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Evaluation of Tensile Properties of Boron Carbide (B_4C) and Tungsten carbide (WC) Reinforced with Aluminium 7075 T6 by using Taguchi Method

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Absract

The Aluminium alloy Al7075 T6 is widely used for automobile and aircraft application because of superior strength to weight ratio. The metal matrix composites have been fabricated through stir casting method using WC and B_4C as hybrid reinforcement materials and evaluated using design of experiment by Taguchi method. The main objective of this paper is to predict the better parameter that gives the highest Tensile strength of hybrid composite. By varying the weight percentage of B_4C as 2.5, 5, 7.5 and 10% while varying weight percentage of WC as 1, 2, 3 and 4% for L_{16} arrays the Tensile properties and % of elongation of the as cast and heat treatment hybrid composites have been evaluated, and microstructural properties of the composites before and after heat treatment were investigated scanning electron microscopy and XRD analysis. The tensile properties of the prepared composites were increased with increasing the weight percentage of there in reinforcement in the composite.

Keywords: Taguchi method, SEM, Al7075, B_4C, WC

1. INTRODUCTION

The Tensile strength of materials with low density has played a vital role in aerospace industries in the past decade which led to use of Metal Matrix composites. A weight loss of materials coupled with an increase in yield strength, stiffness, and ultimate tensile strength can be translated to reductions in structural weight. [1] The Metal Matrix Composite (MMC) is an engineered combination of metal and reinforcement to obtain an enhanced property. [2] The Aluminium metal exhibits low density, easy fabrication ability, high strength, ductility, toughness and good engineering properties due to which it is highly favoured as MMC.[3] The Boron carbide(B_4C) is an excellent reinforcement material with its high thermal and chemical stability along with high hardness and low density when compared to other. [4] The Tungsten carbide (WC) with high stiffness and high hardness can be used as an reinforcement materials. [5]

The high strength Aluminium alloy (Al7075 T6) metal matrix composite when combined with high strength and hardness Boron carbide(B_4C) and Tungsten carbide(WC) in the reinforcing stage has improved high strength , high elastic modulus, high toughness and low density composite materials. [6,7,8] The composite is designed by Taguchi method with L_{16} array by varying the wt % of B_4c along with wt % of WC to obtain superior composite material in terms of low density and high Tensile strength. The microstructure analysis of composite material is completed to identify the heterogenous mixture of reinforcing materials B_4C and WC at perfect ratio to contribute the low density materials. Al-7075–B_4C composites have been prepared by the stir casting method and improved tensile strength, flexural strength, and hardness of the Al-7075-B_4C composite. [9]

2. MATERIALS AND METHODS

2.1 AL7075-T6 (Al 7075-T6)

Aluminium 7075 having good fatigue strength. It exhibits excellent machinability under both as cast and heat treated condition. The temper T6 grade heat treated alloy that is the solution heat-treated and artificially aged until it meets standard mechanical property. The figure shows the ingot of Al 7075 alloy.

Table 1: Composition of Al 7075 alloy

Component	Al	Cr	Cu	Fe	Mg	Mn	Si	Ti	Zn
Weight %	87.1-91.4	0.18-0.28	1.2-2	0.5	2.1-2.9	0.05	0.4	0.2	5.1-6.1

Figure 1. Aluminium 7075 alloy ingot

2.2. Boron Carbide (B_4C)

Boron Carbide (B_4C) is one of the hardest materials known, ranking third behind diamond and cubic boron nitride. It is the hardest material produced in tonnage quantities. Boron carbide powder is mainly produced by reacting carbon with B2O3 in an electric arc furnace, through carbon thermal reduction or by gas phase reactions. For commercial use B4C powders usually need to be milled and purified to remove metallic impurities. Boron Carbide has Extreme hardness, Good chemical resistance, Good nuclear properties, Low density properties.

Table 3: Properties of Boron carbide

Property	Density	Melting Point	Hardness	Young's Modulus
Value	2.52g/cm^2	2445(°c)	2900-3580	450-470 GPA

Figure 2: Boron carbide powders

2.3. Tungsten Carbide (WC)

Tungsten carbide (WC), also referred to as cemented carbide, is a composite material manufactured by a process called powder metallurgy. Tungsten carbide powder, generally ranging in proportion between 70%-97% of the total weight, is mixed with a binder metal, usually cobalt or nickel, compacted in a die and then sintered in a furnace. Tungsten Carbide has high melting point, boiling point at standard atmospheric pressure, thermal conductivity and coefficient of thermal expansion.

