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Evaluation of Microstructure and Mechanical Properties of Al-Cu-TiO_2-ZrO_2 Composites

Debashis Podder*, Sujoy Chakraborty and Uttam Kumar Mandal
Department of Production Engineering, NIT Agartala, Tripura, India, 799 046

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Different types of aluminium alloy based composites are being developed nowadays by using various types of the reinforcements to get better mechanical properties. In this research work, a new aluminium-copper alloy based composite reinforced with 5%, 7.5% and 10% of titania (TiO_2) and zirconia (ZrO_2) mixer have been fabricated and also investigated for mechanical properties like surface hardness, compressive strength, tensile strength and micro-structural characterization has been done by using microscope, energy dispersive spectroscopy, scanning electron micro-graph with X-ray elemental mapping and X-Ray powder diffraction. The new composite has been prepared by combining three processes like sand mould casting, temporary wax pattern and stir casting which has never been used before for casting. Design of experiment has been done by employing Taguchi L18 orthogonal array in this study. It has been found that all the three mechanical properties have been escalated due to reinforcement of abrasive particles in the base alloy and the improved results of Al/Cu composites in terms of percentage are 29.72% for hardness, 31.46% for tensile strength and 43.29% for compressive strength successfully achieved in this work.

Keywords: Al-Cu based composites, Compressive strength, Tensile strength, Surface hardness, Stir casting

Introduction

Aluminium-copper metal matrix composites have been prepared by combining of three processes like temporary wax pattern, sand mold casting and stir casting have been used to prepare these composites.[1] For better surface finish, clay soil over the wax pattern has been used. It has been seen in Bengal that the clay soil is used to prepare idol of God and Goddess at the time of different festivals. The surfaces of these clay idols are very superior and this leads the idea to get a better surface finish of the product. Moreover, as the pattern is a wax pattern, after dewaxing, a layer of wax will be still remained on the inner surface of the mold and due to this, a better surface finish can be obtained.[2] To support the clay mold sand mold casting has been used as this process is cheap and its parameters are easily controllable.

In the modern era of materials, the application of metal matrix composites is extremely demanding due to its high strength range within a very low weight, and other important properties. There are many types of MMC like particle reinforced MMC, fiber reinforced MMC and polymer reinforced MMC etc. Aluminium metal matrix composites (AMCs) are widely used nowadays in aeronautical, electronics, and automobile industries because of their light weight, stiffness even though its strength is comparatively low.[3] Moreover, aluminum alloys cannot be used in the production of compact heat exchangers even though it has a good thermal conductivity. Aluminium alloys also having relatively low corrosion and wear resistance property. These such properties can be enhanced by adding abrasive particles to the base matrix by maintaining the lightweight. It has been found that reinforcement particles can be mixed with metrics by various methods but the stirring process is the most common, as well as inexpensive process where various parameters can easily be controlled.[4] Lot of research has been done to improve the physical and mechanical properties of aluminum alloy based composites by inforceing different types of abrasive particles of various sizes.[5] Srivastava *et al.* has developed A359/Al_2O_3/B_4C composite by wire electric discharge turning and abrasive water jet turning processes and its effect on the micro-hardness and micro-structure were evaluated.[6] Ye *et al.* found that smaller particle size (10 µm) of SiC in aluminium metal matrix composite shows better yield strength than larger particle size (50 µm).[7] They also showed

