ES / 3% RHA	Al/6% RHA	Al/3 % ES / 3% RHA	Al/3 % ES/ 3% RHA
3.	9.0	Al/9 %ES	Al/4.5 % ES/ 4.5 % RHA	Al/9 %RHA	Al/4.5 % ES/4.5 % RHA	Al/4.5 % ES/4.5 % RHA
4.	12.0	Al/12 %ES	Al/6 % ES / 6 %RHA	Al/12 %RHA	Al/6 % ES / 6 %RHA	Al/6 % ES /6 % RHA
5.	15.0	Al/15 % ES	Al/7.5 % ES/ 7.5 % RHA	Al/15 %RHA	Al/7.5 % ES/ 7.5 % RHA	Al/7.5 %ES/ 7.5 % RHA

## 4. Results and Discussions

### 4.1 Microstructure Analysis

Based on a micro structural representation in figure 4, BSIM “ESM” is verified. Reinforcement pellets have been transformed to separate pieces. Commodity chemicals became uniformly blended into the molten material. It has already been discovered how non-ball-milled particles were not evenly dispersed because of densities of egg powder and flour did not align. A more equal allocation of ball-milled specimens to the composite allowed it more ductile. The optimized framework photographs were captured at 320 rpm and when stirring took place for a period of 20 minutes.



**Fig. 5** Ball-milled ES and RHA reinforced composite material

### 4.2 Variation of Tensile Strength with Stirring Speed

The speed of stirrer speed has been varied keeping all other parameters constant and at each value of speed, tensile strength of developed specimen has been calculated. The speed of stirrer screw was measured by a touch

tachometer. Since high speed allows for better blending of reinforcing content, tensile strength improves as speed increases. Since the two materials are well mixed, the tensile strength is strong. As a consequence, a fast speed is often preferred for improved performance [22] The Control of speed is very important for successful production of casting. Table 2 summarizes the varied speed and the corresponding obtained tensile strength.

From the above table it is found that initially the tensile strength increases as the stirring speed increases than at 320 rpm where the corresponding value of tensile strength comes out to be 18.465 MPa. After that, again the tensile strength value drops as the stirring speed increases further. The results obtained in this experimentation validate the claim made that at longer value of stirring speeds and stirring time would lead do fine distribution of particles he concluded that at 700 rpm of stirring speed for 15 mins the microstructure shows more uniformity in the distribution of the reinforcing particles.

### 4.3 Tensile Strength Variation with Stirring Time

At 320 rpm of stirring speed the value of tensile strength comes out to be maximum at this stirring speed the duration of stirring has been varied and the value of tensile strength has been calculated for each of the prepared sample. As the stirring period is raised, the tensile strength improves as well, so the combining of the reinforcement particles is improved as a result of excessive mixing time. Since the two materials are well mixed, the tensile strength is strong. As a consequence, a longer stirring period is often preferable for better outcomes [25]. Table 5 shows the impact of stirring time on the tensile strength. From Table 6 it is quite clear the as the value of stirring time increases the tensile strength value goes on increasing. At 20 mins of stirring time the highest value of tensile strength is obtained i.e., 17.932 MPa. The reason for the rise in the tensile strength in accordance with the stirring time is probably the proper distribution of the reinforcement particles. It is indeed readily evident that primarily the tensile strength has far greater value increases as the stirring speed increases that after 320 rpm the value starts decreasing. Thus, the maximum tensile strength had been at 320 revolutions per minute was determined to be 18.44MPa Speed of stirrer has a quite dominating influence mostly on design and/mechanical/mechanical/structural characteristics of MMC, a very certain impact of the most common effect of increasing the stirrer speed is to encourage proper distribution and enhance the refinement [22]. Table 7 illustrates the ANOVA table for the tensile strength findings.