Table 4 Properties of Tungsten carbide

Property	Density	Melting Point	Modulus elasticity	Shear modulus	Compressive modulus
Value	15.7g/cm^2	2445(°C)	670-707 GPA	262-298 GPA	384 GPA

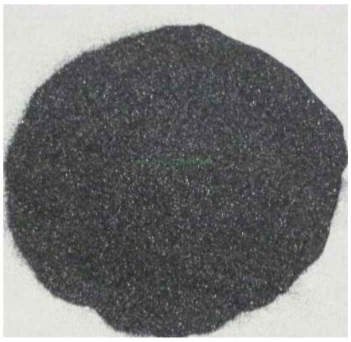
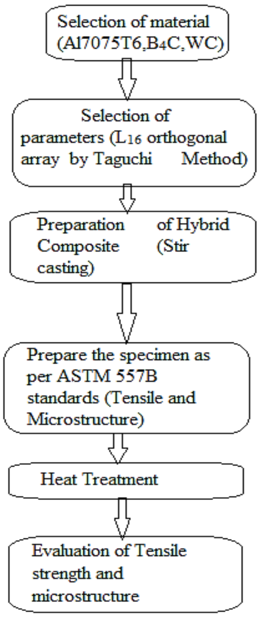


Figure 3: Tungsten carbide powders

3. METHODOLOGY

The detailed method of the work has been shown in the flow chart below



3.1 Stir casting

The aluminium 7075 -T6 is mixed with reinforced materials Boron carbide (B_4C) and tungsten carbide (WC) where wt. % of Boron carbide and wt. % Tungsten carbide are varied for each trail. The stir cast equipment consists three mild steel stirrer blades and main furnance. The figure 4 shows experimental setup of stir casting process.

- Initialy the reinforcement are preheated at 400°c temperature in the empty crucible.
- The Al -7075 ingot is preheated at 550 temperature for 1-2hrs after which the mixture is poured into crucible.
- The Al -7075 is melted upto 750c and preheated reinforcement is mechanically mixed with matrix.
- The stirrer speed is maintained upto 225 rpm for about 25 mints for uniform distribution of reinforcement. Later the mixture is poured into mould cavity.

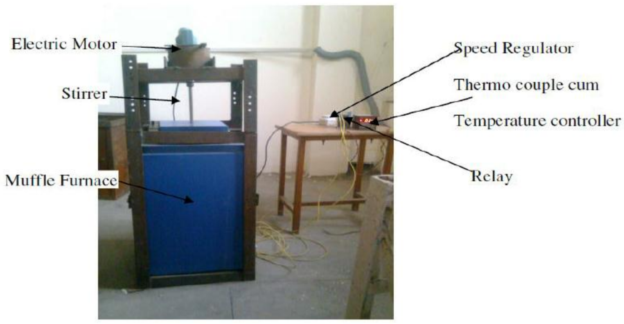


Figure 4: Experimental Set-up of Mechanical Stir Casting Process

3.2 Taguchi Method

Taguchi method uses a special set of arrays called orthogonal arrays, which advocate minimum number of experiments with maximum information about all the factors that affect the outcome.[10] Taguchi Method involves identification of proper control factors to obtain the optimum results of the process. Orthogonal Arrays (OA) are used to conduct a set of experiments. Results of these experiments are used to analyse the data and predict the quality of components produced. [11] The L_{16} Orthogonal array has been used and the selected parameters like wt% of Boron carbide (B_4C), wt% of Tungsten carbide (WC), Melting point Temperature, Stirring time, Stirring Temperature.

Table 5 Process parameters of Taguchi method for optimization stir casting.