*Author for Correspondence
E-mail: debashis5645@gmail.com

that increase in strain rate, results in the enhancement of yield strength. Nathan *et al.* investigated the mechanical properties of ZrO_2 and SiC particle reinforced aluminium alloy composite and found that the impact energy, hardness, compressive strength and tensile strength, all these mechanical properties of the newly developed composites has increased with 6% of SiC and 3% of ZrO_2 reinforcements in the base matrix.[8] From the literature review, it has been found that so many research work has been successfully carried out on aluminium matrix composite (AMC) development by using different casting processes with different abrasive particles like SiC, TiC, B_4C, ZrO_2, TiO_2 etc.[9,10] However, no research work has been found on the mixture of titania (TiO_2) and zirconia (ZrO_2) reinforced aluminium and copper alloy based composites by combining three processes like temporary wax pattern, sand mold casting and stir casting. Moreover, different particle sizes of abrasive particles have also not been used together in any research paper for preparation of aluminium-copper metal matrix composites. This leads the idea to prepare a new aluminium matrix composite and study the different mechanical properties of it. In this study, aluminium 6063 has been chosen due to its wider applicability where copper has been blended with it to improve the density, strength, hardness and other thermal, mechanical or physical properties of the matrix. Zirconia (ZrO_2) has good dispersion stability in the lubricant, high fracture toughness, high strength, high hardness, excellent wear resistance and excellent chemical resistance where titania (TiO_2) has good chemical stability, non-toxicity and also low cost that's why it is being used as a pigment, ointments, sunscreens, toothpaste, paints, sensors etc.[11,12] ZrO_2 and TiO_2 are generally artificial synthetic abrasive which are refractory materials as well. If ZrO_2 is reinforced in the base matrix, MMC occupies the enhanced creep resistance property as well as the enhanced fracture strength. And similarly, if TiO_2 is used as a reinforced particle, MMC also occupies the enhanced corrosion resistance property and other mechanical properties. Moreover, ZrO_2 and TiO_2 are used to reinforce into the base matrix to improve the wear property of the prepared composite. This reinforcement supports the applied load by resisting surface deformations in the dry sliding and abrasive wear conditions. Qiao *et al.* have developed AZ91 MMC reinforced with SiC_p to check the microstructure and mechanical properties of it and found that the mechanical properties of the composite are depend on the microstructural properties.[13] The microstructure has been modified by using heat treatment of the composite which improve the mechanical properties.[14] The kinetics of $Mg_{17}Al_{12}$ has been improved by doing heat treatment of these composite.[15] 3D appearance of the array of component molecules in composite can be found by SEM micrograph and the elemental percentage of the composite can be found by Energy Dispersive Spectroscopy (EDS).[16] Jain *et al.* examined the microstructural properties of the prepared composite by using SEM, which shows homogeneous distribution of reinforcement particles in the base matrix. To find the percentage of different elements in the composite EDS has been performed. XRD test has been performed to know about the intermediate phases.[17] Abbas and Huang have used SEM and universal testing machines (UTM) to check the microstructure, fractography and mechanical properties of ECA Ped composites.[18]

Wu *et al.* have described the metal fracture phenomenon and deformation of A359/SiC MMC by using a microstructure based model. They found that the microstructure-based model can provide the knowledge of major material deformation and failure mechanisms.[19] Fayomi *et al.* have developed ZrB_2-Si_3N_4 reinforced AMMC by using stirrer mechanism to check the microstructural, mechanical and electrical properties of the composite. They also investigated the distribution of the particles in the matrix by using optical microscope, SEM and EDS and got uniformity with no visible porosity.[20] Therefore, in this present work, an attempt has been taken to study the mechanical properties like surface hardness, tensile strength, compressive strength and micro-structural characterization of Al-Cu matrix composites prepared with hybrid solute. These composites have been prepared by combining three processes like temporary wax pattern, sand mold casting and stir casting, a mixer of ZrO_2 and TiO_2 abrasive particles with different particle sizes.

Experimental Procedure

For the casting process, first of all a wax pattern is produced which is of 5×5×5 cm^3 size and the wax is to pour in to some boxes of same size by melting of that wax. After getting all the wax patterns, a layer of clay soil has been applied on the surface of those wax patterns. Once the clay mold is prepared, the wax pattern is melted out from the mold. As the strength of the clay mold is very low, to support it, the mold is placed in a sand mold. The mold material has been prepared with 80% of silica and brick powder mixer, 10% of different types of binder, 7.5% of water and 2.5% of coal dust respectively and all of these have been mixed manually. In this present work, starch has been used as binder and coal dust as an additive to prepare the mold sand. The mold has two parts cope and drag. A wooden pattern is put in the drag part of the mold and the mold sand is then used to fill the mold boxes. Hammering is done to make the mold more compact. The Cope and drag parts are filled and prepared separately. After that the pattern is puled out from the mold very carefully so that a clear impression can be established on that part. Now the cope part is positioned on the drag, thus the mold has been prepared. After the preparation of the mold the molten mixer of aluminium alloy, copper and the hybrid abresive has been poured to the cavity through the sprue of the cope. As dicussed above the mold has been prepared by mixing sand and brick powder as a result the permeability of the mold has been increased which permits rapid flow of heat through the mold and accordingly the cooling of the molten metal gets faster. Due to this, the mechanical properties of the casted products improved. Moreover, the strength of brick concentrated mold is higher than the sand mold. The high temperature chemical reactivity of the brick powder mold is also lesser than the green sand mold. The Brick Powder Size used in this study is 30 AFS (595 micron) and Sand Particle Size used in this study is 80AFS (177 micron). The wax pattern, clay soil mold and sand mold have been used in this study for better surface finish of the casted product and these are easily available in the local market at a minimum cost. Moreover, as the inner surface of the mold is of clay soil, it does not react with the developed composite and also protect the Al-Cu based composite from chemical reaction with different gases present in the environment.

