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Effect of stirring speed and time on the mechanical properties of Al8011-SiC metal matrix composites

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ABSTRACT

In this experimental research work, specimens were fabricated with three different stirring time periods and two different stirring speeds using the standard experimental setup to obtain Al 8011-SiC composites with the reinforcement of SiC by the stir casting method. Al8011 aluminum alloy is the latest explored material in the aluminum sequence which is used in the aerospace industries and heat exchangers. The stir casting method is the most broadly used in the liquid metallurgy technique to manufacture composites and to acquire uniform distribution of particles. Experiments are conducted with different experimental parameter ranges for the pure unreinforced metal alloy and Al8011-SiC composite specimens and results were observed and discussed. The highest hardness, yield strength, and tensile strength were observed in Al8011-SiC composites at the maximum stirring conditions and stirring time. Elongation was also observed to be highest for the same stirring conditions. The toughness of the composites remains the same for all stirring speeds and stirring times. Mechanical properties except the toughness value are gradually increased with the rise of stirring speed and time in the composite specimens because of the homogenous distribution of SiC particles in the Al8011 matrix at the maximum speed and timings.

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1. Introduction

Metal Matrix Composites (MMC) contain metal matrix as the continuous phase in which the reinforcement like metal, organic material (fly ash, bamboo leaf ash), or ceramic material (graphite, SiC, alumina) were diffused. The physical properties like hardness, toughness, ductility, tribological behavior, and corrosion resistance of the unreinforced alloy were improved with the inclusion of reinforcement particles in the composites to get much better mechanical strength. Aluminum, Magnesium, Silicon, Nickel, Copper, and Titanium metals were the frequently used matrix materials. Aluminum is preferred by a variety of researchers as the base element in the Metal Matrix Composites (MMC) due to its high load withstanding capacity, enhanced corrosion and wear resistance, highest thermal and electrical conductivity, and less weight. In the developing world, aluminum composites are found applied in aeronautical, automobile, and construction technologies as unconventional materials because of their superior mechanical properties and wear resistance at maximum load and higher temperature. The manufacturing methodology of Aluminium MMC is generally classified into two important categories known as solid-state processing and liquid state processing. Stir casting method, spray casting, squeeze casting, in situ (reactive) method; ultrasonic casting is the different forms of liquid state processing method. Powder metallurgy, vapor deposition, friction stir process, high energy ball milling, and diffusion bonding method belong to the solid-state process. The fabrication of aluminum Metal Matrix Composites involves high costs; therefore cost-efficient method should be followed to expand its application. Among the various manufacturing methods stir casting is considered an easy, less costly, and extensively used method by the researchers. Sahin et al., found that Aluminium MMC can be used in various applications such as vehicle bodies and aircraft for the replacement material [1]. Kevorkijan experimented and concluded that aluminum alloy reinforced with various percentages of SiC exhibits superior mechanical and tribological properties than the unreinforced alloy [2]. Pugalenthi et al., investigated to improve the mechanical properties of MMC's

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through practical experiments and found good enhancement in hardness and strength when adding the SiC and Al2O3 reinforcements[3].

Nai et al., investigated the influence of stirring speed and noted that homogenous distribution of SiC particles was obtained at the optimum stirring speed parameter in Al-SiC composites [4]. Radhika et al., investigated the mechanical and tribological behavior of LM25/SiC/alumina composites and confers that the composites exhibit superior results than the unreinforced alloy [5]. Komai et al., conducted experiments in Al7075-SiC composites samples to enhance the tensile and fatigue behavior [6]. Hashim et al., conclude that by varying stirring speed as one of the parameters there is an increase in mechanical properties of the composites[7]. Ravesh et al., conducted experiments using Al6061-SiC-fly ash Metal Matrix Composites which were produced by using stir casting methods with unreinforced alloy and confers that the increase in SiC content enhances the mechanical properties of the composites[8]. Sharanabasappa et al., were conducted different strength of material tests such as hardness, tensile test, and impact test on the unreinforced alloy and the composite specimen. They concluded that the homogenous distribution of SiC and alumina particles in the aluminum metal matrix can be obtained in the stir casting method and it shows good performance than the unreinforced alloy. Properties of Al-SiC-alumina composites depend on alumina content in Hardness and Tensile strength but it reduces the impact strength when it exceeds [9].

