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EXPERIMENTAL OPTIMIZATION OF HYBRID REINFORCEMENT OF BORON CARBIDE AND ZIRCONIUM DIOXIDE IN AL7075 USING ANT COLONY OPTIMIZATION

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ABSTRACT: Aluminium Metal Matrix Composites (AMC) are used in an application like automobiles and aircraft industries. Some researches involved in using the Hybrid reinforcements to improve the characteristic of AMC. In this research, Boron Carbide (B_4C) and Zirconium dioxide (ZiO_2) are used as the reinforcements in Al7075 using Stir casting method and Ant colony technique is used for optimization. The input parameters such as wt%, stirrer speed, stirrer time and Temperature are considered for optimization. Taguchi method is used for optimize the input parameters to improve the characteristics such as Ultimate Tensile Strength (UTS) and micro hardness. The analysis shows that wt% is the important parameter that affects the characteristics such as UTS and micro hardness of the material. The Ant Colony optimisation shows that 1.95 wt% of B_4C and ZiO_2, stirrer speed 495 RPM, 24 min stirring time, processing temperature (PT) of 817°C provides the higher UTS of 210 MPa and microhardness of 197.57.

KEYWORDS: Aluminium Metal Matrix Composites, Ant colony technique, Boron Carbide, Stir casting method and Ultimate Tensile Strength.

I. INTRODUCTION

The matrix composition is often made by mixing the metal matrix with any appropriate material such as reinforcement, which are used in a steel frame to improve characteristics such as rocket strength and rigidity [1]. Among MMCs, aluminium (Al)-based materials are the largest component of the volume produced for commercial applications, such as automotive and aircraft [2]. The stiffness used in the reinforcement affects the strength and durability of the product compared to its original compound [3]. Combined metal composite materials are used in more than one type of reinforcement with different sizes, shapes and weight percentages to obtain better mechanical strength [4]. The solid state method consists of powder metallurgy (PM) methods, while the liquid state method includes mixing, casting of squeeze and resistance methods. The method of stimulation with stirring continues to be the most studied method for producing HAMCs because of their ease of flexibility, production and cost [5].

Semi-conductor materials such as Al2O3 and SiC are the most commonly used particles of reinforcement for Al-MMCs. For these semi-conductor materials, B_4C is used as a substitute in many applications due to its low density (2.52 g / cm3), high strength, good strength and stability in chemical compositions [6]. Recently, a new group of reinforcements, such as ZrO2, ZrB2, etc., has been used to obtain sensitive results [7]. Since the manufacture of a casting with mechanical properties is very important in many applications, a systematic determination of the optimal variable setting is essential to achieve the same. Some researchers report that the casting threshold should be improved to provide a high-quality castings [8]. The Taguchi is the perfect solution for experimentation, because it provides simple, effective, and systematic approaches to improve design, quality, and design cost [9, 10]. In this research, the reinforcement of B_4C and ZiO_2 in Al7075 using stir casting method and Ant colony optimization is applied to improve the characteristics such as UTS and microhardness of the material.

The organization of the paper is in the form of Literature Survey is in section 2, The methods and materials in section 3, the experimental results in section 4 and conclusion in section 5.

II. LITERATURE SURVEY

Aluminium metal matrix composites are used in the applications such as automobiles and aircraft industries. Manufacturing process has been optimized to improve the characteristics of the composites. Some researches related to the aluminium metal matrix and optimization are surveyed in this section.

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Dirisenapu, *et al*. [11] fabricated the reinforced al7010 metal matrix with two nanoparticles (B_4C and ZiO_2) using ultrasonic assisted stir casting technique. The ANOVA method was used to optimize the effect of processing parameters such as weight percentage, stirring speed, stirring time and temperature on UTS and microhardness. The analysis shows that weight percentage is the important parameter affect the characteristics. The optimization method is need to applied for other reinforcement to analysis the characteristics.

Dhanalakshmi, *et al.* [12] analysis the dry sliding wear behaviour of Al 7075 reinforced with Al_2O_3 and B_4C. The Liquid Metallurgy route of Stir casting method was used to fabricate the metal matrix composites. The B_4C is kept constant at 3 wt% and Al_2O_3 is varied as 3, 6, 9, 12 and 15 wt%. The analysis on wear rate and coefficient of Friction is carried out on the input parameters such as applied load, sliding speed and sliding distance. The optimal condition for obtaining the minimum wear rate has been determined in this method. The analysis shows that wear resistance of hybrid materials increases with increasing in Al_2O_3 wt%. The result shows that sliding speed and distance has higher influence on both wear rate and coefficient of friction. The optimization technique is need to be applied on manufacturing process to improve the characteristics of material.

