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Experimental Investigation of Physical and Mechanical Properties of Al-Cu-ZrO_2-TiO_2 Composites

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Composite Materials plays a vital role in the formation of mankind, ranging from the habitation of early civilisation to enable future modernisation. In this present work titania and zirconia reinforced Al6063-Cu composite has been developed by using a new casting process comprising of clay soil and sand mold. On top of that stirrer mechanism has also been used to mix the hybrid abrasive particles of Single Particle Size (SPS), Double Particle Size (DSP) and Triple Particle Size (TPS) in the Al-Cu alloy which is a completely new approach. Taguchi L18 orthogonal arrays have been used in this study to reduce the number of tests. For this present research work, 5%, 7.5% and 10% of hybrid abrasive have been mixed in the alloy to investigate its different properties like elastic modulus, ductility and density. It has been observed that in addition of the reinforcements in the newly developed composites elastic modulus, ductility and density have been improved to 31.42%, 40% and 19.81% respectively. Due to this improved properties this composite can be used to manufacture bearing, valve, aircraft electronics and many other appliances. The experimental results were analyzed by the SN ratio plot and an RSM model was used to predict these properties and to estimate the affecting factors for each property. Further, the RSM models have been corroborated by performing the experiments on the newly manufactured composites for elastic modulus, ductility and density. The result obtained from RSM model shows good similarity with the experimental results.

Keywords: Aluminium matrix particulate composites, Casting, Hybrid abrasive, Particle size, Response surface model

Introduction

Making Metal Matrix Composite (MMC) with advanced mechanical properties has been practiced for decades.[1] The addition of ceramic particles to the lightweight base matrix helps materials achieve high market demand and huge application area at low cost and better performance. The main advantages of composites include better tribological, physical and mechanical properties and high resistance to degradation.[2–4] The application field of MMC includes aeronautical, structural applications, space shuttle, electronics automobile and military applications, bicycle industries etc.[5–7]

Aluminium, Copper, Magnesium, Titanium and their alloys are the most common base matrices which are used for making composites as they are light in weight and Al_2O_3, AlN, B_4C, BN, flyash, MgO, SiC, TiB_2, TiC and TiO_2 ceramic particles are used as reinforcements into those base matrices.[8–12] Venugopal and Karikalan have developed an AA6061-TiO_2-SiC composite by using stir casting techniques to check the physical properties of the composite and found better properties by adding the reinforcements.[13] Ogawa and Masuda have reviewed and found that addition of nano-carbon reinforcement enhances the ductility and other mechanical properties of the composite.[14] Morampudia *et al*. have developed an Aluminium based Composites and check the effect of ZrB_2 reinforcement particles on the corrosion and physical properties of the composite.[15] Aluminum is the most widely used base matrix for low weight and low density but its electrical and thermal conductivity is not better than copper. Also, copper possesses improved formability, softness, plasticity and oxidation resistance.[16] So, aluminium-copper alloys are extensively used in different fields due to their better thermal, mechanical and electrical properties.[17–19] For this reason, aluminium and copper alloys of different weight percentages have been used in the present research work.

Hitherto lots of work have been done with different types of reinforcement like MgO and chitin whiskers, B_4C and cow dung ash, ZnO, CuO, TiC, Al_2O_3, SiC nanoparticles and carbon fibers, fly ash and zirconia etc. but not any work has been found with the mixer of TiO_2 and ZrO_2.[20–24] Titania (TiO_2) has non-toxicity and chemical stability and on the other hand, it is also

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cheap and easily available. For this reason this is used as a sensors, sunscreens, toothpaste, lotion and color paints etc.[25] where as Zirconia (ZrO_2) has high hardness and strength value, good dispersion stability in the lubricant, tremendous chemical resistance property, high fracture toughness and exceptional wear resistance.[26] For enhancing the creep resistance, corrosion resistance, fracture strength and other mechanical properties of the base matrix titania and zirconia can be added as reinforcement. So, for this present research work different particle sizes of (single, double and triple particle size) mixer of TiO_2 and ZrO_2 have been used as reinforcement to check elastic modulus, density and ductility of this newly developed MMC. Further the casting process is also a new process, which is a combination of clay soil mold supported by sand mold.