**Table 5** Variation of tensile strength with stirring speed

S. No.	Stirring Speed	Tensile Strength
1	200	147.63
2	220	147.92
3	240	153.24
4	260	157.65
5	280	164.39
6	300	177.60
7	320	184.65
8	340	175.68
9	360	172.32
10	380	169.78

**Table 6** Tensile strength variation due to time of stirring at speed 320 rpm

S. No.	Stirring Time (in Min.)	Tensile Strength (MPa)
1	2	184.65
2	4	185.62
3	6	194.57
4	8	195.93
5	10	200.98
6	12	203.45
7	14	204.24
8	16	205.62
9	18	207.83
10	20	209.32

**Table 7** ANOVA table for tensile strength

Source	Sum of Square	DF	Mean Square	F Value	p-value Prob>F
Model	76345.78	9	8483.02	91.99	<10 <sup>-5</sup>
A-Temperature	16291.23	1	16291.17	178.23	<10 <sup>-5</sup>
B-Speed	14536.24	1	14537.24	158.02	<10 <sup>-5</sup>
C-Time	31252.00	1	31251.01	338.89	<10 <sup>-5</sup>
AB	0.26	1	0.26	2.816E-3	0.9621
AC	0.0000	1	0.0000	0.0000	1.0002
BC	1610.00	1	1610.00	18.43	0.0043
A2	4664.00	1	4664.00	51.73	0.0003
B2	1408.23	1	1408.23	15.34	0.0061
C2	7245.78	1	7245.78	79.01	<10 <sup>-5</sup>
Residual	645.07	7	91.97		
Lack of fit	516.27	3	169.98	5.27	0.0712
Pure error	129.87	4	33.02		
Cor Total	76987.89	16			
Std. Dev.	9.63			R-Squared	0.9876
Mean	328.93			Adj R-Squared	0.9821
CV%	3.01			Pre-R-Squared	0.8769
PRESS	8457.26			Adeq-Precision	35.732

$$\text{Tensile Strength} = 324.02 - 44.98 \times A + 41.97 \times B + 63.01 \times C + 0.23 \times A \times B + 0.0000 \times A \times C + 21.01 \times B \times C + 32.87 \times A^2 + 17.79 \times B^2 - 42.36 \times C^2$$

The Analysis of Variance (ANOVA) technique is employed to assess the statistical significance of differences among multiple groups or treatments. It involves partitioning the total variation observed in a dataset into different components, such as variation within groups and variation between groups. By comparing these components, ANOVA helps determine whether the observed differences between groups are likely due to random variation or if they represent true effects. In ANOVA, the null hypothesis assumes that there are no significant differences between the group means, while the alternative hypothesis suggests that at least one group mean is different from the others. The technique calculates a test statistic (F-statistic) by comparing the variation between group means to the variation within each group. If the F-statistic is large enough and exceeds a critical value based on the chosen significance level, the null hypothesis is rejected, indicating that at least one group mean differs significantly from the others. In figure 6, perhaps every identified value is linked to the forecasted values generated using the model. The regression model suits the measured data reasonably fine (a). Figure 6 (b) represents the normal probability % and its relationship with the standardized residuals for the tensile strength. It is observed from the graph that the residuals are likely to follow on the straight line, hence the errors are distributed normally.