Kuldeep, *et al*. [13] analysis the hybrid reinforcement of Boron Nitride and ZiO_2 in al7075 using stir casting method. The Boron Nitride composition is kept constant at 3% and Zirconium dioxide is varied to analyse the characteristics of the material. The analysis shows that reinforcements increases the strength and hardness of the material. The wear rate of the material decreases with increases of reinforcement. The optimization technique can be applied to improve the characteristics of the material.

Subramaniam, *et al.* [14] studies the reinforcement of B_4C and Coconut shell fly ash in Al7075. Stir casting method was used to fabricate the material and analysis the characteristics. The analysis shows that reinforcement increases the strength and hardness of the material. The Hardness of the material is increases with increases in the reinforcement of the material. The stir casting process is need to be optimised to increases the characteristics such as strength and hardness.

Mahanta, *et al.* [15] analysis the reinforcement of B_4C and fly ash in Al7075 material. The stir casting process is used to fabricate the material with Boron carbide kept as constant and fly ash is varied. The analysis shows that wear resistance properties of the material has been improved. The optimization method can be applied to improve the strength and hardness of the material.

III. METHODS AND MATERIALS

Al7075-0 is used as a matrix material, and the composition of its chemical is presented in Table 1. B_4C and ZiO_2 had the density of 2.52 gm/ cc and 5.69 gm/ cc are used for Al7075 reinforcement.

Table 1. Al 7075 constitutes

Composites	Zinc	Magnesium	Copper	Chromium	Iron	Manganese	Titanium	Silicon	Aluminium
Wt.%	5.5	2.3	1.6.	0.23	0.20	0.2	0.12	0.1	Remaining

The stir casting method is used to make composite materials using furnace of resistance. The Al7075 ingots are cut and melted in a furnace at 760°C, and the heat exchanger is used to control the temperature. Hexchloroethene tablets (C2Cl6) are inserted into an ingots of molten for degassing. Wettability is the major problem in reinforcing of metal matrix [13]. Angle of contact denotes wetting, better wetting can be achieved by smaller angle of contact. Increasing the solid surface energy or reduce the interface energy between solid and liquid reduces the angle of contact. In order to achieve this, small amount of alloy is added in the metal composites.

To increases the wettability, the magnesium of 1.5 – 2 % (not greater than 2%) is added and to reduce the metal surface tension, Coverall (1%) is used that also increases the wettability. In order to protect from the atmospheric hydrogen absorbing and oxidation, continuous layer is formed using Coverall. The cast specimens are tested for the mechanical and wear characteristics as per ASTM standards. Tensile strength of the composites was analysed based on ASTM E8M standard with gauge length of 30 mm. The sample size was measured using the Vickers hardness test model DHB1 and the test is taken at a load of 1000 grams for 10 s.

3.1 Taguchi technique

Taguchi technology is one of the design experiments, which is a powerful systematic tool and a useful framework for optimizing process metrics. This technology consists of parameter selection, experimental design, testing, data analysis and evaluation of inaccurate results and validation [11]. This reduces the number of test cases, while comparing with other experimental designs. In the research work, B_4C (wt%) and ZiO_2, operating temperature, stirring speed and time are considered as process parameters and also every parameter's effect on the UTS and microhardness are measured. This method is developed to customize the process and determine the most appropriate levels of parameters for the given responses. The orthogonal design of Taguchi provides a versatile and efficient way to reduce production costs and time by producing high quality products. The following Tables 2 and 3 presents the selected control parameters and orthogonal patterns.

Table 2. Control Parameters and values

S. No	Control Parameters with Units			
	B_4C and ZiO_2 (wt%)	Stirrerspeed (RPM)	Stirring time (Min)	PT (°C)
1	0.5	200	10	700
2	1	300	15	750
3	1.5	400	20	800
4	2	500	25	850
5	2.5	600	30	900

Table 3. Orthogonal array values for stir casting technique

Ex.No	B4C and ZiO2	Stirrerspeed	Stirring time	PT
1	0.5	200	10	700
2	0.5	300	15	750
3	0.5	400	20	800
4	0.5	500	25	850
5	0.5	600	30	900
6	1	200	15	800
7	1	300	20	850
8	1	400	25	900
9	1	500	30	700
10	1	600	10	750
11	1.5	200	20	900
12	1.5	300	25	700
13	1.5	400	30	750
14	1.5	500	10	800
15	1.5	600	15	850
16	2	200	25	750
17	2	300	30	800
18	2	400	10	850
19	2	500	15	900
20	2	600	20	700
21	2.5	200	30	850
22	2.5	300	10	900
23	2.5	400	15	700
24	2.5	500	20	750