After that, the crucible is placed into the induction furnace and copper pieces are put in it. Slowly the temperature of the induction furnace rose up to 1100ºC and within 15 minutes the copper was melted to its liquid form. Then, aluminium is added to the molten copper and mixed with the help of stirrer. After preparation of the molten base alloy, it was kept for five minutes. Meanwhile, the hybrid abrasive particles reinforced into the base alloy with the help of a stirrer mechanism. Then, the preheated hybrid abrasive has been poured in to the crucible of molten aluminium copper mixer and stir it for various level of stirrer times as per the design of experiment (DOE). Taguchi L18 orthogonal array has been used as a DOE in this present study. The different levels of stirrer time like 12 minutes, 7 minutes and 5 minutes have been chosen based on the trial run. The proper distribution of the reinforcement particles into the base metal is fully depends on stirrer time. If stirrer time increases, the probability of proper distribution of the reinforcement particles into the base metal also increases. Thus, stirrer time is very much needed during this casting process. Other stir casting process parameters like; shape and size of the stirrer, depth of stirrer and stirring speed were kept constant like the shape of the stirrer is U which is deepen 4 inch from top, the width and height of the stirrer is 3 cm and 5 cm respectively and the speed of the stirrer is 450 rpm. After the proper mixing of the aluminium alloy, copper, zirconia and titania, the molten mixer has been proceeded to the cavity and leaves it for few minutes for cooling of the product. Cooling is required for any type of casting process for solidification purpose to get the final product. Generally cooling process has been done at normal room temperature for solidification. Different cooling time has been used for different types of casting processes as per the design of the products and other requirements. During casting process, cooling time plays a very vital role because the grain size of the casted product fully depends on this cooling time. If cooling time increases, grain size will be coarse and if decreases, grain size will be fine. Thus, based on this theory and literature survey, the cooling times have been chosen in this study and cooling has been done at room temperature only. The input parameters and their different levels for experimentation are given in Table 1. A mixed level L-18 orthogonal array has been chosen for this present work which is given in Table 2.[21] All the value of the input parameters has been chosen based on the trial run. The experimental results of mechanical properties are also given in Table 2. For the present study three different sizes of abrasive particles have been used to make the composite single particle size (SPS), double particle size (DPS), triple particle size (TPS). In case of SPS 10 μm of both the abrasive particles have used to produce the MMC. In case of DPS, mixer of 10 μm and 30 μm of both of the abrasive particles have used as a result quantity of abrasive particles is greater in case of DPS than the SPS per unit weight/volume.

Table 1 — Input parameters and their levels

Sl. No.	Parameters	Level 1	Level 2	Level 3
A	Binder (%)	5%	10%	—
B	Abrasive Composition (ZrO_2:TiO_2)	50:50	30:70	70:30
C	Abrasive (%)	5%	7.5%	10%
D	Weight Percentage of Copper (%)	20%	33%	54%
E	Abrasive Size	SPS	DPS	TPS
F	Stirrer time (min)	5	7	12
G	Brick powder (%)	50%	25%	0%
H	Cooling time (hour)	0.33	0.50	0.667