Materials and Method

Materials

In the present study, Aluminium Alloy 6063 rods and copper rods have chosen as base matrix. Magnesium and silicon are the major alloying elements of the aluminium alloy 6063. This grade of aluminium has been chosen as the properties of other grade of this alloy are not good as AA 6061 or AA 7 series. The properties of AA 6063 have been shown in Table 1. The base alloy has prepared by melting different percentage (54%, 33% and 20%) of copper in Al 6063 in induction furnace by means of stirrer mechanism. Mixer of Zirconia (ZrO_2) and Titania (TiO_2) at different proportion like (7:3), (3:7), (1:1) and different particle sizes (SPS, DPS and TPS) are utilized as reinforcements in this present study. The mixing of abrasive particles has been done mechanically. Different percentages like 10%, 7.5% and 5% of this mixed abrasive (TiO_2 + ZrO_2) have been reinforced with the base matrix by using stirrer mechanism.

Table 1 — Properties of AA6063

Sl. no.	Property	Value
1.	Density	2.7 g/cm^3
2.	Elastic modulus	70–80 GPa
3.	Poisson's ratio	0.33
4.	Ductility	10–12%
5.	Tensile strength	90 MPa

Method

The steps involved in preparation of aluminium-copper metal matrix composites are shown in flow chart (Fig. 1).

Experimentation

The design of experiment for this current research work has been done by using Taguchi's L18 OA. Mechanical stirring process has been used to mix the ceramic reinforcements in the Al-Cu base alloy and different slots of stirring duration has taken in consideration, such as 5 min, 7 min and 9 min, were selected based on the trial run, and other stirrer parameters were fixed. The correct dispensation of titania and zirconia particles in the base alloy depends entirely on the time allotted for stirring process. Maximization of the turbulence time enhances the probability of correct dispensation of zirconia and titania particles in the base alloy. Thus, it is very essential to consider different time levels for stirring process. After the molten matrix and the abrasive particles have been properly mixed, it has been molded and left for cooling for some time. Solidification of the molten metal by cooling is very essential for getting improved properties of the composite. The cooling process for solidification is usually done at room temperature. For this reason different levels of cooling times have been chosen. Therefore, as per the aforesaid theories and literature survey, different levels of cooling time to solidify the MMC have been preferred for this current study. All values of the input parameters are selected based on the trial runs. For this research work, three different particle sizes of mixer of zirconia and titania have been used to manufacture composite viz. TPS, DPS

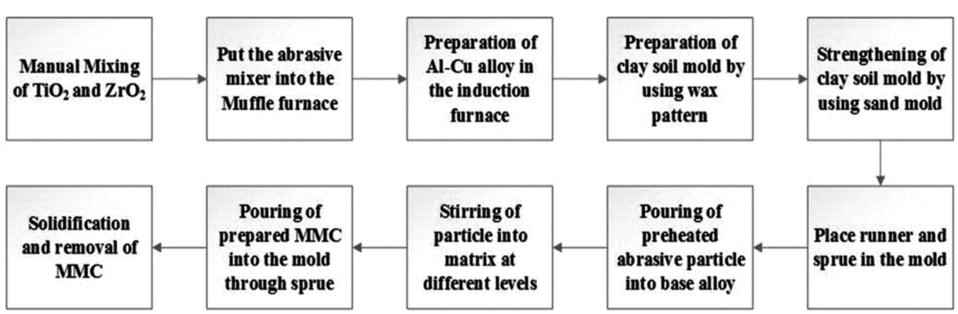

Fig. 1 — Preparation of aluminium-copper metal matrix composites

Table 2 — Different Input variables used and their levels

Sl. No.	Input Parameter	Level 1	Level 2	Level 3
1.	Binder's wt% in mold material (A)	5% of the mold material	10% of the mold material	--
2.	Hybrid Abrasive mixer ratio (ZrO_2: TiO_2) (B)	50% + 50%	30%+ 70%	70% + 30%
3.	Wt% of reinforcement in Al-Cu alloy (C)	5%	7.5%	10%
4.	Wt% of Cu alloyed with Al6063 (D)	20% of Cu	33% of Cu	54% of Cu
5.	Particle Size of reinforcement (E)	Single (SPS)	Double (DPS)	Triple (TPS)
6.	Time for Stirring process in minutes (F)	5	7	9
7.	Wt% of brick powder in the mold (G)	50% of brick powder	25% of brick powder	0% of brick powder
8.	Time for Cooling in minutes (H)	30	35	40

and SPS. The TPS particle size contains abrasive particles in excess as it contains abrasive particles of size 50 µm, 30 µm and 10 µm. In the case of DPS, both 50 µm and 30 µm abrasive particle mixers have been used so that the amount of abrasive particles per unit weight/volume in DPS should be less than TPS. In case of SPS particle size, 10 µm sizes of both zirconia and titania abrasive particles have been used for manufacturing of the MMC. Different factors and their levels for the fabrication of AMMCs have been shown in Table 2.