Anand Kumar et al., conducted the experiments in Al-4.5% Cu/10TiC composites manufactured by In-Situ powder metallurgy Method and the result shows that after the inclusion of 10% TiC in the Al-4.5%Cu the yield strength is increased from 76 to 87 MPa, an increase of 12.64%, ultimate tensile strength increased from 118 to 147 MPa, increase of 19.72% and hardness of the composites improved by 35.79%[10].

Mahendra Boopathi et al., compared the performances of different specimens such as Al2024-SiC, Al2024-fly ash, Al2024-SiC-fly ash composites, and the final experimental result indicated that Al2024-SiC-fly ash composites exhibit superior mechanical properties than the Al2024-SiC and Al2024-fly ash composites[11]. Kumar et al., concluded that the mechanical and tribological properties of the Al-7Si-TiB2 composites can be enhanced by adding the proper percentage inclusion of titanium diboride[12]. Alaneme et al., states that the wear resistance of hybrid composites increased with the increase in weight percentage of bamboo leaf ash and the Corrosion resistance of Al-SiC-BLA composites display better property in the NaCl solution compared to the H_2SO_4 solution[13].

Karthik Kumar et al., studied the mechanical behavior of Al8011-B4C-red mud composites fabricated by the stir casting method. Their result indicated that the reinforcement of red mud and boron particles increases the mechanical properties of the hybrid composites [14]. Sreenivas Rao et al., conducted experiments like hardness test, ultimate tensile test, and compressive test on the Al8011-red mud composites produced by the stir casting method. They concluded that there is an enormous improvement in the mechanical properties of Al8011-red mud composites due to the addition of red mud particles in the Al8011-matrix [15]. Lathashankar et al., analyzed the wear behavior of Al8011-graphite composites produced by the stir casting route. Their study revealed that the wear resistance of Al8011-graphite composites increases due to the uniform distribution of graphite particles [16]. Ashok et al., studied the effect of particle size of SiC on the mechanical behavior of Al8011-SiC composites. They conferred that the addition of fine SiC particles enhances the mechanical properties of Al8011-SiC composites more than the intermediate and coarse particles [17]. Ashok et al., analyzed the wear behavior of Al8011-SiC composites fabricated by the reinforcement of three different SiC particles (63, 76, 89 μm). It was clear that the wear resistance of Al8011-SiC coarse composites was higher than the intermediate and fine reinforced Al8011-SiC composites [18].

Balasivanandha Prabhu investigated the different particle-reinforced aluminum composite specimens fabricated at various stirring speeds and stirring times. Experimental results confirm that better microstructure and hardness were obtained at higher ranges of stirring parameters [19]. Raju et al., experimented with Al7075-alumina composites specimens produced with three different speeds (300,400,500 rpm) and three different stirring time periods (5, 10, 15 min). They state that the homogenous distribution of alumina reinforcement enhances the properties of the composites at higher levels of stirring parameters [20].

Jebeen Moses et al., revealed that the selection of stir casting parameters directly enhances or diminishes the mechanical properties of the composites by investigating the various process parameters of stir casting on the ultimate tensile strength of the Al6061-TiC composites. Also, the experiments show that better ultimate strength was achieved if there is less porosity and uniform distribution of particles [21]. Aquida et al., found that at lower stirring speed particle clustering takes place which leads to lower porosity formation, and at maximum speed, gases formation causes higher porosity but at medium speed, there is no formation of porosity and particles were distributed evenly by studying different stirring speed and reinforcement in the porosity formation in Aluminium Metal Matrix Composites [22].

Guan et al., conducted the experimental research work with different stirring time periods (20 and 30 min) and stirring speed of 300 rpm to fabricate Al6061 composites and its different mechanical behavior was investigated. The experimental outcomes confer that homogenous distribution of reinforcement was derived at the higher stirring time, which enhances the properties of the composites [23].

2. Materials & methods

2.1. Aluminum 8011

In this investigation, aluminum alloy (Al8011) was used as a base alloy. The fabrication of the Metal Matrix Composite (MMC) used in the current study was carried out by the stir casting method (liquid metallurgy method). The composition of the Al8011 alloy used in the present research work is listed in Table 1.

2.2. Silicon carbide

Silicon carbide otherwise known as carborundum received from the supplier Sapna Abrasives Limited (Bangalore, India) composed of high-quality was used for the present research. The size of the SiC was measured by a sieve. As per the examination, the size of the SiC was in the range of 63 μm.