25	2.5	600	25	800

3.2 Ant Colony Optimization

According to the natural behaviour of ants, the swarm intelligence developed an ACO, which is one of the best heuristic methods [16]. The shortest path is used by the ants for the food source based on the information of pheromone without any visual stimulus. The Two-Reservoir Problem (TRP) problem is solved by the ACO and also it is used to solve many complex problems. This has been applied to a multidimensional problem because of its transparency [16]. A description of the ACO in TRP is being discussed, and the major tasks of TRP is to find the shortest route that transverses all the cities in one-way direction. Consider, $m \text{ and } n$ as ants and cities, where the n is fully connected with the edges E^n. The following steps describes the optimization steps as below:

1. **Initialization:** Randomly initialize the $m \text{ and } n$ and positive variable with small number is defined as small pheromone value.
2. **Path construction:** According to the transition probability in Eq. (1), the next city for visit is selected by every ant.

$$p(i,j) = \begin{cases} \frac{[\tau(i,j)]^\alpha[\eta(i,j)]^\beta}{\sum_{u\in J}[\tau(i,u)]^\alpha[\eta(i,u)]^\beta}, & if\ j \in J \\ 0, & otherwise \end{cases} \qquad (1)$$

Where ant k is in the city i and the next city is j, the amount of pheromone is illustrated as τ on the edge (i,j), η_{ij} is depicted as the heuristic edge value, α and β defines the weighting factors, which controls the importance between the pheromone and heuristic information, and J is represented as set of cites that is not visited.

3. Go to next step only when all ants completes the traverses path for all cities. If not, step 2 will be continued.
4. Eq. (2) is used to update the pheromone

$$\tau(i,j) \leftarrow (1-\rho).\tau(i,j) + \rho.\Delta\tau(i,j) \qquad (2)$$

Where, the evaporation rate is represented as $\rho \in (0,1)$ and the fitness function value is related to the value $\Delta\tau\ (i,j)$.

5. The process is stopped, when the stopping condition is achieved. If these condition is not satisfied, place the ants randomly and go to step 2 for achieving best results.

IV. EXPERIMENTAL RESULTS

AMCs are highly used in application like automobile and aircraft industries. Reinforcements were added in the AMC's to improve the characteristics of the materials. Optimization techniques can be applied in the manufacturing process to identify the optimum condition. In this research, the ant colony optimization method is applied to identify the optimum input parameters in the stir casting process. The effects of each parameter are analysed in the method. This section provides the detailed description about the performance of the proposed method.

Table 4. UTS and microhardness of Experimental value

Ex.No	Ultimate Tensile Strength	Microhardness
1	164	120.12
2	168	129.52
3	173	133.78
4	177	139.49
5	166	135.35
6	178	140.12
7	181	145.38
8	184	148.32

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9	176	146.25
10	179	146.19
11	191	153.84
12	189	151.59
13	186	155.86
14	191	158.65
15	192	160.12
16	197	166.69
17	199	192.31
18	200	173.45
19	203	174.28
20	197	170.85
21	117	144.73
22	180	138.52
23	182	140.87
24	189	148.39
25	190	152.35

The ultimate tensile strength and microhardness of the various parameter are shown in Table 4. The UTS and microhardness are found to be higher in the 2 wt% of B_4C and ZiO_2 reinforcement. The reinforcement wt% is the important parameter that influences the UTS and microhardness. The input parameters of the manufacturing process such as wt%, stirring speed, stirring time and Temperature are shown in Table 3.