Total 18 numbers casting have been done and 18 composite pieces have been manufactured based on the Design of Experiment (DOE). The size of the composite blocks is (5 × 5 × 5) cm^3. Then these pieces have been further cut into small pieces and different sizes as per the requirement for performing different experiments.

Results and Discussion

Elastic modulus

A circular or rectangular cross section is used to measure the elastic modulus of a material. The first step is to measure the length and cross sectional area of the sample. Then, a known force has to be applied on the sample to stretch it. After the force was removed, the newly extended length of the sample was measured. From that stage, the stress and strain of the sample can be easily measured and the elastic modulus from that stress and strain value can also be measured by dividing it by the strain.

Elastic Modulus can be obtained by simply stress divided by strain.

Modulus of Elasticity, $E = \sigma / \varepsilon$

where, σ = Stress and ε = strain

For the majority of materials, Modulus of Elasticity is very large that it is usually expressed as gigapascals (GPa) or megapascals (MPa).

Three specimens have prepared for each experimental set-up. The average elastic modulus of the all samples is listed in the Table 3.

Table 3 — Observation of elastic modulus of all 18 samples

	Data Set 1	Data Set 2	Data Set 3	Mean	Standard Deviation	Standard Error
1.	86	82	87	85	2.646	0.624
2.	93	93	90	92	1.732	0.408
3.	99	101	97	99	2	0.471
4.	85	88	88	87	1.732	0.408
5.	94	94	95	94	0.577	0.136
6.	90	90	92	91	1.155	0.272
7.	107	100	103	103	3.512	0.828
8.	104	105	106	105	1	0.236
9.	70	70	75	72	2.887	0.68
10.	111	115	109	112	3.055	0.72
11.	100	100	102	101	1.155	0.272
12.	97	99	101	99	2	0.471
13.	102	104	100	102	2	0.471
14.	105	105	107	106	1.155	0.272
15.	77	76	76	76	0.577	0.136
16.	116	115	112	114	2.082	0.491
17.	99	98	98	98	0.577	0.136
18.	93	94	92	93	1	0.236

Influence of Input Parameters on Elastic Modulus

Signal to noise ratio (S/N) analysis has been done by using the values from Table 3. The S/N ratio plot for elastic modulus of the composite is shown in Fig. 2.

As per the S/N ratio graph, sample no. 16 is showing better elastic modulus and the parametric set-up for the same is: 10% of binder, (50% of ZrO_2+ 50% of TiO_2) of Abrasive mixer, 5% of reinforcement in the base alloy, 46% Al6063 and 54% of copper, SPS size, Stirring duration is 9 minutes, amount of brick powder is 0% and 40 minutes of cooling time has given the maximum value for Elastic Modulus within this range of study.

From the Fig. 2 and Table 3, it has been found that sample number 16 is having greater elastic modulus value which is 114 GPa.

The reasons for getting this parametric level for elastic modulus value are as bellow:

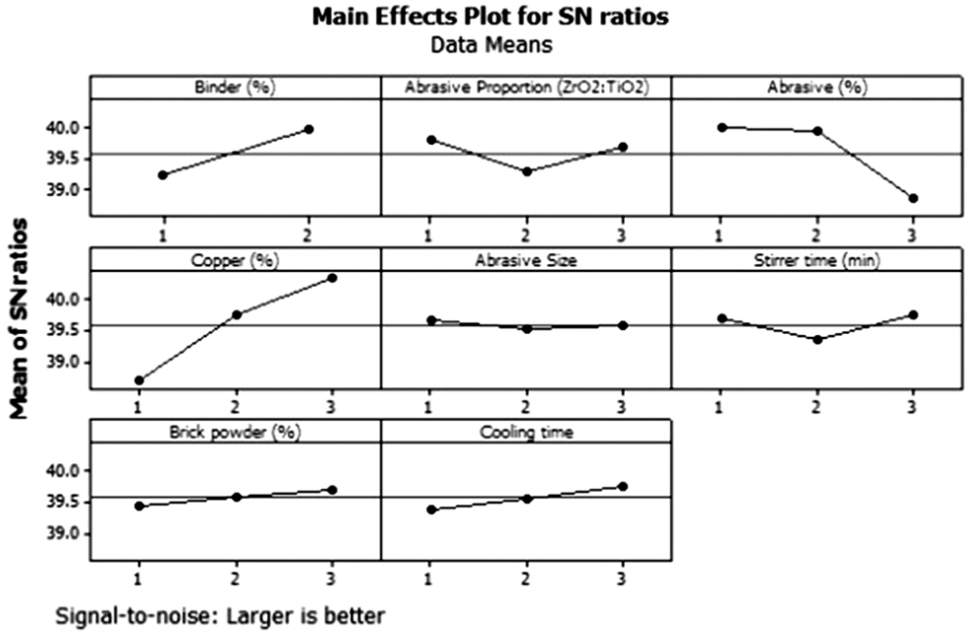

Fig. 2 — S/N ratio graph of elastic modulus

1. Increasing the amount of binder in sand mold casting reduces the density of the casting product. A high percentage of the binder increases the collapsibility of the mold,[27] which reduces the density of the cast product. As the density increases, so does the elastic modulus.
2. The combination of 50% of ZrO_2 + 50% of TiO_2 are giving the best elastic modulus value as the elastic modulus value of zirconia is higher than the titania due to this reason, 50% of both the ceramics is showing the highest elastic modulus value.
3. Five percent of hybrid abrasive gives the highest elastic modulus. A lower percentage of abrasive means a higher percentage of the base matrix which affects the elastic modulus of the product. The percentage of abrasive compounds in the base matrix has a large effect on the elastic modulus. The SN ratio graph shows that the elastic modulus decreases with increasing percentage of abrasive weight.
4. Maximum elastic modulus readings are observed with 54% copper with aluminum. To make the base alloy (Al6063-Cu), the maximum amount of copper has been added to aluminum. A higher percentage of copper in the base alloy means a lower percentage of aluminum which increases the elastic modulus of the product because copper has a higher elastic modulus value than aluminum.
5. As per the Table 3 and Fig. 2, the effect of abrasive size on the prepared composites is negligible.
6. Nine minutes of stirrer time is the maximum time level which is offered for stirring process. Maximum stirring time helps for proper mixing of reinforcement in the base alloy and the correct dispensation of abrasive particles in the base matrix is essential for obtaining good elastic modulus values.
7. Zero percent of brick powder in the mold gives better compactness of mold which can provide highest elastic modulus value.
8. The minimum cooling time of 30 minutes is showing better elastic modulus value. Lesser cooling time means fast solidification which leads fine grain structure of the composite and this fine grain of composite is providing the better elastic modulus value.

Ductility

Ductility is defined as the percentage elongation of a wire under tensile load. Ductility test can be performed in a universal testing machine with the help of an extensometer.

$$\text{Ductility} = \frac{\Delta l}{l} \times 100\%$$

where, Δl = elongation due to tensile stress

l = original length of the specimen before applying the stress

Three specimens has prepared for each experimental set-up. The average ductility value of the all samples is listed in the Table 4.

Influence of Input Parameters on Ductility

Signal to noise ratio (S/N) analysis for ductility has been done by considering the values of Table 4. The S/N ratio plot for ductility of the composite has been shown in Fig. 3.

Table 4 — Observation of ductility of all 18 samples

	Data Set 1	Data Set 2	Data Set 3	Mean	Standard Deviation	Standard Error
1.	22	22	24	23	1.155	0.272
2.	23	22	21	22	1	0.236
3.	22	24	25	24	1.528	0.36
4.	22	20	19	21	1.528	0.36
5.	23	23	24	23	0.577	0.136
6.	21	21	29	24	4.619	1.089
7.	19	18	22	20	2.082	0.491
8.	28	29	28	28	0.577	0.136
9.	18	21	23	21	2.517	0.593
10.	27	26	30	28	2.082	0.491
11.	19	24	23	22	2.646	0.624
12.	22	22	20	21	1.155	0.272
13.	25	25	26	25	0.577	0.136
14.	30	31	27	29	2.082	0.491
15.	18	17	22	19	2.646	0.624
16.	33	30	32	32	1.528	0.36
17.	21	23	25	23	2	0.471
18.	24	22	22	23	1.155	0.272

As per the S/N ratio graph, sample No. 16 is showing better ductility. Weight percentage of binder in the mold is 10%, (70% of ZrO_2 + 30% of TiO_2) of Abrasive mixer, 5% of reinforcement in the base alloy, 46% Al6063 and 54% of copper, TPS size, Stirring duration is 5 minutes, amount of brick powder is 50% and medium cooling duration which is 35 minutes has given the maximum ductility value.