Table 2 — Modified L-18 orthogonal array

Ex. No.	Binder (%)	Abrasive Composition (ZrO_2:TiO_2)	Abrasive (%)	Copper (%)	Abrasive Size (SPS, DPS, TPS)	Stirrer time (min)	Brick powder (%)	Cooling time (hour)	Hardness (HV)	Tensile Strength (MPa)	Compressive Strength (MPa)
1	1	1	1	1	1	1	1	1	81.75	263	654
2	1	1	2	2	2	2	2	2	85.14	233	649
3	1	1	3	3	3	3	3	3	98.2	256	668
4	1	2	1	1	2	2	3	3	79.27	264	656
5	1	2	2	2	3	3	1	1	93.27	226	652
6	1	2	3	3	1	1	3	3	96.61	261	665
7	1	3	1	2	1	3	2	3	80.01	243	648
8	1	3	2	3	2	1	3	1	87.35	221	662
9	1	3	3	1	3	2	1	2	83.67	267	651
10	2	1	1	3	3	2	2	1	88.75	212	658
11	2	1	2	1	1	3	3	2	85.95	266	670
12	2	1	3	2	2	1	1	3	81.89	250	650
13	2	2	1	2	3	1	3	2	87.46	234	673
14	2	2	2	3	1	2	1	3	101.99	229	642
15	2	2	3	1	2	3	2	1	85.27	271	639
16	2	3	1	3	2	3	1	2	88.85	207	669
17	2	3	2	1	3	1	2	3	80.31	274	618
18	2	3	3	2	1	2	3	1	81.69	241	637

TPS particle size has the more quantity of particles per unit weight or volume as it consists of 10 µm, 30 µm and 50 µm sizes of abrasive particles.

Performance Measures for Surface Hardness, Tensile Strength and Compressive Strength

Hardness is defined as the resistance to the plastic deformation of a material by indentation. However, the term may also be referred to stiffness or temper or scratching, abrasion, cutting or machining.[22] On the other hand, micro-hardness testing is a technique for determining the hardness of a material on a microscopic scale. There are several methods to measure the micro-hardness. In this present work, Vicker hardness test method has been applied to measure the micro hardness of the specimens. Five readings have been taken on one specimen at different positions and the average value has shown in Table 2 as per the Taguchi L-18 orthogonal array.

It has been clearly observed from the Table 2 that experiment no. 14 shows the better result for surface hardness within this range of study. The parameter setting for the experiment no. 14 was 10% of binder, 30% of ZrO_2+ 70% of TiO_2, 7.5% of abrasive mixed with base alloy, 54% of Cu mixed with AA-6063, single particle size, 7 minutes of stirring, 50% of brick powder to prepare the mold and 40 minutes cooling time respectively.

The tensile test (Fig. 1) has been done by using Universal Testing Machine (UTM) and the samples have been prepared by maintaining ASTM E8 standard. From Table 2, it has been observed that the tensile strength is varying from 207 MPa to 274 MPa for the Al-Cu alloy composites. The measured values of tensile strength for all the 18 samples have been listed in Table 2.

The compression test has been done by using Universal Testing Machine (UTM) and the samples have been prepared by maintaining ASTM E9 standard. The test has been carried out at 2000 N/Sec load rate to check the compressive strength property of the composites. From Table 2, it has been clearly