2.3. Stir-Casting method

The stir casting method is the technique in which the ceramic particles are incorporated into molten metal and the mixture is allowed to coagulate. The most significant thing in this coordination is achieving exceptional wetting among the molten metal and the reinforcement particle. This cheapest and simplest model is moreover called as vortex method. In this vortex procedure, the metal alloy is melted and with the help of a rotating impeller, the molten metal is stirred convincingly to form a vortex on the surface of the metal. The mechanical properties and other properties of the composites depend on the even distribution of reinforce-

Table 1
Different material composition of Al 8011-SiC composites.

Element	Al	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Pb	Ca	Ni
In mass fractions (w/ %)	97.14	0.53	0.99	0.27	0.21	0.25	0.049	0.19	0.028	0.10	0.008	0.045

ment in the matrix alloy. Homogenous distribution of reinforcement particles within the metal matrix is obtained when there is an exceptional chemical reaction and good wettability between matrix alloy and reinforcement particles. Mohammad Taha., revealed that the stir casting method was the most cheapest and effective method to produce aluminum metal matrix composites [24]. Shanmuhasundaram et al., indicated that by stir casting methodology route uniform distribution of reinforcement was achieved; which enhances the mechanical properties of the composites [25]. The irregular distribution of reinforcement particles in the metal matrix leads to the breakdown of the composites when it is subjected to loading conditions.

The experimental specimens were fabricated with three different stirring time periods (5, 10, 15 mins) and two different stirring speeds (300 and 400 rpm) using the experimental setup shown in Fig. 1. The same stirring time period was maintained by the different researchers[14–16]. The temperature of the furnace was controlled by the three-phase electrical resistance.300–400 g of the alloy was deployed in each specimen of experiments. The weight fraction of 6 %SiC was used as reinforcement by the stir casting method to obtain Al 8011-SiC composites and its different material composition is shown in Table 1. The 300 Degree Celsius preheated reinforcement SiC particulates are continuously mixed with the 720 Degree Celsius molten metal by using a mechanical stirrer arrangement setup shown in Fig. 2.

During the fabrication of the composites, the stirrer speed was maintained at 300 and 400 rpm and stirring time period of 5, 10, 15 mins respectively. SiC particles were reinforced into molten Al8011 matrix at different processing combinations. The Al8011-SiC composite specimens produced by using the experimentation are shown in Fig. 3.

Fig. 1. Stir casting setup.

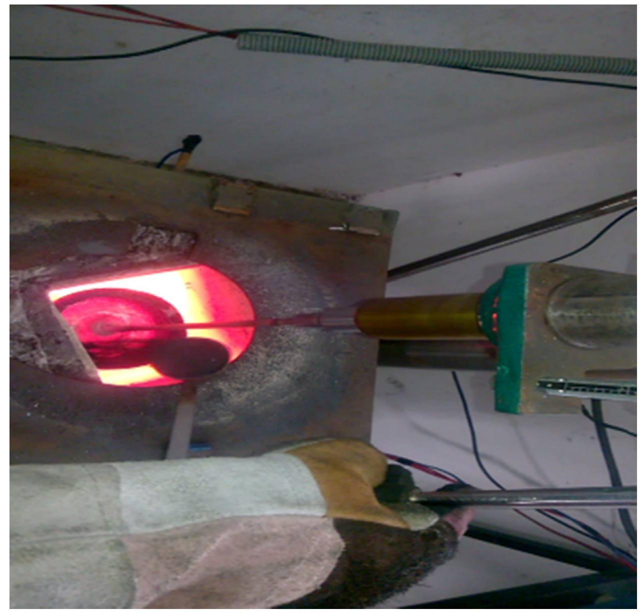

Fig. 2. Stirring of the reinforcement.

Fig. 3. Fabricated Al8011-SiC composites.

3. Experimentation

3.1. Mechanical properties

Metal matrix composites exhibit higher tensile strength, better hardness and higher modulus of elasticity, improved toughness and compressive strength, high corrosion resistance, and mild coefficient of thermal expansion than the unreinforced alloy. The enhancement in the mechanical properties of the composites was accomplished by the suitable choice of matrix elements and reinforcement particles. Sharanabassapa et al., stated that equal distribution of alumina particles in the aluminum matrix was obtained, therefore mechanical properties of the composites increased. With the increase in reinforcement, the hardness and tensile strength of the composites increase [26].