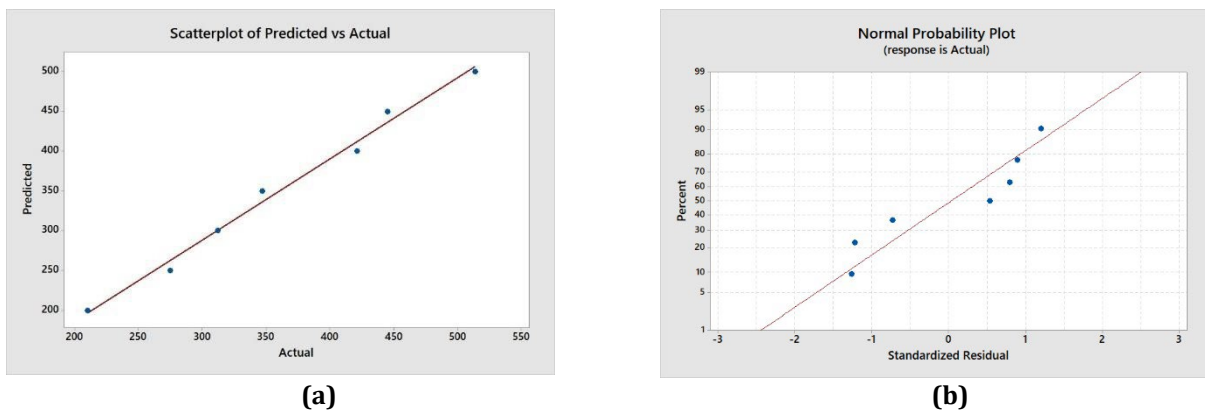
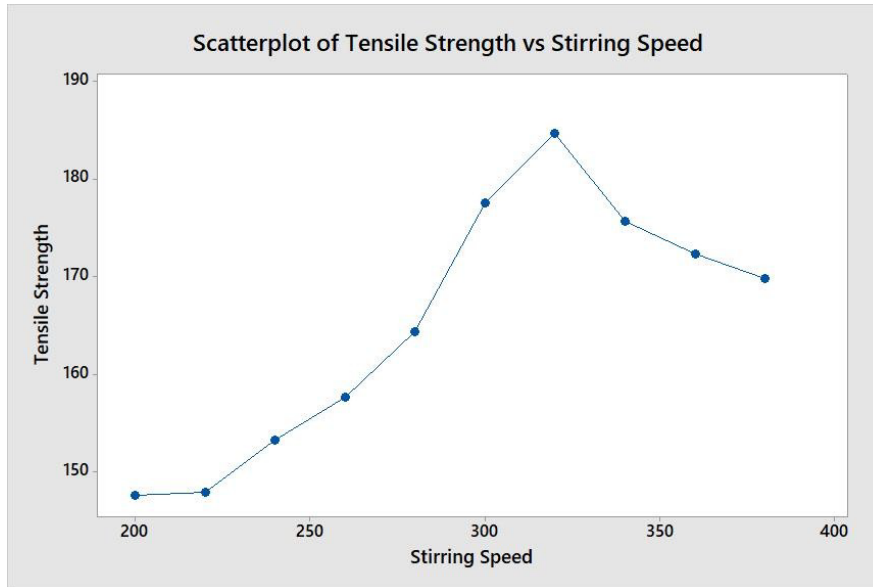
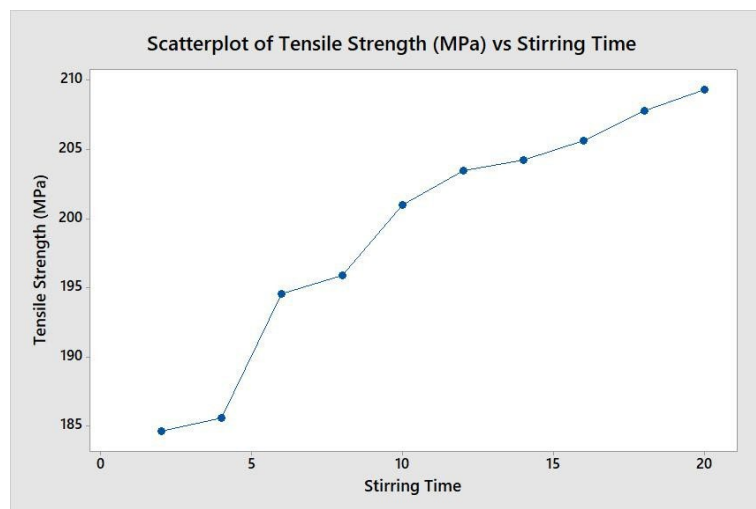


Fig. 6 (a) Relation between predicted vs actual value; (b) Normal prob. % vs. residuals



**Fig. 7** Tensile strength variation with stirring speed

From the graph as shown by Fig 7 it is quite evident that tensile strength increases as the stirring speed increases. Therefore, the maximum tensile strength value at 20 minutes of stirred time was found to be 20.932 MPa. The test findings revealed that perhaps the composite yielded metallurgical characteristics at 10 wt. percent SiC at a blade's angles of 30 degree and a stirring frequency of 100 rpm. Findings showed the particles aggregation existed in certain locations while slower speed as well as low stirring period, whereas for some cases SiC involvement was not recognized. It could be expected to enhance the uniform distribution of SiC within the Aluminum matrix through the rising in the "stirring speed and stirring time. Best SiC distribution have been identified at 30° blade angle", 100 rpm stirred velocity [23]. As the stirring period is raised, the tensile strength improves as well, so the combining of the reinforcement particles is improved as a result of excessive mixing time. Figure 8 illustrates the graphical relationship between stirring time and tensile strength. Since the two materials are well mixed, the tensile strength is strong. As a consequence, a longer stirring period is often preferable for better outcomes. Figure 8 (a) and (b) represent the contour and surface plots of tensile strength, stirring time and stirring speed.