From the Fig. 3 and Table 4, it has been found that sample number 16 is having maximum ductility which is 32%.

The reasons for getting this aforesaid input parameter setting for the maximum value of ductility are as bellow:

1. Using 10% of the binder to form the mold increases its compactness resulting in slower heat flow which increases the plasticity of the casted product and increases the ductility of the casted product.[28]
2. About 70% of ZrO_2 + 30% of TiO_2 are giving the best ductility value as the density of zirconia is higher than the titania and for this reason this level is showing the better ductility value.[29]
3. Percentage of reinforcement particles present in the composite has a great influence in ductility of the composite. Highest ductility is achieved with 5% of hybrid abrasive. Less percentage of abrasive means greater percentage of base matrix which influences the ductility of the product. If the percentage of reinforcement increases, non wet ability and non uniformity in the matrix has

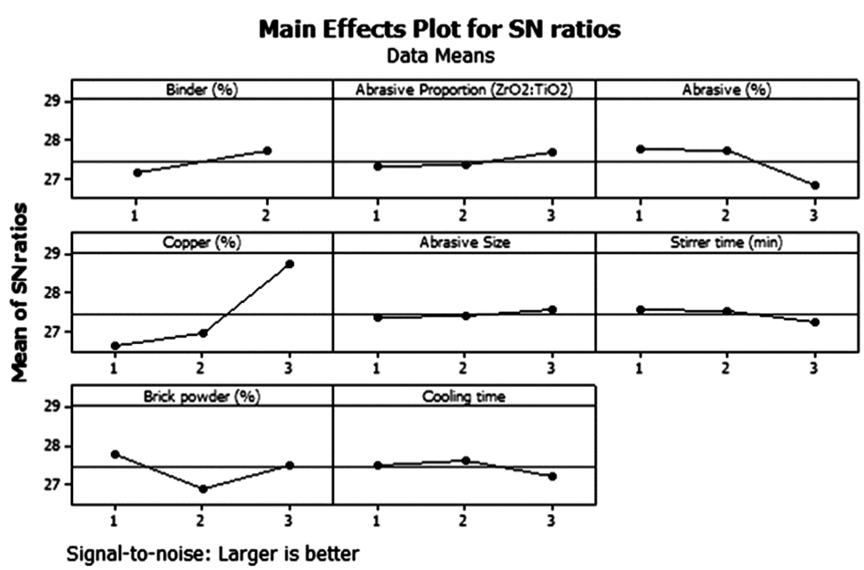

Fig. 3 — S/N ratio graph of ductility

introduced which leads to high viscous property of the composite. Due to this high viscosity, it is difficult to pour the composite material into the mould. This reduction in the ductility is due to increase in the hardness.[30] From the results it can be concluded that the percentage elongation of the prepared composites reduced as the wt% of reinforcement is raised from 5% to 10%.[31–34]

4. From SN ratio graph it has been found that higher amount of copper in the base alloy showing better ductility value of the composite. Highest ductility reading is observed with 54% Cu with Al 6063. This wt% of copper is the maximum amount of copper added into the aluminium 6063 for developing the base matrix (Al6063-Cu alloy). Copper is more ductile than aluminium 6063, as a result, more percentage of copper in the base alloy means less percentage of aluminium which increases the ductility of the product.
5. TPS particle size is showing the best ductility value as the amount of reinforcement is lesser than DPS and SPS.
6. 5 minutes of stirrer time is the minimum stirring time. If stirring time increases entrapment of gases in the molten composite at high temperature and hence reduces the ductility. So, less stirring time gives better ductility value.
7. The minimum amount of brick powder which is 0% provides maximum ductility value. The lowest percentage of brick powder in the mold and this means a compact mould which can provide highest ductility value.
8. Cooling duration of 30 minutes is the minimum time duration provided for cooling purpose. This leads fast solidification and fine grain structure of the composite and this fine grain of composite is providing the better ductility value.

