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Research Article

Analysis of Mechanical Properties for Al-MMC Fabricated through an Optimized Stir Casting Process

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This work concentrated on preparation of Al-based composites through stir casting process. Al6082 was chosen as base material that is reinforced with zirconium silicate and titanium carbide. As per Taguchi design L16 orthogonal array, specimens are produced with variation of casting parameters for performing tensile and hardness test. In this process, $ZrSiO_4$ is kept constant to 10 wt%, whereas TiC concentration varied from 2.5 to 10wt%. For analyzing the properties of optimized stir cast samples for AA6082/ZrSiO4/TiC, three input variables with four levels are taken such as Stir speed (SS) 300-750 rpm, Stir time (ST) 5-20 min, and Reinforcement (RI) 2.5-10 wt%. The Taguchi technique was used as an analyzer to determine optimal parameter on Tensile Strength (TS) and Hardness (HN). The Minitab-17 software is assisting to find analysis of variance (ANOVA), regression equation, and contour plots of the selected parameters. Finally, it is witnessed that SS (65.9%) is the maximum influenced factor that increases TS, followed by RI (23.1%) and ST (11%). The best combinations of parameters on TS and HN were found at SS2-ST1-RI2 (450 rpm, 5 min, and 5wt%) and SS3-ST2-RI4 (600 rpm, 10 min, and 10wt percent), respectively. From the contour plots, the casting variables SS (600-650 Rpm), ST (15-17.5 min), and RI (5-8 wt%) were proposed for achieving excellent mechanical properties.

1. Introduction

Al matrix composites are frequently preferred in many applications to create various lightweight items [1]. Stir casting is one of the manufacture processes which makes effective components by pouring of molten metal in to standard dies [2]. These cast products minimize porosity and have a uniformly mixing of grain particles [3, 4]. Al alloy properties were developed by choosing nano and microlevel reinforcements. Ceramic particles such as TiC, silicon carbide and alumina were mostly added with AL for improving microhardness and UTS [4–9]. Ravikumar et al. studied about behavior of AA 6082/TiC by execution of different examinations like SEM investigation, XRD, and destructive tests [10]. Rajaganapathy explained that the addition of both TiC and WC (3-10%) particles with

6082 alloy enhanced wear resistance at dry condition [11]. Zrsio4 is one of the greatest corrosion resistances which is contributed in several productions such as boilers and valve vessels [12–14]. Sharma et al. aimed to study the WEDM process parameter of AA6063/ZrSiO4 and optimization process and also carried out the Box-Behnken-RSM method [15]. Gurusami et al. selected three factors and prepare 15 composites (AA7068/B4C) by casting route, the outcome of ANOVA revealed that the most influenced optimal factor on wear resistance was at sample no. 10 (B4C-6%, speed of stirrer-750 rpm, and stir time-7minutes) [14]. Adeolu fabricated Al7075-TiO_2 composites through stir-casting way and detected that temperature (750°C) and stir speed (500 rpm) are premier significant variables which exhibited the best UTS [16]. Sathishkumar et al. have done microstructure study and material behavior and properties Mg matrix nanocomposites (MMNCs) [17]. Due to the increment of TiC particles from 0 to 12% in AA2014 matrix, ductility reduced around 45% and tensile strength and BHN are improved to 52% and 21%, respectively [18]. Talikoti et al. fabricated AA 7075 reinforced SiC/graphite hybrid composites by liquid metallurgy method, from optimization process, more contribution of silicon carbide increased yield strength and elongation about 68% and 51%, respectively [19].The improvement of mechanical properties of AA6063/SiC/MoS2 mainly depends on the grain size of abrasives and corrosion resistance which decreased due to raising of temperature [20]. The 5059-Al reinforced on 30 lm size silicon carbide (5-15%) and molybdenum-disulphide (about 2%) hybrid compounds were made by stir casting. The metal removal rate (MRR) was examined with variation of voltage level, feed rate, and electrolyte quantity on the L27 Taguchi design [21]. Zhu established composite of Al6082 alloy with nanosize of SiC via gravity casting procedure. It was noticed that tensile (29%) and yield strength (43%) improved at T6 heat treatment [22]. The prepared composites mostly are used in many fields such high-stress applications, bridges, winches, transport applications, ore skips, beer barrels, and milk can.

In this research, optimal performance done for tensile strength (TS) and hardness (HN) is the prime concern. The measurements of TS and HN are needed to be analyzed, the main effort of research process is to determine optimal input considerations, improving output responses (TS) in the design of experiments.