**Fig. 8** Tensile strength variation with stirring speed

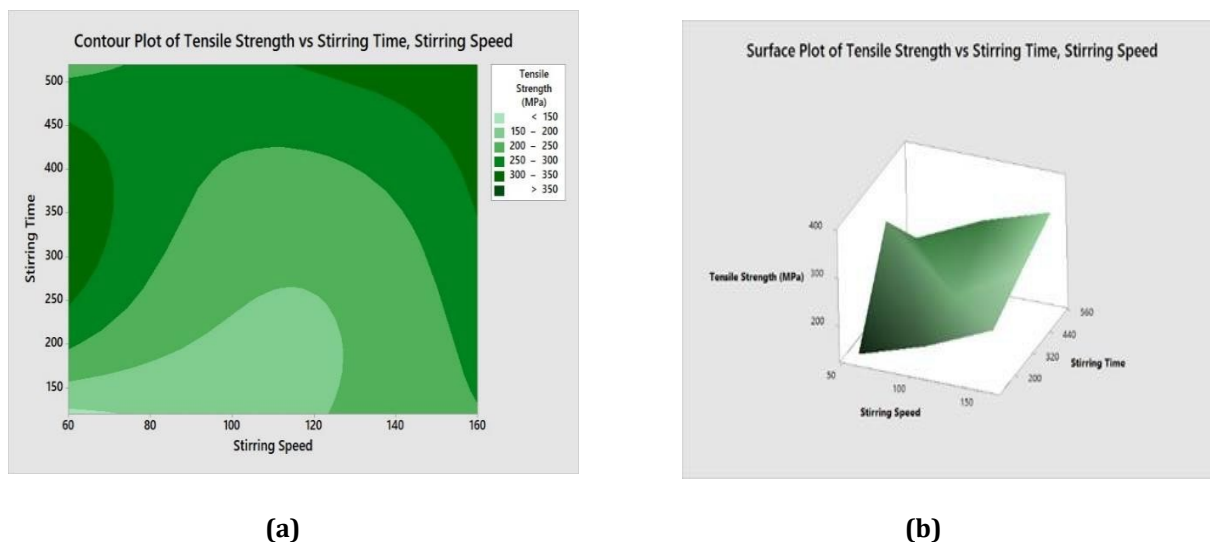


Fig. 8 (a) Contour plots; (b) 3D Surface plots between tensile strength vs. stirring time, stirring speed

## 5. Conclusions

Eggshells (ES) and ash of rice husk (RHA) that are considered as a waste product are significantly creating a lot of environmental issues (pollution). Although, the most promising technique for coping with such problems is the utilization of these waste products.

- i. ESA and RHA have such properties that will enhance the mechanical properties of the base material (Al-alloy), thus in current study such wastes (ESA and RHA) have been used as primary and secondary reinforcements.
- ii. Ball milling technique has been used to distribute these reinforcements namely, RHA and ESA in order to distribute them into the metal matrix AA3105 uniformly.
- iii. Tensile strength and hardness examination for the finally developed MMC was carried out and it was found that for AA3105/5% ES powder/5% RHA wt. % of reinforcement these were enhanced by 25.41% and 50% in their respective manner. Moreover, the toughness and ductility were observed to be decreased.
- iv. In current study, the examination was carried out based on varying the process parameters to evaluate their effect on the mechanical properties (Tensile Strength) of the composite.
- v. 320 rpm with a stirring time of 20 minutes was observed to be the optimum value to obtain the maximum tensile strength value i.e., 20.932 MPa.

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## Conflict of Interest

The authors declare that there is no conflict of interest.

## Author Contribution

The authors confirm contribution to the paper as follows: **Study conception and design, data collection, analysis and interpretation of results, draft manuscript preparation** Rajat Yadav; **analysis and interpretation of results, draft manuscript preparation** Vijay Kumar Dwivedi. All authors reviewed the results and approved the final version of the manuscript.

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