3.2. Tensile test

The tensile strength tests were carried out on the standard Al8011-SiC composite alloy machined using ASTM E8:2015 standard dimensions shown in Fig. 4 in standard tensile testing equipment and the mean value is taken into the account from different sampling tests.

3.3. Hardness test

The hardness of the unreinforced Al8011 alloy and Al8011- SiC-composite specimens in the standard testing conditions using Rockwell hardness testing machine MSM model with ASTM E18:2014 standard was used to evaluate and the mean value is taken into the account from different sampling tests to avoid minor deviations and error ratios.

3.4. Impact test

The specimen dimension shown in Fig. 5was made to resist the pendulum notch which was released from a certain height from the opposite end and fracture samples were collected. The experimental tests were conducted on the Al8011 alloy and Al8011-SiCcomposites using standard Charpy impact testing equipment. ISO-148–1:2009 method was used to determine the toughness of the composites. Tests were conducted on the samples for three times and the average of three readings determines the toughness of the composites.

4. Results and discussion

The Different Mechanical Properties of Al8011-SiC composites specimens at various conditions of experiments are shown in Table.2. Fig. 6 shows the Hardness value of 90 in the pure material and it varied from 102 to 114 with the increase in stirring time and speed in the composite specimens. The maximum hardness is obtained at 27% more than the pure material and it is obtained at the higher ranges of process parameters. The results match with the previous researchers Balasivanandha Prabhu et al., and Raju H. P et al., [19,20]. Balasivanandha Prabhu et al., declared that at higher stirring speed and stirring time better homogenous distribution of SiC particles in the aluminum metal matrix was obtained. Hence there is an increase in the hardness of the A384-SiC composites [19]. Raju HP et al., used three different stirring speeds (300,400,500 rpm) and three different stirring time periods (5, 10, 15 mins) to fabricate Al7075-alumina composites by the stir casting method. Their results infer that when there is an increase in stirring speed and stirring time hardness of the composites increases. At a stirring speed of 500 rpm, the hardness obtained was 95.2 HV for 5 min stirring time period, 98.3 HV for 10 min stirring time period, 105.3 HV for 15 min stirring time period. Similarly there is increase in hardness of 22.5 % of the Al7075-alumina composites for the time period 15 min, when there is an increase in stirring speed from 300 rpm to 500 rpm [20].

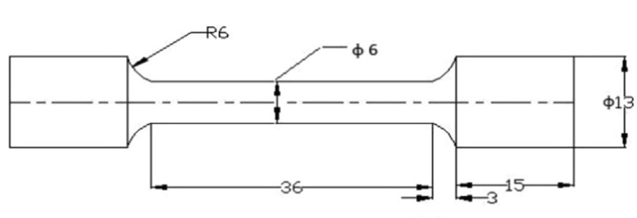

Fig. 4. Schematic diagram of tensile specimen.

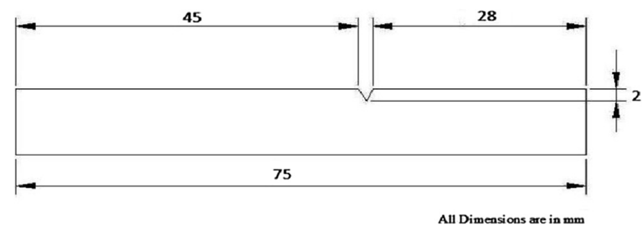

Fig. 5. Schematic diagram of impact specimen.

Fig. 7 shows the yield strength of 46 MPa in pure unreinforced metal alloy whereas in the Al8011-SiC composites yield strength gradually varied from 81 MPa to 86 MPa with stirring time variation of 5 to 10 min at 300 rpm and it varied further from 87 MPa to 91 MPa for the same timing range with the increase in speed of 400 rpm which was 97 percent better than the pure raw material.