Experiment No	Weight % of B4C	Weight % of WC	Melting point temperature	Stirring time	St Stirring speed
1	2.5	1	700	15	100
2	5	2	71	20	150
3	7.5	3	730	25	200
4	10	4	750	30	250

3.3 Heat treatment

The Heat treatment is metal working process used to alter the physical and chemical properties of materials. The Al-7075 is heated to T6 temperature grade and age hardening process is carried out at 480˚c for 4hrs. The Al7075 T6 is mixed with reinforcement B_4C and WC in solution form and solution hardening process is carried out for 120˚c for about 24hrs before pouring into mould cavity.

Figure 5: Heat treatment Process

3.4 Tensile test

The tensile test of the specimens were prepared as per ASTM 557B as in figure 4.4, and the average results for each of the composition were tabulated. One of major attributes of tensile test is to get the UTS (ultimate tensile strength) for the specimens and its percentage elongation. An instron make universal testing machine of 300 k N Capacity which is servo controlled and hydraulic actuated is used for tensile tests on the specimens.

Design of Experiments

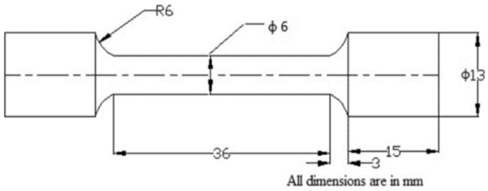


Figure 6: Specimen cross-section

Figure 7: Tensile test Specimen

3.5 Microstructure analysis

Specimens for metallographic observations were prepared by standard polishing techniques. Keller's reagent with composition of HCL=1.5 cc, HNO3=2.5 cc and H2O=95 cc was used as etching agent.[12] The microstructures of the specimen were analysed by means of SEM (scanning electron microscope) and XRD (X-ray Diffraction) techniques to determine the uniform distribution of reinforcements

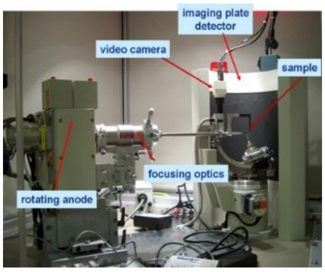


Figure 8 XRD equipment

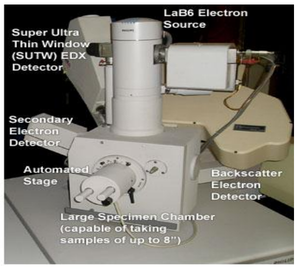
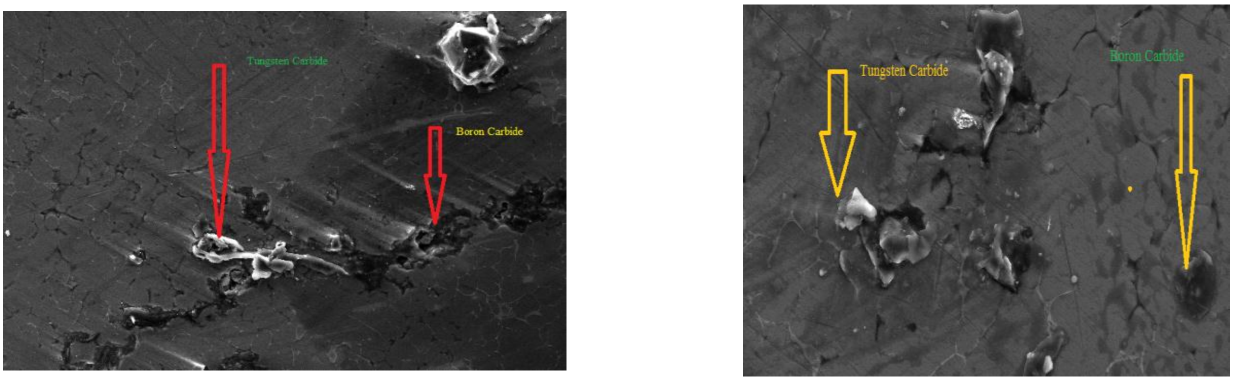