2. Experiment Setup

Al alloy (6082) is one of the best 6xxx type alloys, with outstanding wear resistance, and is extensively used in machining. Strengthening materials ZrSiO4 and TiC were added to Al 6082 at varied percent weights. To create a hybrid composite, 6082 was cast with Zrsio4/TiC. Stirrer was rotated at various rates by an electrical motor. To bring the stirrer into touch with the compound components, a safe lifting mechanism was used. Initially, Al alloy was put in a crucible and burned in an electric furnace at roughly 700°C. Heat the zirconium silicate (2.5 percent wt) and titanium carbide (5 wt percent) particles at 350°C simultaneously with the use of a second furnace after measuring with a digital weigh scale. Thereafter, molten Al alloy metals and reinforcements were combined and heated to roughly 750°C. For 5 minutes, the melt was continually agitated by a stirrer linked to the motor; then, the prepared melted particles were poured into the desired mold to generate Al-based composites. Variate the stirrer speed, mixing time, and weightiness % of reinforced materials to continue the procedure for creating many samples. With the help of grinding machine, remove unnecessary portion from the developed samples.

Table 1: Casting input parameters.

Factors	Levels			
	1	2	3	4
Stir speed (SS)	300	450	600	750
Stir time (ST)	5	10	15	20
Reinforcement (RI)	2.5	5	7.5	10

3. Result and Discussion

Four different levels of parameters mentioned in Table 1 were selected to find optimal outputs of hardness and tensile strength. The Taguchi is one of the finest approaches to be used as tool on optimization solution even though many methods like Box-Behnken exist. Conclusions of investigational examinations were scrutinized with the assistance of ANOVA 95% level [23]. The experimental and S/N ratio effects on both TS and BHN have been exposed in Table 2. It was witnessed that greatest and lowest optimum combinations of parameters on TS were identified at SS2-ST1-RI2 (450 rpm, 5 min, and 5 wt%) and SS1-ST1-RI1 (300 rpm, 5 min, and 2.5 wt%), respectively. Best and least for HN were also detected at SS3-ST2-RI4 (600 rpm, 10 min, and 10 wt%) and SS4-ST1-RI4 (750 rpm, 5 min, and 10 wt%). S/N ratios and means at all level parameters are displayed in Figures 1 and 2. RI and SS are peak-manipulating parameters, followed by ST as the lowest contribution to improve composite strengths. Optimized significance of every input consideration for both properties can be found according to signal and noise which is exposed in Tables 3 and 4. From tabulation effects, SS1 (-49.47) has been a chief influencing factor on tensile property tailed by RI2(-50.10) and ST2(-50.26). Likewise, RI4 (-38.29) has a primary factor which followed via ST4 and SS1.

4. Regression Equation

The correlation was recognized among input considerations of casting procedure which calculate the value of HN and TS and equations of regression analysis (Equations 1 and 2) which was symbolized from the Optimize software (Minitab-17 version).

Table 2: Experiment and S/N results.

Experiment no.	Process parameters			Experimental observations		S/N ratio	
	SS (Rpm)	ST (min)	RI (wt%)	TS (Mpa)	HN	TS(dB)	HN(dB)
L1	300	5	2.5	289.83	92	-49.2429	-39.2758
L2	300	10	5.0	297.52	83	-49.4703	-38.3816
L3	300	15	7.5	302.58	86	-49.6168	-38.6900
L4	300	20	10.0	300.80	79	-49.5656	-37.9525
L5	450	5	5.0	415.57	90	-52.3729	-39.0849
L6	450	10	2.5	387.52	86.2	-51.7659	-38.7101
L7	450	15	10.0	298.79	78.5	-49.5073	-37.8974
L8	450	20	7.5	352.74	85.5	-50.9491	-38.6393
L9	600	5	7.5	375.71	92	-51.4971	-39.2758
L10	600	10	10.0	326.28	98.3	-50.2718	-39.8511
L11	600	15	2.5	406.23	79.6	-52.1754	-38.0183
L12	600	20	5.0	394.63	75.3	-51.9238	-37.5359
L13	750	5	10.0	357.27	74.8	-51.0599	-37.4780
L14	750	10	7.5	299.56	82.9	-49.5297	-38.3711
L15	750	15	5.0	347.83	95	-50.8273	-39.5545
L16	750	20	2.5	362.94	92.6	-51.1967	-39.3322