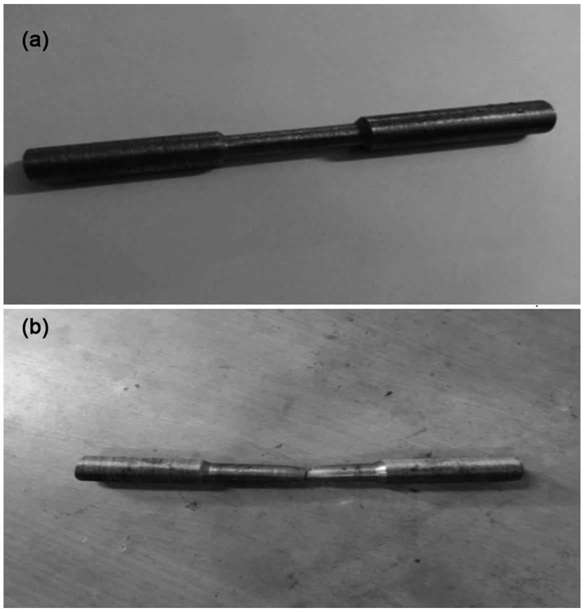


Fig. 1 — Tensile Strength specimen: (a) before test, (b) after test

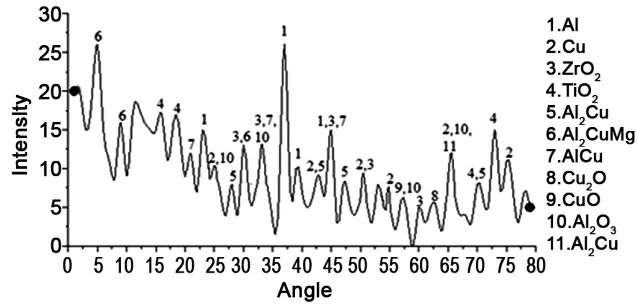
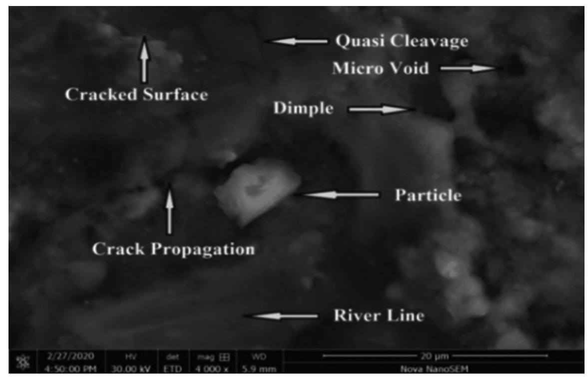
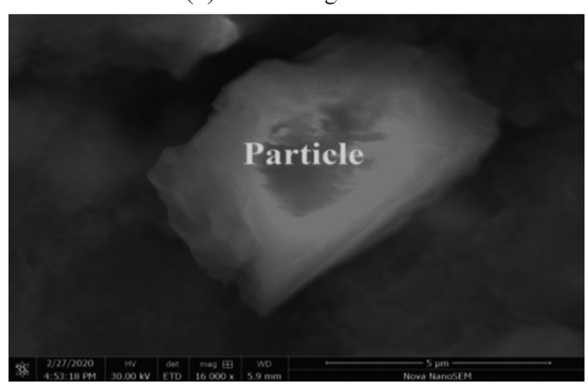


Fig. 2 — XRD plot of developed sample



(a) SEM Image at 4000x



(b) SEM Image at 16000x

Fig. 3 — SEM images of a developed sample at different magnification: (a) 4000x, (b) 16000x

observed that the compression value is varying from 618 MPa to 673 MPa for the Al-Cu alloy composites. The measured values of compressive strength for all the 18 samples have been listed in Table 2.

Results and Discussion

XRD Analysis

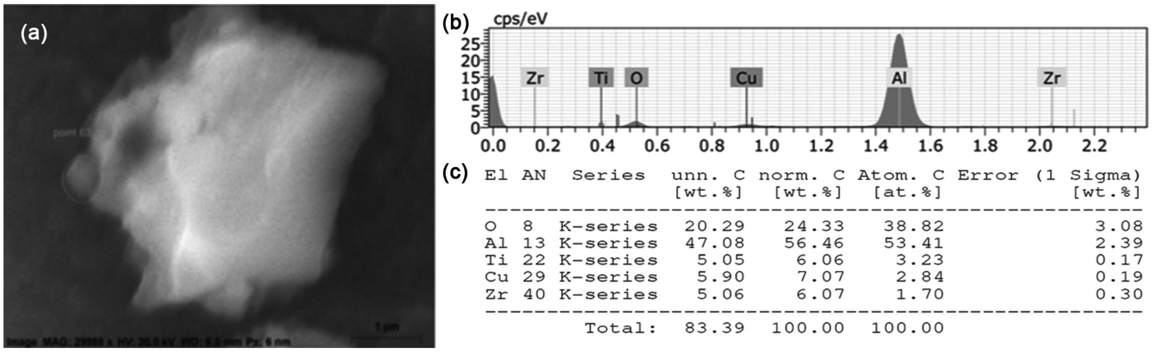
On the top surface of one developed sample, the XRD analysis has been done to confirm the presence of aluminium, copper, ZrO_2 and TiO_2. From the XRD analysis, the peaks of aluminium, copper, titania and zirconia are found along with the peaks of inter metallic phases Al_2Cu, Al_2CuMg, AlCu, Cu_2O, CuO, Al_2O_3 and Al_2Cu_9.[(23)] The XRD plot of developed sample is shown in Fig. 2.