Figure 9 Scanning Electron Microscope

4. RESULT AND DISCUSSION

4.1 Microstructure analysis

The scanning electron micrographs of hybrid metal matrix composite as shown in Figure10a-b and11a-b which shows particles reinforcement is of boron carbide and particles represents tungsten carbide. The distribution of particles is uniform when added in lower percentages with 2.5wt % boron carbide and 1wt% tungsten carbide. With the increment of wt% of reinforcements, particle agglomeration was observed in the matrix which occurred due to increased particle–particle interactions. Further, it is observed that the dispersion behavior of boron carbide is better due to better wettability in comparison to tungsten carbide particles. The size of particles also plays a serious role in material loss of composite. In present study, although size was not considered as a factor, it was reported that bimodal reinforcement helps in better mechanical properties in terms of load bearing capacity, better wear resistance and hardness. [13] The SEM image of hybrid composite is shown in Figure 10a-b and 11a-b which shows distinct interfaces without the presence of micro cracks. The fig 12a-b shows that X-Ray diffraction of different Al hybrid composites which confirms the presence of boron, tungsten and aluminium as main elements.

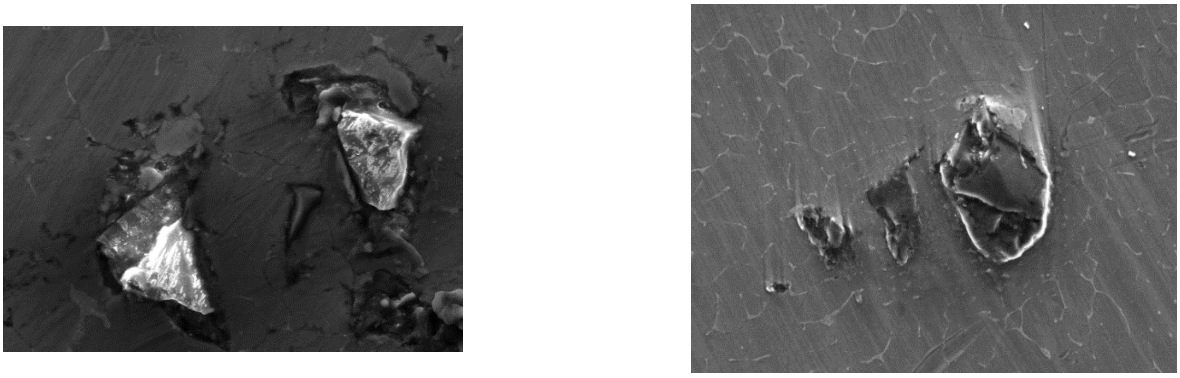


(a) **(b)**

Figure 10 (a) SEM image of Al 7075/with 2.5 % B4C, 2%WC as cast **(b)** SEM image of Al 7075 with 2.5 % B4C, 2%WC Heat treatment

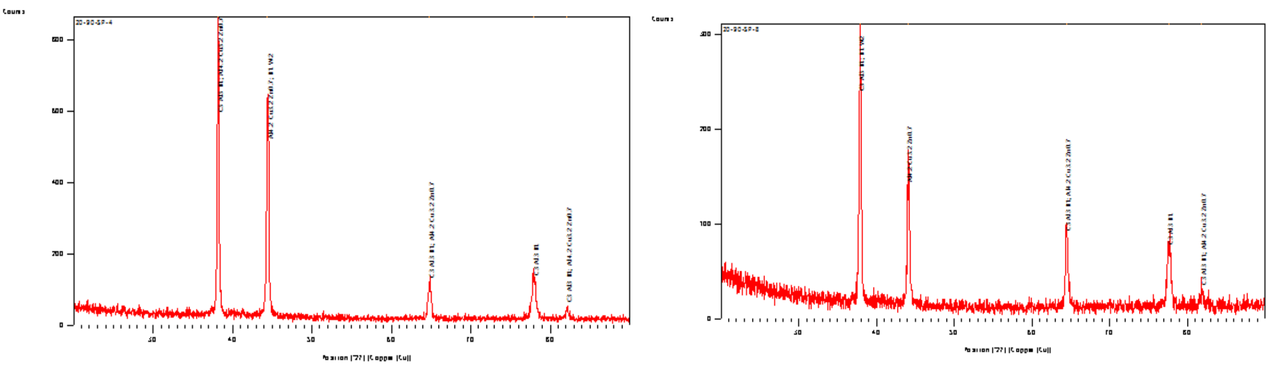
Al 7075 alloy with of B4C- WC for 2.5 wt%, 2 wt% MMCs. In the XRD pattern majorly noticed five peaks ranging from 250 - 900 span and the obtained values are 2 theta for 38.375, 44.5600, 64.870 and 78.180 with respect to Al and 2 theta at 82.390 belongs to WC.