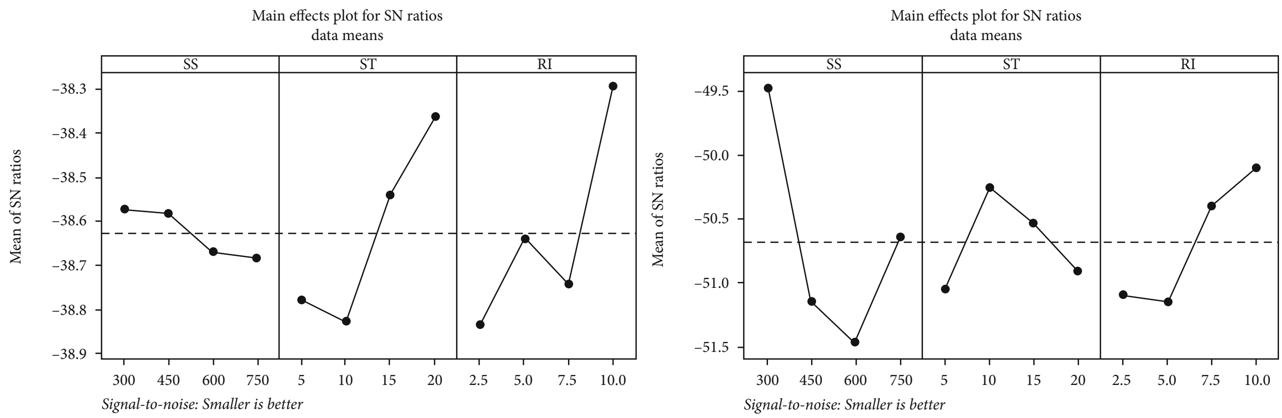

Figure 1: S/N ratio—TS and HN.

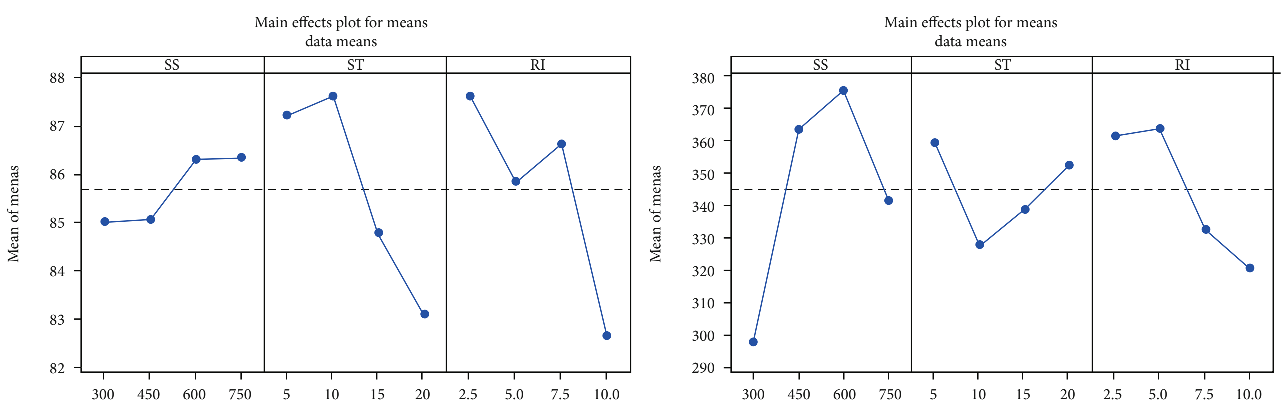

Figure 2: Means—TS and HN.

Table 3: S/N ratio response—TS.

Level	SS	ST	RI
1	-49.47	-51.04	-51.10
2	-51.15	-50.26	-51.15
3	-51.47	-50.53	-50.40
4	-50.65	-50.91	-50.10
Delta	1.99	0.78	1.05
Rank	1	3	2

Table 4: S/N ratio response—HN.

Level	SS	ST	RI
1	-38.57	-38.78	-38.83
2	-38.58	-38.83	-38.64
3	-38.67	-38.54	-38.74
4	-38.68	-38.36	-38.29
Delta	0.11	0.46	0.54
Rank	3	2	1

$$\text{Tensile Strength} = 334.9 + 0.0965\ \text{Stir speed} - 0.19\ \text{Stir time} - 6.15\ \text{Reinforcement} \quad (1)$$

$$\text{Hardness} = 91.14 + 0.0035\ \text{Stir speed} - 0.303\ \text{Stir time} - 0.563\ \text{Reinforcement} \quad (2)$$

5. ANOVA Analysis and Contour Graphs

The formulation of analysis of variance was done by mathematical statistical method (Minitab-17). Table 5 exposes that effect of each parameter contributed on the experimental values of tensile stregth and hardness. It was established that stir speed (65.9%) is the most significant factor that improves mechanical properties of AMC (Al6082-Zrsio4-TiC) and reinforcement (23.1%) is considered as the next effective parameter followed by stir time (11%).Contour graphs attained for TS and HN against input process factors are shown in Figures 3 and 4. From the plotted observation, the ranges of casting factors SS (600-650 Rpm), ST (15-17.5 min), and RI (5-8 wt%) were recommended for attaining high tensile strength and hardness values.

Table 5: ANOVA result—TS.