Density

Density of the developed composites was assessed with polished specimen of size $5 \times 5 \times 5\ mm^3$. Mass of the same composite is measured using an electronic weighing machine. Different sizes i.e. length, width and height of the specimens were measured by using a vernier calliper with least count of 0.001 mm. Volume of the casted samples is then evaluated and the density of the same is calculated by dividing volume against mass.

Three specimens has prepared for each experimental set-up. The average density of the all samples is listed in the Table 5.

Influence of Input Parameters on Density

The values in Table 4 are taken for the signal to noise ratio (S/N) analysis. The S/N ratio plots for density of the composite are shown in Fig. 4. The levels with higher S/N ratios of corresponding factors are deemed to be optimum irrespective of the chosen quality characteristics for that particular response in case of Taguchi analysis.

As per the S/N ratio graph 10% of binder, (30% of ZrO_2 + 70% of TiO_2) of Abrasive mixer, 5% of reinforcement in the base alloy, 80% Al6063 and 20% of copper, SPS size, cooling time of 5 minutes, amount of brick powder is 25% and Stirring and cooling duration of 5 and 35 minutes respectively is giving the minimum value for the Density. From the Fig. 4 and Table 2, it has been found that sample number 1 is having minimum density which is 3.68 gm/cc.

The reasons for getting this aforesaid input parameter levels for the better value of density are as bellow:

1. Increase in amount of binder in sand mould casting decreases the density of the casted product. A higher percentage of binder maximizes the collapsibility of the mold,[25] due to which density of the casted product decreases.[35]

Table 5 — Observation of density of all 18 samples

	Data Set 1	Data Set 2	Data Set 3	Mean	Standard Deviation	Standard Error
1.	3.61	3.73	3.70	3.68	0.062	0.015
2.	5.67	4.58	4.48	4.91	0.66	0.156
3.	6.84	6.26	5.78	6.29	0.531	0.125
4.	4.11	4.06	3.77	3.98	0.184	0.043
5.	4.99	5.36	5.37	5.24	0.217	0.051
6.	5.22	5.20	5.13	5.18	0.047	0.011
7.	4.91	5.03	4.88	4.94	0.079	0.019
8.	6.01	5.89	6.19	6.03	0.151	0.036
9.	6.07	5.68	5.87	5.87	0.195	0.046
10.	5.23	4.98	5.82	5.34	0.431	0.102
11.	4.33	4.12	3.62	4.02	0.365	0.086
12.	5.71	5.76	5.72	5.73	0.026	0.006
13.	5.02	4.56	4.76	4.78	0.231	0.054
14.	5.18	5.03	4.97	5.06	0.108	0.025
15.	4.88	4.89	4.85	4.87	0.021	0.005
16.	5.45	5.45	5.44	5.45	0.006	0.001
17.	4.51	4.57	4.54	4.54	0.03	0.007
18.	6.01	6.08	6.14	6.08	0.065	0.015