Al 7075 alloy with B4C- WC for 10 wt%, 2 wt%. In the XRD pattern majorly noticed with five peaks varies between 250-900 span. The 2 theta of 38.370, 44.650, 64.990 and 78.109 peaks value were obtained with respect to Al and 2 theta of 82.400 belongs to B4C- WC



(a) (b)

Figure 11 (a) SEM image of Al 7075/with 10% B4C and 2%WC % as cast, (b) SEM image of AL7075 with 10% B4C 2%WCheat treated



(a) **(b)**

Figure 12 (a) XRD pattern for Al 7075 –10 % B4C- 2 % WC, (b) XRD pattern for Al 7075 –2.5% B4C- 2 % WC

3.2 Tensile strength

The experimental results obtained with respect to L_{16} orthogonal array are tabulated in table no 6 , and the critical constraints are considered based on results. The tensile test experimental results for varied different wt% of reinforcement and process parameter with respect to Taguchi method L16 orthogonal array as tabulated below, where the tensile strength of as cast specimen varies from minimum to maximum of 249.67 MPa to 361.33 MPa respectively and tensile strength of heat treated specimens varies from a minimum to maximum of 279.67MPa to 398 MPa.

Table 6: Results of tensile test with respect to L16 Orthogonal array.

Experiment No	Tensile strength MPa	
	As cast	Heat treatment
1	249.67	279.67
2	280.67	304.67
3	326.00	360.33
4	336.33	373.00
5	361.33	398.00
6	350.67	384.67
7	286.33	305.33
8	273.33	322.67
9	325.33	374.67
10	301.67	319.33
11	326.33	351.33
12	300.00	329.67
13	312.00	337.67
14	319.67	345.67
15	333.33	369.67
16	321.33	337.67

The Taguchi method is used to the process parameters are fixed in certain way to minimize the variability and optimize the results. The Taguchi method deals with designing the experiments such as SN ratios (Signal to Noise ratios). The SN ratios are obtained by the loss function from Taguchi method. In present work, “Larger is Better” condition were contemplated for obtaining the SN ratio to assess the effects of design factors on Tensile behaviour of hybrid composite. The response contemplated for assessment of tensile strength in MPa with different factors considered as wt% of B4C ,wt% of WC, stirring duration in mins, stirring speed in rpm, and melting point temperature in. The chart obtained after Taguchi analysis is mean of means versus temperature and mean of SN ratios versus temperature. The censorious elements of results of the Taguchi analysis are arranged in table (**Table 7**).

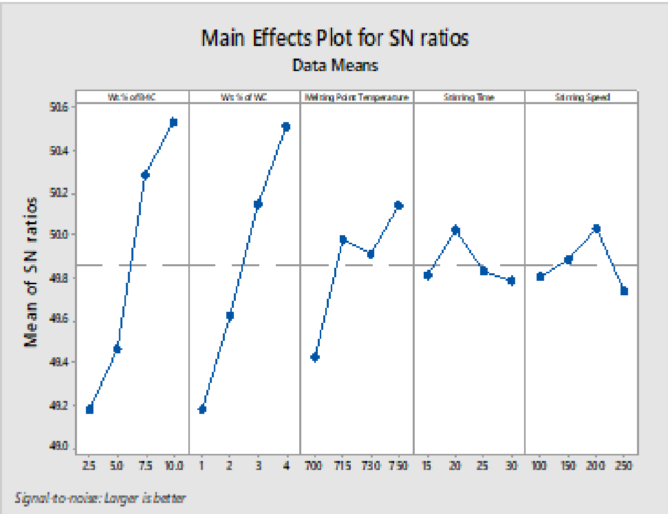
Table 7: Design of experiments using Taguchi L16 orthogonal array statistical validation methods