Source	DF	Sum of square (SOM)	Mean sum(MS)	F	P	Contribution (%)
SS	3	9.178	3.0593	4.79	0.049	65.9
ST	3	1.532	0.5106	0.80	0.538	11
RI	3	3.225	1.0751	1.68	0.269	23.1

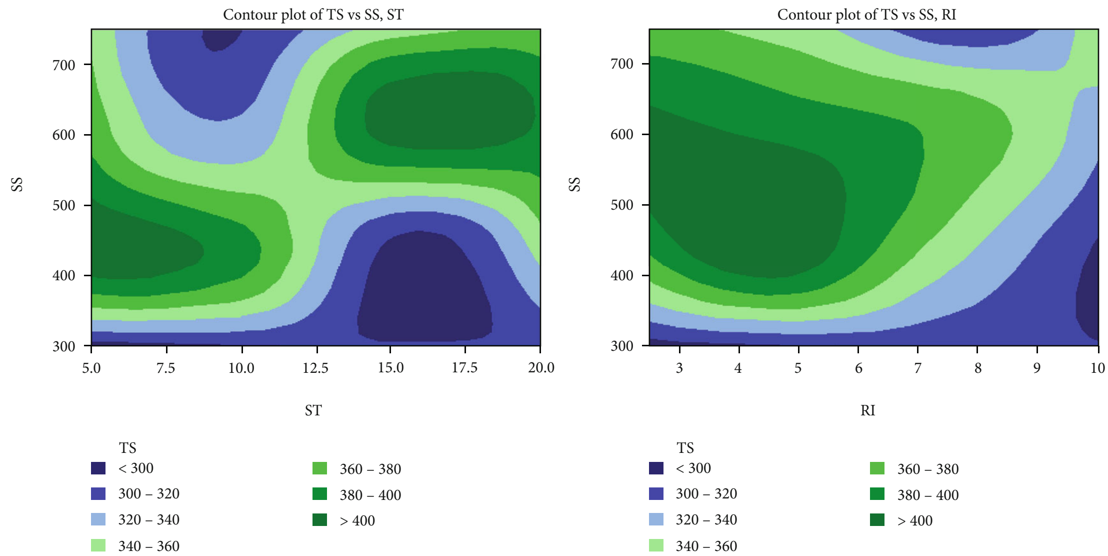

Figure 3: Contour plot on TS for casing variables.

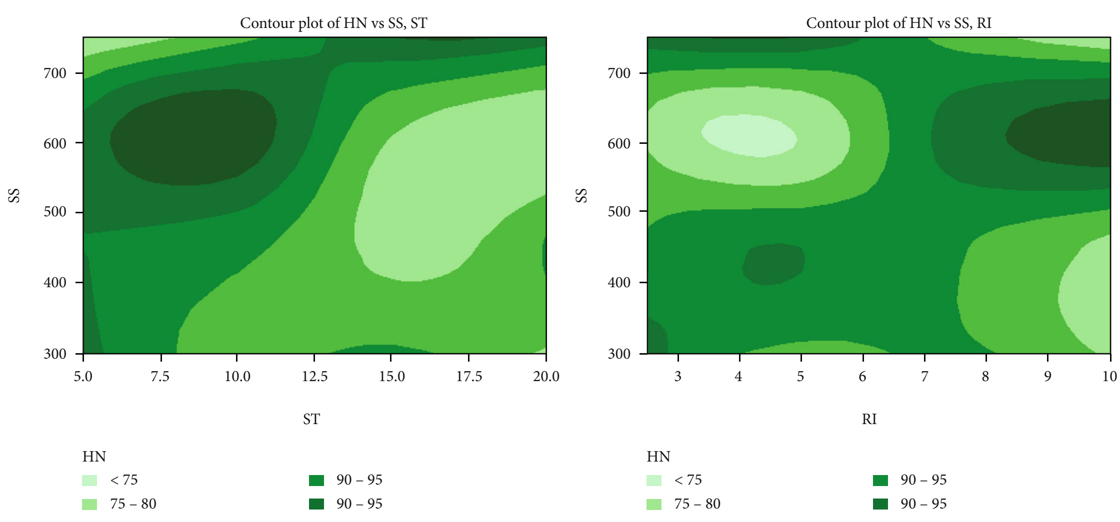

Figure 4: Contour plot—HN vs. stir parameters.

6. Conclusion

In this work, stir casting (SC) was used to make several AMC (Al6082-ZrSio4-TiC) samples. In Taguchi's design, the orthogonal array (L16) has been effectively used to optimize the SC variables of stir speed (SS), stir time (ST), and reinforcements (RI). At L5, the maximum tensile strength (TS) was achieved (SS:450 rpm, ST:5 min, and RI:5 wt%). When it came to hardness, the highest HN was found at L10 sample (SS-600 rpm, ST-10 min, and RI-10 wt%). The lowest TS and HN were reported at L1 and L13, respectively. According to the ANOVA results, the most important element in developing AMC characteristics was SS-65.9%, followed by RI-23.1% and ST-11%.

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 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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