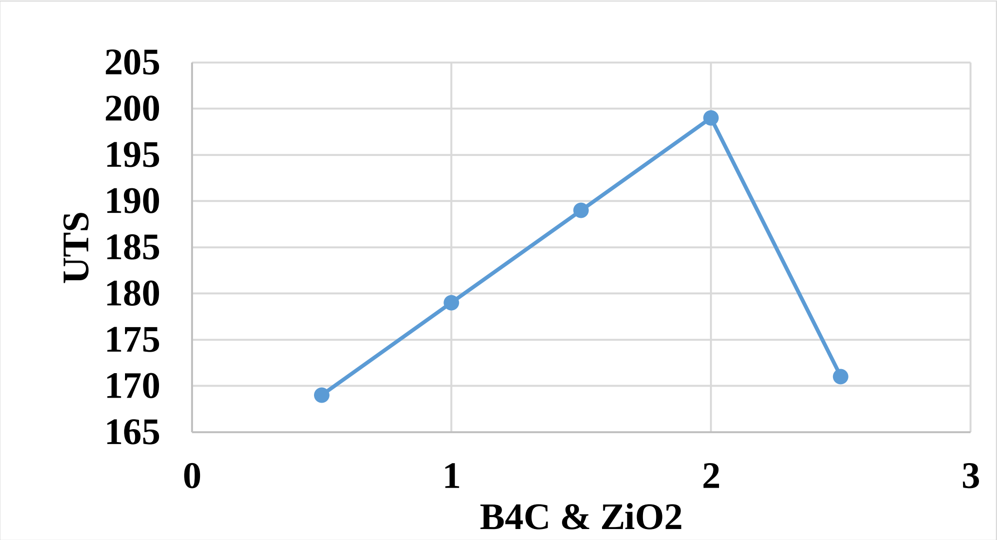

Figure 1. The UTS analysis of reinforcement wt%

The UTS analysis of the B_4C and ZiO_2 reinforcement wt% in stir casting process is shown in figure 1. This shows that B_4C and ZiO_2 reinforcement wt% has the higher influence in the UTS. The 2 wt% of B_4C and ZiO_2 reinforcement in the stir casting process provides the higher UTS in the analysis.

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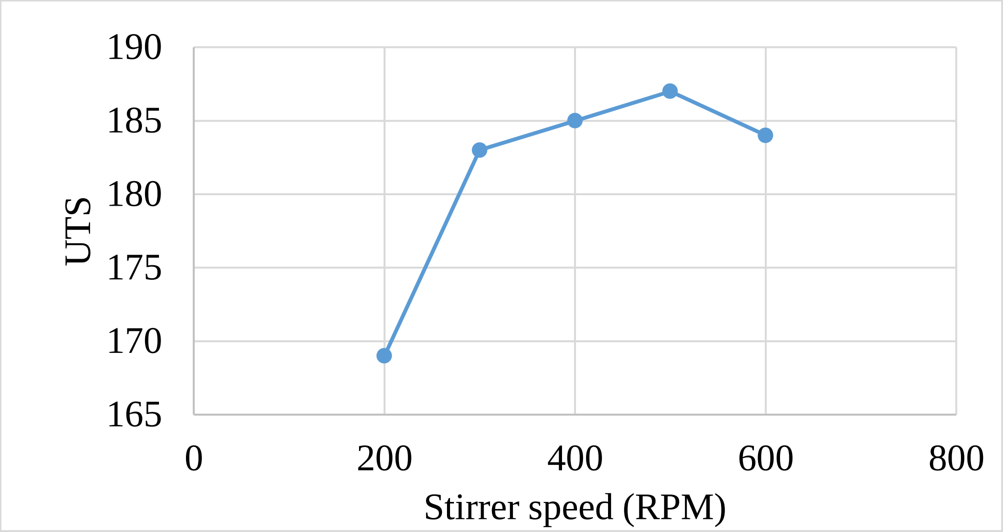

Figure 2. The UTS analysis of Stirrer speed

The stirring speed parameter in stir casting process is analysed in the UTS, as shown in figure 2. The stirrer speed of 500 rpm provides the higher UTS of 187 MPa in the reinforcement composites.