Experiment No	Weight % of B4C	Weight % of WC	Melting point temperature	Stirring time	Stirring speed	Tensile strength MPa	
						As cast	Heat treatment
1	2.5	1	700	15	100	249.67	279.67
2	5	2	700	20	150	280.67	304.67
3	7.5	3	700	25	200	326.00	360.33
4	10	4	700	30	250	336.33	373.00
5	7.5	4	715	20	100	361.33	398.00
6	10	3	715	15	150	350.67	384.67
7	2.5	2	715	30	200	286.33	305.33
8	5	1	715	25	250	273.33	322.67
9	10	2	730	25	100	325.33	374.67
10	7.5	1	730	30	150	301.67	319.33
11	5	4	730	15	200	326.33	351.33
12	2.5	3	730	20	250	300.00	329.67
13	5	3	750	30	100	312.00	337.67
14	2.5	4	750	25	150	319.67	345.67
15	10	1	750	20	200	333.33	369.67
16	7.5	2	750	15	250	321.33	337.67

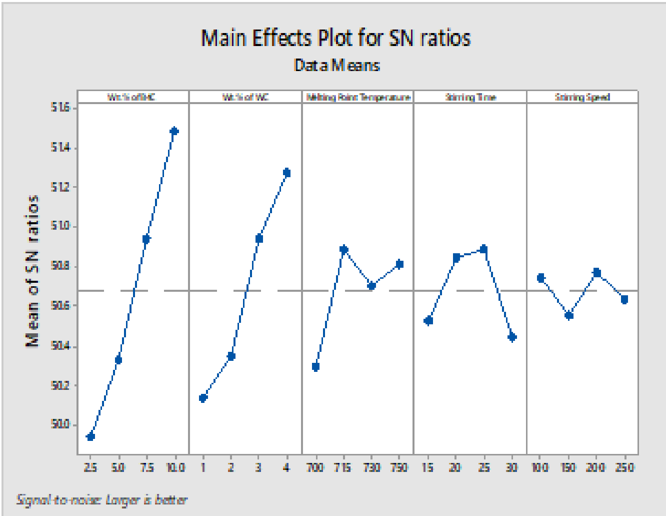
The signal to noise ratios are evaluated to assess the process parameters considered in design of experiments. **Table 9** shows the response table of SN ratio for tensile strength of the as cast specimen. It is observed that the main contributor for the tensile strength is the wt ratio of B_4C followed by wt ratio of WC, melting point temperature, stirring time, and stirring speed.

From censorious assessment of the response **table 9** for SN ratios, there is an major factor it the wt% of boron carbide that enhances the tensile strength to 1st rank among all the other contributing parameters such as wt% of tungsten carbide, melting temperature, stirring time, and stirring speed. The mixture of wt% of 10% of boron carbide, wt% 4% of tungsten carbide, melting temperature 750˚C, stirring duration of 20 minutes and stirring speed of 200 rpm is the advanced set of factors that provides the optimum result, i.e. the maximum tensile strength as shown in **figure 14 a** similarly heat treated is shown in **figure 14 b**.

From response **table 10** for mean of means, the maximum tensile strength is 10wt% of boron carbide, 4wt% of tungsten carbide, melting temperature 750˚C, stirring duration of 20 minutes and stirring speed of 200 rpm. Based on the Taguchi method the advanced set of values are obtained for maximum tensile strength for as cast and heat treated composites.

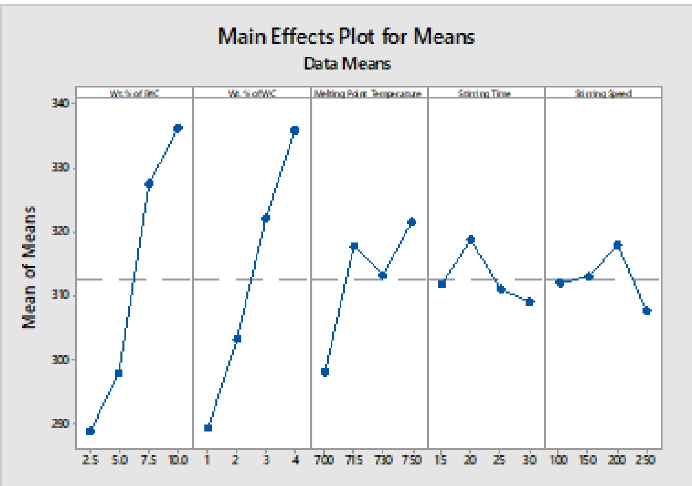


(a)