Scanning Electron Microscopy Analysis

The SEM image of the tensile test specimen is shown in Fig. 3(a). It is found that due to shearing ductile failure is occurred in the composites; as a result of this Dimples are formed. Existence of voids in the form of pores is also found along the surface of the aluminium 6063-Cu alloy. Generation of crack in the MMC can be minimized by reinforcing abrasive particles in it. These cracks also characterized by the existence of smaller dimples.

Quasi-cleavage appearances can be found in the figures. The quasi-cleavage fractures are seen in this research are very similar to those reported by Nagao *et al.*[24] According to Huang *et al.* ductile tearing, micro-void structures and dimples are ductile fracture features which can be observed in the above figures. The fracture of the dendrites in the material belongs to ductile fracture.[25] Lynch stated that quasi-cleavage can be found along the martensite lath boundaries or across martensite laths.[26] According to him quasi-cleavage surface is the resultant of crack growth across boundaries of martensite laths or along the interface which can be considered as smooth surface features, and did not show prominent grain boundaries.

A “river like pattern” of radiating lines is come in existence due to cleavage mechanism. This is a characteristic of brittle fracture mechanism.



El	AN	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error (1 Sigma) [wt.%]
O	8	K-series	20.29	24.33	38.82	3.08
Al	13	K-series	47.08	56.46	53.41	2.39
Ti	22	K-series	5.05	6.06	3.23	0.17
Cu	29	K-series	5.90	7.07	2.84	0.19
Zr	40	K-series	5.06	6.07	1.70	0.30
		Total:	83.39	100.00	100.00	

Fig. 4 — Spot EDX of one of the developed sample: (a) Spectrum of EDS, (b) presence of different constituent elements, (c) EDS spectrum showing different constituent elements

Energy Dispersive Spectroscopy Analysis

Energy dispersive spectroscopy (EDS) of one of the newly developed composite sample also confirms the presence of constituents of TiO_2 and ZrO_2 inside the aluminium 6063 and copper alloy matrix. Spectrum of EDS has been shown in Fig. 4(b). In Fig. 4(b) the presence of Aluminium (Al), Copper (Cu), Oxygen (O), Zirconium (Zr), Titanium (Ti) etc. respectively inside the matrix has been shown. The spoted area shown in the left side has been selected for EDS spectrum which is Fig. 4(a). Obtained EDS spectrum shows different elements have been shown in Fig. 4(c).

Taguchi Analysis

The results obtained in Table 2, have been taken for signal-to-noise ratio (S/N) analysis. The S/N ratio plot for surface hardness, tensile strength and compressive strength of the composite has shown in Fig. 5 (a), (b) and (c) respectively. In case of Taguchi analysis, the high levels S/N ratios of related factors are considered to be optimal irrespective of the selected quality characteristics for cach responses.

Taguchi Analysis of Surface Hardness

Density of reinforcement particles, proper distribution of reinforcement particles, rate of solidification and less porosity are few major influencing parameters for the mechanical properties of composites.[27] The S/N ratio plot for surface hardness is depicted in Fig. 5(a). The reason behind getting parametric level for the better value of hardness is as below:

1. From the figure, it has been observed that for the both levels of binder the hardness value is almost same. Increase the wt% of binder increases the collapsibility of the mould which leads to increase in hardness of the casted product.[28] Lack of collapsibility can introduce crack formation due to which tensile strength can decrease. Besides use of 5% of binder to make the mold, increases its compactness and if compactness increases slow cooling takes place which results better hardness value of the casted product.
2. The highest hardness value is given by 30% of ZrO_2+ 70% of TiO_2 as the micro-hardness of TiO_2 is greater than the ZrO_2. As a result this combination is showing the highest micro-hardness value. It has been observed from the Orowan strengthening mechanism, presence of reinforcement particles raise the load bearing capacity of the fabricated composite and this phenomenon prevents the movement of dislocations which restrict the plastic deformation of the material. This is why the figure is showing that increase in wt% of ZrO_2 decreases the hardness value of the composite.
3. The highest hardness is given by 7.5% of hybrid abrasive. The highest percentage used for this present work was 10% but at the time of stirring clustering of the abrasive has been found when percentage of abrasive has been increased and due to this hardness of the composite decreases. In the figure it is shown that from 5% to 7.5% of abrasive particle increases the hardness value but further addition of abrasive particles decreases the hardness this is due the crack propagation and formation of porosity.
4. Better hardness value is given by 54% copper with aluminium as hardness of copper is 37.63 HV and for aluminium is 17.03 HV. So it is obvious that higher percentage of copper will give higher hardness value.
5. In case of SPS 10 μm of both the abrasive particles have used to produce the MMC. In case