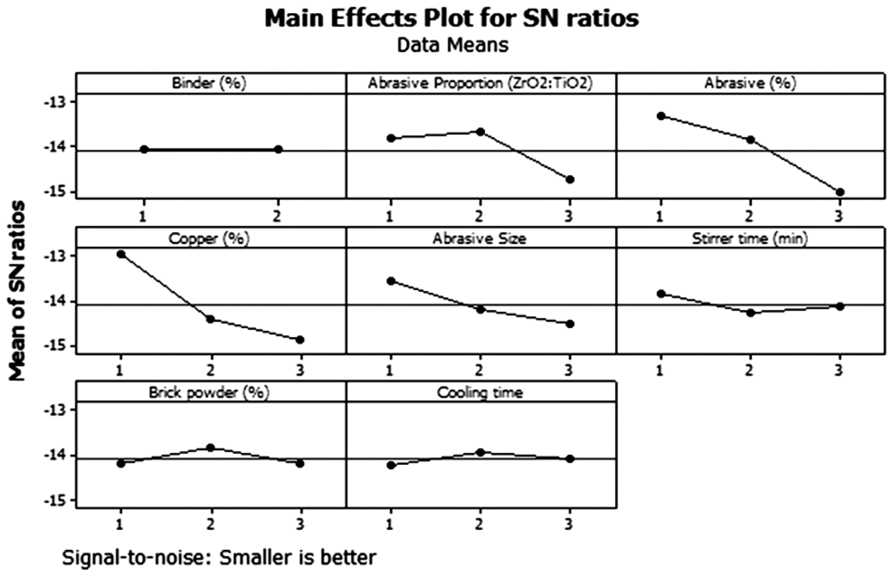

Fig. 4 — S/N ratio graph of density

2. Lowest density value is seen with 30% of ZrO_2 + 70% of TiO_2 as the density of zirconia is higher than titania as a result this level of input variable is offering the minimum density value.
3. Lowest density is achieved with 5% of hybrid abrasive. Less percentage of abrasive means greater percentage of aluminium which influences the density of the product. The density of the reinforcements is greater than the base matrix as a result of this addition in wt% of reinforcements the density also increases.[36] From the Fig. 4, it is easily observed that the density increases with the increase in the percentage of abrasive due to the higher density of the abrasive particles.
4. With 20% copper along with aluminium is giving lowest density reading which is the minimum amount of copper added into the aluminium. Less percentage of copper in the base alloy means greater percentage of aluminium which decreases the density of the product. From the SN ratio graph, it has been observed that if the proportion of the Cu in the Al-Cu alloy increases, it helps to improve the density of the composite; this is due to the greater influence of high density value of copper present in higher proportion in the composite.
5. SPS size is giving the minimum density value as it is having the maximum amount of reinforcement particles in the base alloy.
6. Five minutes of stirrer time is the lowest stirring time as stirring time increases proper mixing of the reinforcements as a result of this more stirring time is giving better density value.
7. The 25% of brick powder is the medium range which provides the lowest density value.
8. Better density value can be obtained at a cooling time of 35 minutes.

Response Surface Model Analysis of AMCs

The RSM analysis was carried out for output parameters of TiO_2 and ZrO_2 reinforced Al6063-Cu composites. All the predicted values have been validated with the experimental data shown in Table 6, also the standard deviation and standard error for all the properties have been shown in the same Table and Table 7 shows the all optimum parametric levels for all of the properties. The regression models developed for all these parameters taken from Table 2 have shown in Eqs 1 to 3 subsequently.

$$\text{Elastic Modulus} = 107.362 + 5.476 \times A + 4.810 \times B - 8.476 \times C - 0.048 \times D + 4.429 \times E + 2.976 \times F - 1.417 \times G + 2.250 \times H - 8.611 \times B^2 - 7.310 \times C^2 - 11.330 \times D^2 - 13.725 \times E^2 + 1.235 \times F^2 + 5.869 \times G^2 + 19.200 \times H^2 - 1.310 \times A \times B - 13.310 \times A \times C \quad ...(1)$$

Table 6 — Validation of RSM for elastic modulus, ductility and density

	Elastic modulus				Ductility				Density			
Ex. No.	Predicted value	Exp. value	Std deviation	Std error	Predicted value	Exp. value	Std deviation	Std error	Predicted value	Exp. value	Std deviation	Std error
1.	97.38	85	8.754	2.063	26.09	23	2.185	0.515	5.37	3.68	1.195	0.282
2.	106.88	92	10.522	2.48	23.56	22	1.103	0.26	5.45	4.91	0.382	0.09
3.	109.94	99	7.736	1.823	23.64	24	0.255	0.06	5.54	6.29	0.53	0.125
4.	116.34	87	20.747	4.89	20.13	21	0.615	0.145	5.18	3.98	0.849	0.2
5.	110.14	94	11.413	2.69	23.21	23	0.148	0.035	5.33	5.24	0.064	0.015
6.	104.77	91	9.737	2.295	25.13	24	0.799	0.188	5.22	5.18	0.028	0.007
7.	71.45	103	22.309	5.258	30.87	20	7.686	1.812	5.87	4.94	0.658	0.155
8.	69.76	105	24.918	5.873	32.29	28	3.033	0.715	5.97	6.03	0.042	0.01
9.	77.51	72	3.896	0.918	28.75	21	5.48	1.292	6.00	5.87	0.092	0.022
10.	103.32	112	6.138	1.447	26.03	28	1.393	0.328	5.51	5.34	0.12	0.028
11.	99.84	101	0.82	0.193	24.81	22	1.987	0.468	5.32	4.02	0.919	0.217
12.	111.51	99	8.846	2.085	22.73	21	1.223	0.288	5.51	5.73	0.156	0.037
13.	112.72	102	7.58	1.787	22.05	25	2.086	0.492	5.25	4.78	0.332	0.078
14.	106.09	106	0.064	0.015	25.60	29	2.404	0.567	5.27	5.06	0.148	0.035
15.	108.92	76	23.278	5.487	22.37	19	2.383	0.562	5.21	4.87	0.24	0.057
16.	74.17	114	28.164	6.638	31.93	32	0.049	0.012	6.01	5.45	0.396	0.093
17.	81.10	98	11.95	2.817	27.50	23	3.182	0.75	5.93	4.54	0.983	0.232
18.	63.66	93	20.747	4.89	32.91	23	7.007	1.652	5.86	6.08	0.156	0.037