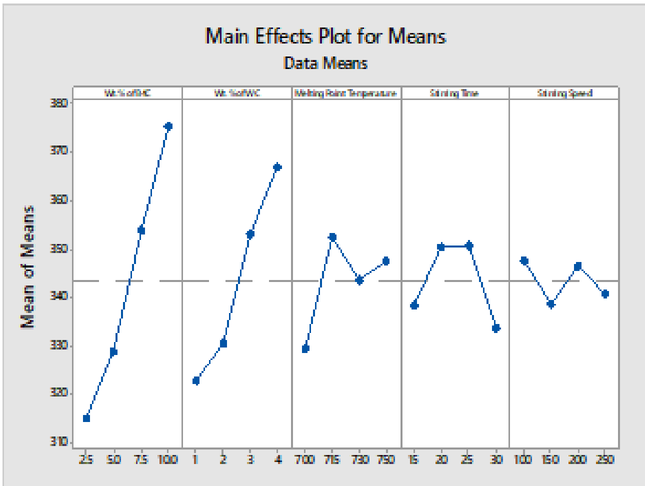


(b)

Figure 13 (a) Main Effects Plot for SN ratios (As cast) **(b)** Main Effects Plot for SN ratios (heat treatment)



(a)



(b)

Figure 14 (a) Main Effects Plot for Means (As cast), **(b)** Main Effects Plot for Means (heat treatment)

Table 9: Response Table for Signal to Noise Ratios (Tensile-As cast and Heat treated)

Level	Weight percentage of B_4C		Weight percentage of WC		Melting Temperature		Stirring Time		Stirring Speed	
	As-cast	Heat treated	As-cast	Heat treated	As-cast	Heat treated	As-cast	Heat treated	As-cast	Heat treated
1	49.18	49.94	49.18	50.14	49.43	50.29	49.81	50.53	49.81	50.74
2	49.46	50.33	49.62	50.35	49.98	50.89	50.03	50.885	49.89	50.56
3	50.29	50.95	50.15	50.94	49.91	50.71	49.83	50.89	50.03	50.77
4	50.53	51.49	50.52	51.28	50.14	50.82	49.79	50.45	49.74	50.64
Delta	1.35	1.55	1.33	1.14	0.72	0.60	0.24	0.44	0.30	0.22
Rank	1	1	2	2	3	3	5	4	4	5

Table 10: Response Table for Means (Tensile-As cast and Heat treated)

Level	Weight percentage of B_4C		Weight percentage of WC		Melting Temperature		Stirring Time		Stirring Speed	
	As-cast	Heat treated	As-cast	Heat treated	As-cast	Heat treated	As-cast	Heat treated	As-cast	Heat treated
1	288.9	315.1	289.5	322.8	298.2	329.4	312.0	338.3	312.1	347.5
2	298.1	329.1	303.4	330.6	317.9	352.7	318.8	350.5	313.2	338.6
3	327.6	353.8	322.2	353.1	313.3	343.8	311.1	350.8	318.0	346.7
4	336.4	375.5	335.9	367.0	321.6	347.7	309.1	333.8	307.7	340.8
Delta	47.5	60.4	46.4	44.2	23.4	23.3	9.8	17.0	10.2	8.9
rank	1	1	2	2	3	3	5	4	4	5

Table 11: Response Table for SN ratios (Tensile-Heat treated)

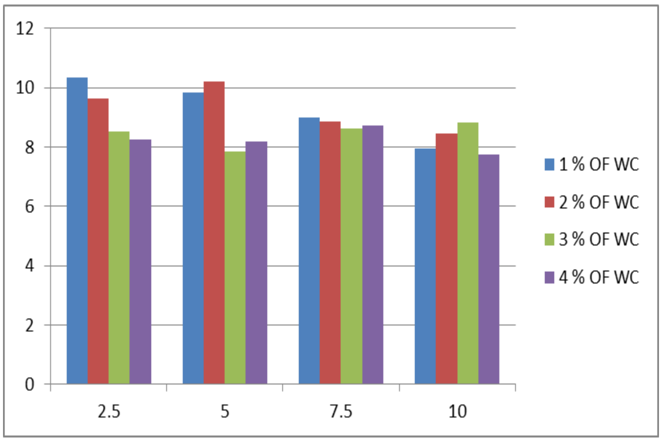
Level	Weight percentage of B_4C	Weight percentage of WC	Melting Temperature	Stirring Time	Stirring Speed
1	49.94	50.14	50.29	50.53	50.74
2	50.33	50.35	50.89	50.885	50.56
3	50.95	50.94	50.71	50.89	50.77
4	51.49	51.28	50.82	50.45	50.64
Delta	1.55	1.14	0.60	0.44	0.22
Rank	1	2	3	4	5