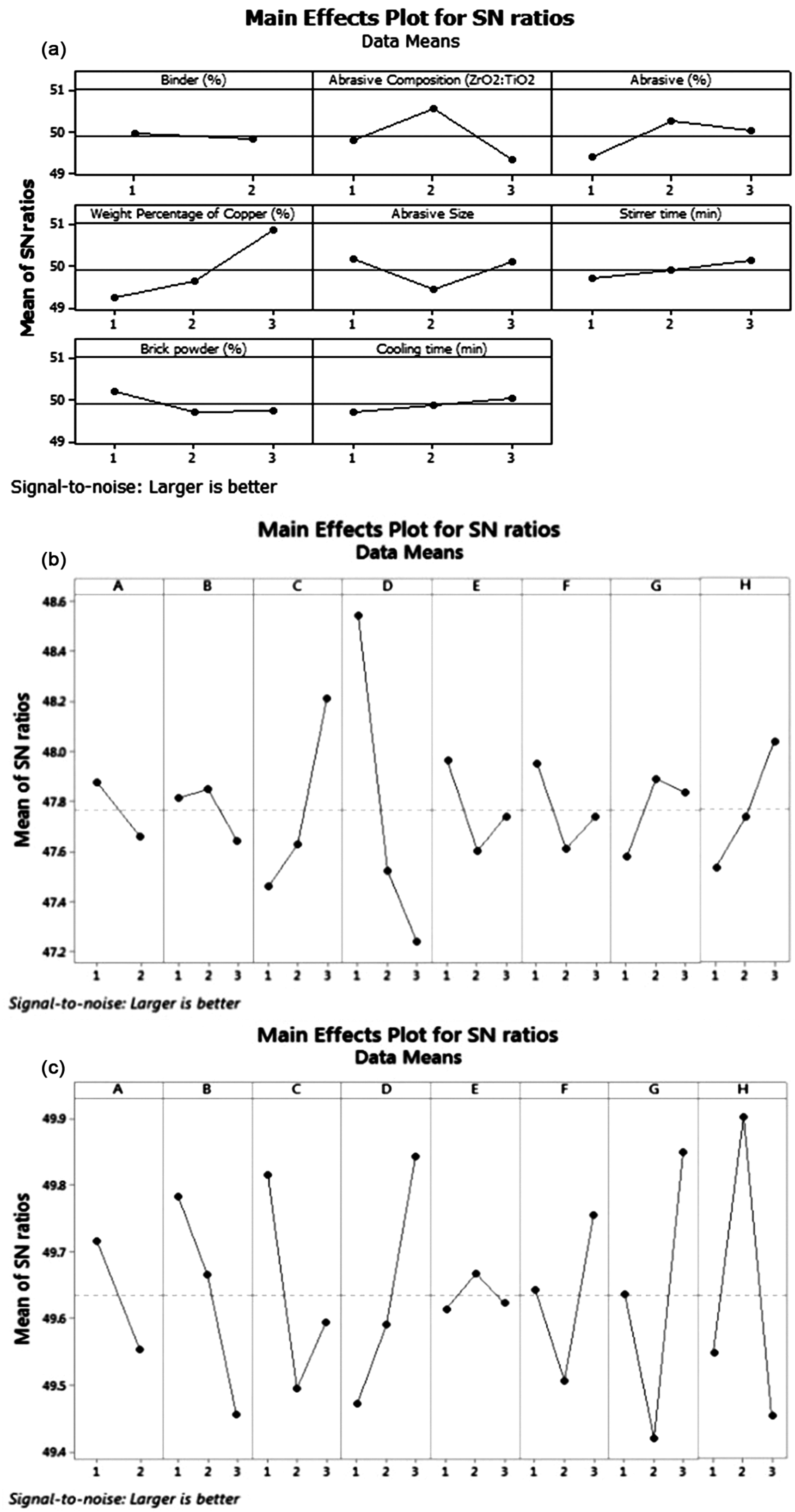


Fig. 5 — Signal to noise ratio graph for (a) Hardness, (b) Tensile Strength, (c) Compressive Strength

of DPS, mixer of 10 µm and 30 µm of both of the abrasive particles have used as a result quantity of abrasive particles is lesser in case of DPS than the SPS per unit weight/volume. TPS particle size has the least quantity of abrasive particles per unit weight/volume as it consists of 10 µm, 30 µm and 50 µm sizes of abrasive particles. As SPS abrasive particle size consist of maximum volume contain in it so that SPS particle size is giving the best micro-hardness value.