Table 7 — Optimum parametric level for each of the properties

	Optimum parametric level for elastic modulus	Optimum parametric level for ductility	Optimum parametric level for density
Binder's wt% in mold material (A)	10%	10%	10%
Hybrid Abrasive mixer ratio (ZrO_2: TiO_2) (B**)**	50% of ZrO_2 + 50% of TiO_2	70% of ZrO_2 + 30% of TiO_2	30% of ZrO_2 + 70% of TiO_2
Wt% of reinforcement in Al-Cu alloy (C)	5%	5%	5%
Wt% of Cu alloyed with Al6063 (D)	54%	54%	20%
Particle Size of reinforcement (E)	SPS	TPS	SPS
Time for Stirring process in minutes (F)	9	5	5
Wt% of brick powder in the mold (G**)**	25%	50%	0%
Time for Cooling in minutes (H)	40	35	35

$$\text{Ductility} = 21.3778 + 0.6667 \times A + 0.0000 \times B - 0.9167 \times C + 5.4167 \times D - 1.6667 \times E - 0.8333 \times F + 0.5000 \times G - 0.5000 \times H + 1.3889 \times B^2 - 0.5833 \times C^2 + 3.5027 \times D^2 + 4.1645 \times E^2 + 0.1543 \times F^2 + 0.6667 \times G^2 - 5.6716 \times H^2 + 0.8333 \times A \times B + 3.8333 \times A \times C \quad ...(2)$$

$$\text{Density} = 5.04059 - 0.01167 \times A + 0.34333 \times B + 0.46083 \times C + 0.54333 \times D - 0.32250 \times E + 0.09917 \times F - 0.01250 \times G - 0.05833 \times H + 0.01111 \times B^2 + 0.18917 \times C^2 - 0.39293 \times D^2 + 0.12280 \times E^2 - 0.16939 \times F^2 + 0.27417 \times G^2 + 0.09115 \times H^2 - 0.11667 \times A \times B + 0.075 \times A \times C \quad ...(3)$$

Conclusions

Al6063-Cu-TiO_2-ZrO_2 composites have been successfully developed in this present work and different properties of the composite have also been successfully analyzed. The following conclusions can be drawn which are as follows.

a) Experimental data showed a wide range of elastic modulus (72–112 GPa), ductility (19–32%) and density (3.68–6.29) gm/cm^3. All these properties have been enhanced from 2 to 4 times than the base metal.

b) The percentage of copper, percentage of abrasive reinforcement and wt% of binder has a strong effect on the different properties of the newly casted composites. It has been found that composite with maximum amount of Cu exhibit better elastic modulus and ductility and minimum amount of copper exhibit better density. Whereas 5% hybrid abrasive and 10% binder for making the mold affect the MMC to improve density, ductility and elastic modulus value.

c) In case of size of the reinforcement particles, SPS shows better density and elastic modulus value. However, in case of ductility, TPS shows the minimum ductility value. Duration for Stirring and cooling also plays an important role on the properties of the newly developed composites.

d) A RSM model for elastic modulus, ductility and density have been successfully developed which shows very less variations with the experimentation results.

This newly developed Al-Cu-TiO_2-ZrO_2 composite can be used for aircraft electronic equipment. Due to their good physical mechanical properties, these composites are used for manufacturing of underwater parts, aircraft propellers, valves, automotive bodies and heat exchangers. Only one type of binder has been used to make the mold whereas so many easily available binders can be used for making the mold. The cost of the composite for making the daily use equipments is comparatively high which restricts the application area of the MMC in the above mentioned fields only.

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