Similarly, Tensile strength of 67 MPa is derived in pure unreinforced metal alloy whereas in the Al8011-SiC composites tensile strength gradually varied from 105 MPa to 111 MPa with steering time variation of 5 to 10 min at 300 rpm, and further it reaches the maximum Tensile strength of 113 MPa in the case of 400 rpm steering speed which was shown in Fig. 8. This Tensile strength value is comparatively better than the pure raw material specimen. The above results of maximum tensile strength at the highest stirring speed and stirring time were due to the more uniform distribution of reinforcement and decrease in porosity which matches with the researchers. Raju HP et al., analyzed the effect of different stirring speeds and stirring time on the tensile behavior of Al7075-alumina composites. It was observed to be 162.9 Mpa for Al7075-alumina composites fabricated at 5 min stirring time period (300 rpm), 169.6 MPa for Al7075-alumina composites fabricated at 10 min stirring time period (300 rpm), 175.2 MPa for Al7075-alumina composites fabricated at 15 min stirring time period (300 rpm). Correspondingly tensile strength increases from 175.2 MPa to 192.1 MPa for the increase in stirring speed from 300 rpm to 400 rpm at a similar time period (15 min) [20]. Guan et al confirmed that the same stirring speed of 300 rpm, highest tensile strength of 290 MPa was observed for Al6061 composites fabricated at 30 min stirring time when compared to the tensile strength of 240 MPa for the Al6061composites fabricated at 20 min stirring time period [23].

Al8011-SiC composites have a higher elongation of 7.7 % at the higher range of steering speed of 400 rpm and steering speed time of 15 min which was shown in Fig. 9. Minimum elongation of 7.4 % was found for the composites at 300 rpm and 5 min and 7 % for the pure unreinforced metal alloy. The increase in elongation of the Al8011-SiC composites from 7.4 % to 7.6 % is in line with researcher Guan et al., They concluded that elongation of Al6061 composites increases due to the additional settling time of reinforcement when there is the increase in stirring time from 20 min to 30 min [23].

From Fig. 10 it is observed that there is not too much change in the toughness of the composites with the increase in experimental process parameters like previous mechanical properties. The minimum toughness of Al8011-SiC composites was observed to be 13 Joules for the stirring speed of 300 rpm and 5 min. The toughness value is slightly increased to 14 Joules for maximum ranges of experimental parameters. Adediran et al.,[27] indicated that toughness remains unaffected at 14Joules at 400 rpm for all stir-

Table 2
Different Mechanical Properties of specimens at various conditions.

SI. No	Stirring Speed (Rpm)	Stirring time (mins)	Hardness (BHN)	Yield Strength (MPa)	Tensile Strength (MPa)	Elongation (%)	Toughness (Joules)
1	300	5	102	81	105	7.4	13
2		10	105	84	108	7.5	13
3		15	107	86	111	7.6	14
4	400	5	109	87	113	7.5	14
5		10	112	89	115	7.6	14
6		15	114	90	117	7.7	14

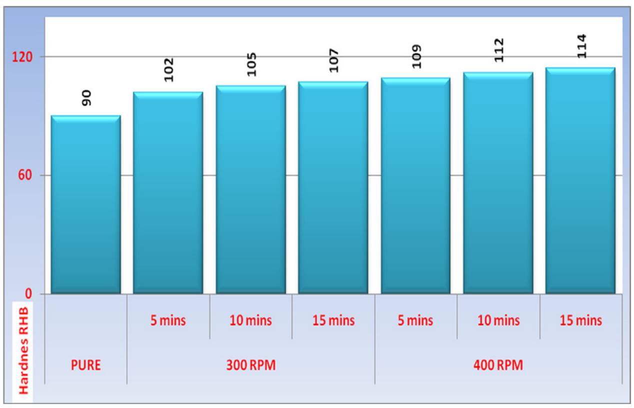

Fig. 6. Hardness Numbers of different specimens.

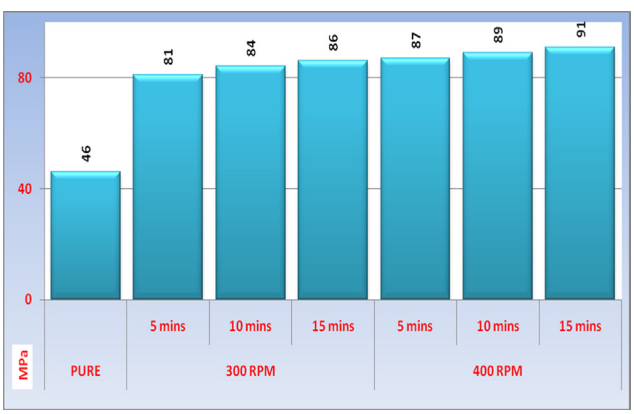

Fig. 7. Yield strength (MPa) values of different specimens.