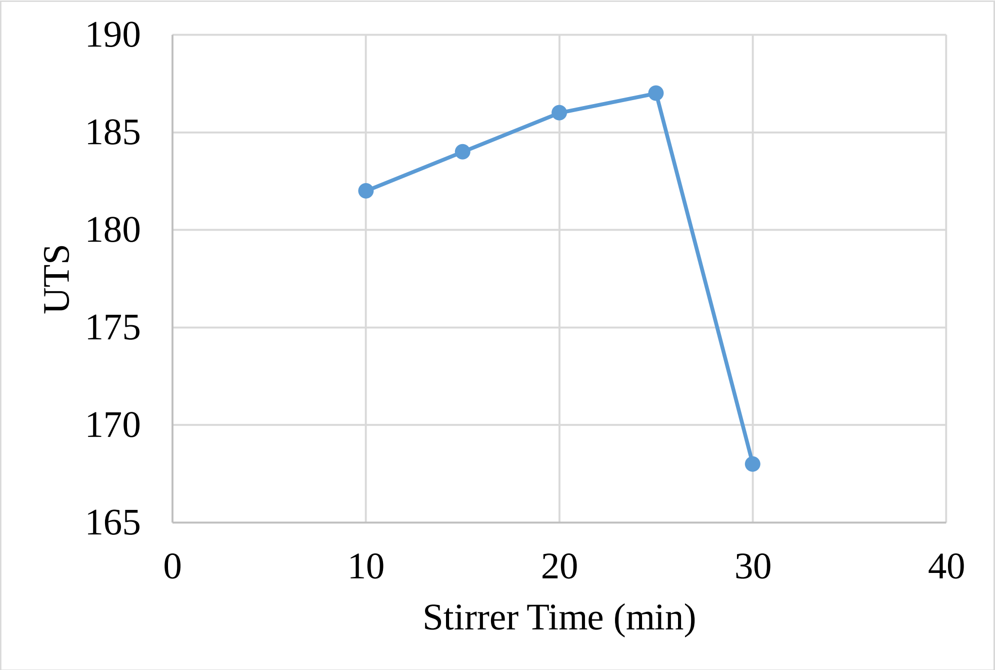

Figure 3. The UTS analysis of Stirrer Time

The stirrer time parameter in the stir casting process is analysed in the UTS, as shown in figure 3. The stirrer time of 25 min provides the higher UTS of 187 MPa and 20 min of stirrer time provides UTS of 186 MPa in the analysis.

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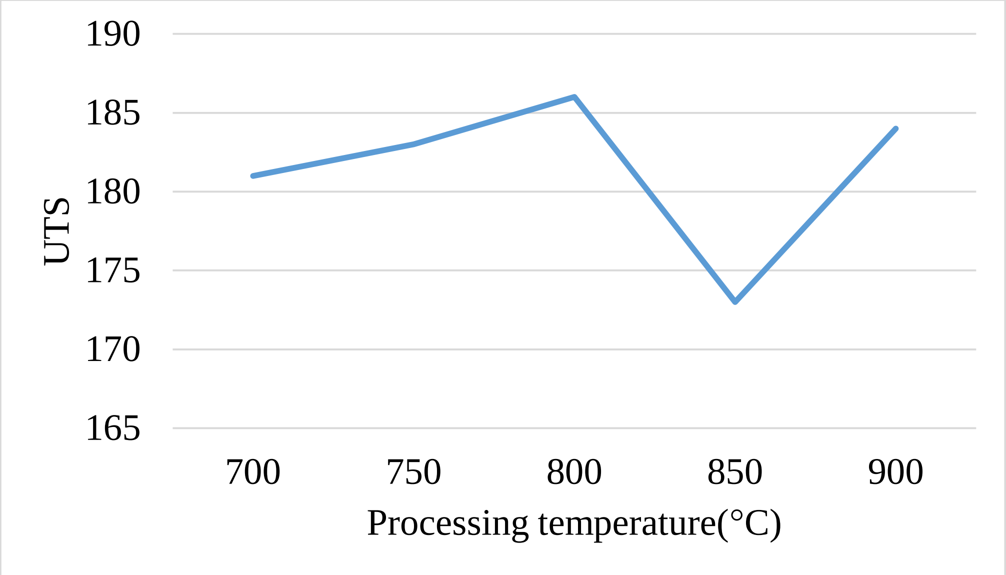

Figure 4. The UTS analysis of Processing Temperature

The PT in the stir casting process is analysed in UTS, as shown in figure 4. The PTof 800°C provides the higher UTS of 186 MPa and 850°C provides the lower UTS of 173 MPa.

Table 5. The output of Ant colony optimisation

S.No	B4C and ZiO2	Stirrer speed	Stirring time	PT	UTS	Microhardness
1	1.95	495	24	817	210	197.57
2	1.83	460	24	802	206	190.35
3	1.77	442	23	785	201	185.26
4	1.63	427	22	779	198	178.46
5	1.55	408	21	771	196	172.76

The output of Ant colony optimisation for UTS and microhardness in stir casting process is shown in table 5. The four input parameters such as wt%, stirrer speed, stirring time and PT are considered in the Ant colony optimisation. The Ant Colony optimisation shows that 1.95 wt% of B_4C and ZiO_2 with stirrer speed 495 RPM in 24 min stirring time at PT of 817°C provides the higher UTS of 210 MPa.

V. CONCLUSION

AMC are used in applications like automobiles and aircrafts industries. Hybrid reinforcements are used to improve the characteristics such as strength and hardness. In this research, B_4C and ZiO_2 are used as the hybrid reinforcement in Al 7075 and ant colony optimization is used for the optimization. Stir Casting method is used for manufacturing the reinforced composites. The input parameters such as wt%, stirrer speed, stirring time, and PT are used for optimization. The analysis shows that wt% is the important parameters that influence the characteristics such as UTS and microhardness. The Ant Colony optimization shows that 1.95 wt% of B_4C and ZiO_2, stirrer speed 495 RPM, 24 min stirring time, PT of 817°C provides the UTS of 210 MPa and 197.57 microhardness.

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