Table 12: Response Table for Means (Tensile-Heat treated)

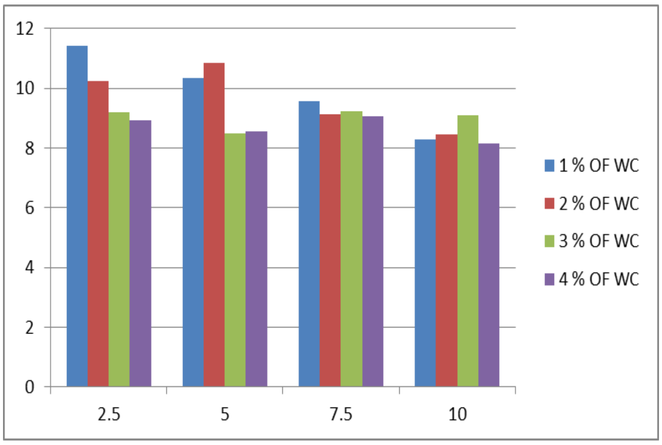
Level	Weight percentage of B_4C	Weight percentage of WC	Melting Temperature	Stirring Time	Stirring Speed
1	315.1	322.8	329.4	338.3	347.5
2	329.1	330.6	352.7	350.5	338.6
3	353.8	353.1	343.8	350.8	346.7
4	375.5	367.0	347.7	333.8	340.8
Delta	60.4	44.2	23.3	17.0	8.9
Rank	1	2	3	4	5

Percentage of Elongation

Impact of tungsten carbide particles on percentage of elongation of aluminium composite is shown in Figure 20. It can be noticed that the overall percentage of elongation of composite decreases with increase in tungsten carbide and boron carbide particles. When the composite specimen is heat treated most of the stats increases where maximum is almost 12. It is observed that after heat treatment none of the composites went blow 8, and for every percent of WC at 7.5% B_4C remained between 9-10. This is shown in the figure 21.



(a)



(b)

Figure 15 (a) percentage of elongation Al7075/B4C/WC as cast, **(b)** percentage of elongation Al7075/B4C/WC heat treatment

CONCLUSIONS

In this present study Al-7075, B_4C and WC hybrid composites successfully fabricated by using liquid metallurgical route by stir casting.

1) The Tensile strength of hybrid composite ranges from 249.69MPa to 398.67MPa where wt% of B_4C is increased from 2.5wt% to 7.5wt% along with wt% of WC from 1wt% to 4wt% at stirring speed of 100 rpm, melting point temperature 700°c-715°c and stirring duration of about 15mins-20mins.

2) Based on L_{16} orthogonal array of the Taguchi method the advanced variables for the factor are contemplated for the experimentation. "Larger is best condition" is contemplated for SN ratio plot where B_4C has obtained highest delta value and melting-point temperature being the least. i.e wt% of B_4c has contributed more for the tensile strength, followed by wt% of WC, stirring speed, stirring duration and melting point.

3) The optimized tensile strength obtained from SN ratio and mean and mean values of Taguchi method bearing 7.5wt% B_4c, 4wt% WC with stirring speed 100rpm for duration of 20mins at melting point 715°c.

4) The percentage elongation decreasing with increasing of boron carbide and tungsten carbide, after heat treatment percentage of elongation increasing.

5) The microstructure of the specimens clearly depict the uniform distribution of matrix reinforcements in Al-matrix phase thereby validating the use of stir casting process in the synthesis of a novel aluminium 7075 – boron carbide – tungsten carbide composites for advanced engineering applications

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