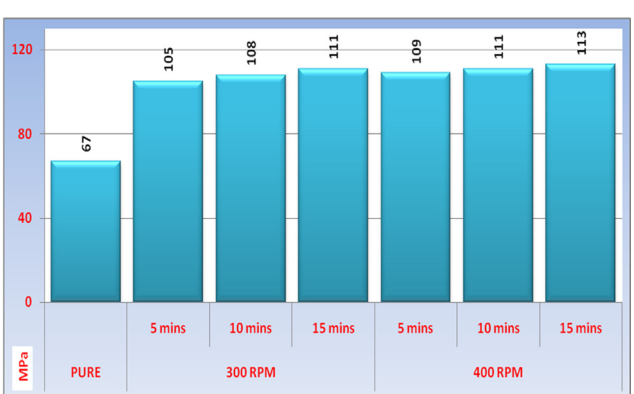

Fig. 8. Tensile Strength (MPa)of different specimens.

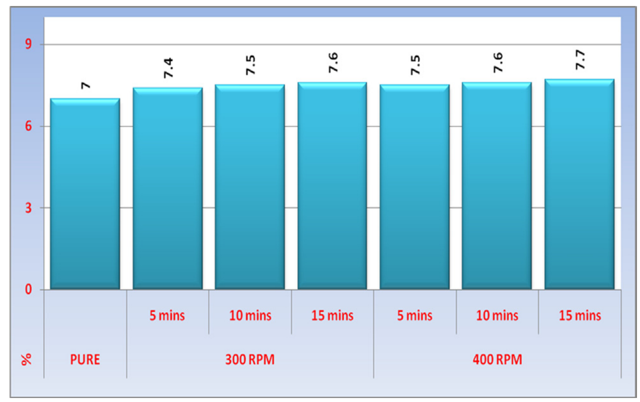

Fig. 9. Elongation percentages of different specimens.

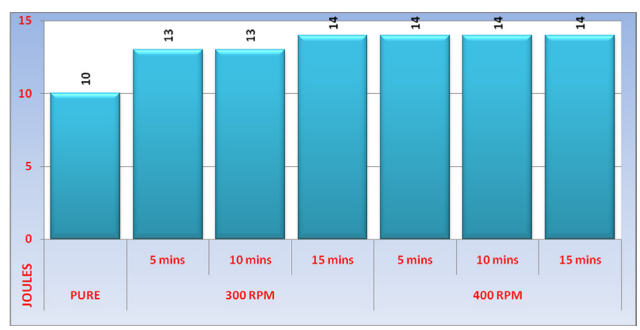

Fig. 10. Toughness (Joules) of different Al8011-SiC composites.

ring time periods. Further improvement in toughness of Al8011-SiC composites will be observed if there is more stirring speed applied to the stirrer and stirring time given for the settling of reinforcement.

5. Conclusions

The following conclusions are drawn from this detailed experimental research work after manufacturing the Al8011-SiC composite specimens with different experimental parameter ranges. The highest hardness value of 114 RHB was obtained for Al8011-SiC composites fabricated at the maximum stirring speed of 400 rpm and 15 min stirring time period for the selected ranges of stirring parameters. The yield strength and tensile strength of Al8011-SiC composites were observed as a maximum of 91 MPa and 113 MPa for the sample fabricated at the stirring conditions of 400 rpm and 15 min. Elongation was also observed to be highest at 7.7 % for the same stirring conditions. The toughness of the composites (14 Joules) remains the same for all stirring speeds and stirring times. Mechanical properties except the toughness value are gradually increased with the rise of stirring speed and stirring time in the composite specimens because of the homogenous distribution of SiC particles in the Al8011 matrix at the maximum stirring conditions. The enhancement of mechanical properties of Al8011-SiC composites was due to the settling of reinforcement of SiC particles evenly in the Al8011 matrix if we allow the stirrer to engage furthermore time.

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CRediT authorship contribution statement

N. Ashok: Investigation, Data curation, Conceptualization, Methodology, Resources, Writing – original draft. **A. Johnson Santhosh:** Investigation, Data curation, Conceptualization, Methodology, Resources, Writing – original draft. **Amanuel Diriba Tura:** Software, Data curation, Formal analysis, Resources. **Hana Beyene Mamo:** Software, Data curation, Formal analysis, Resources. **Eyuel Abatae:** Validation, Supervision. **Lingerew E. Melaku:** Validation, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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