6. In the figure it is shown that 12 minutes of stirring is giving better the hardness result than the other levels. Larger stirrer time provides the proper distribution of the reinforced particles without clustering of reinforcement particles in the composite. Due to this reason, the surface hardness value of the developed composite is showing better result at higher value of stirrer time.
7. Three levels i.e. 50%, 25% and 0% of brick powders have been used for making the mold in this study. From the figure it is observed that maximum amount of brick powder affects the hardness value of the composite more than the other levels of brick powders. 50% of brick powder for making the mold material is the highest percentage and this high amount of brick powder increases the permeability of the mold due to which the surface hardness of the composite also increases.
8. From the figure it is seen that increase in cooling time increases the surface hardness of the composite. Cooling time of 40 minutes is the maximum cooling time and this cooling time is providing the better hardness.

Taguchi Analysis of Tensile Strength

The results of Table 2 were used for signal-to-noise (S/N) analysis. The S/N plot for tensile strength is shown in Fig 5(b).

As per SN ratio graph 5% binder, 30% of ZrO_2+ 70% of TiO_2, 10% of abrasive mixed with base alloy, 20% of Cu mixed with AA-6063, single particle size, 5 minutes of stirrer time, 25% brick powder for making the mold and 40 minutes cooling time can provide the better tensile strength property. The following reasons can be summarized:

1. It has been already discussed that 5% of binder provides better collapsibility and compactness of the mould. That's why, 5% of binder to make the mold, gives better tensile strength.
2. The highest tensile strength value is given by 30% of ZrO_2 + 70% of TiO_2 gives as the tensile strength of TiO_2 is greater than the ZrO_2. As a result this combination is showing the highest tensile strength value.
3. Tensile strength is dependent on amount of abrasive particle added into the base matrix if percentage of abrasive increases tensile strength also increases.[29,30] From the figure it can be seen that 10% of abrasive in the composite is showing the maximum tensile strength.
4. In case of tensile strength, copper and aluminium exhibits almost similar values. From the figure it has been observed that increase in wt% of copper decreases the tensile strength.
5. Particle sizes of the reinforcements are also playing an exigent role in the manufacturing of the composite. From the figure, it is found that SPS is giving the higher value of the tensile strength than DPS and TPS as SPS is having the maximum volume of abrasive particles in the composite and due to the proper distribution of the particles in to the composite without any clustering in the manufacturing of the composite.[31] It also has been found that there is a sudden drop in case of DPS this may be because of the presence of porosity at that level.
6. It can be seen from the figure that 5 minutes of stirring of the reinforcement particle with the base matrix is showing better tensile strength value than the other two levels. It has been found that density of the composite decreases with the increase in stirrer time, but on the other side, higher stirrer time helps for well scattering of the hybrid abrasive particles in the base alloy.[32] This is why tensile strength value is showing better at minimum stirrer time compare to the other levels. Besides increase in stirrer time increases the probability of oxidation of the material at high temperature.
7. The highest value of tensile strength is provided by 25% of brick powder. The particle size of the brick powder is 80AFS and sand grain size is 30AFS. So increase in wt% of brick powder decreases the cohesiveness of the mold due to which porosity increases. Refractiveness of the mould increases with the increase in grain size. That's why 25% of brick powder provides the better tensile strength. But further decrease in grain of mould material decreases the permeability which causes lower tensile strength.

8. From the figure it has been found show that tensile strength increases with the increase in cooling time. 40 minutes of cooling time is the maximum cooling time and this cooling time is providing the better tensile strength.

Taguchi Analysis of Compressive Strength

The results of Table 2 were used for signal to noise(S/N) analysis. In Fig. 5(c) the S/N plot for compressive strength is shown.

As per SN graph 5% of binder, 50% of ZrO_2 + 50% of TiO_2, 5% of abrasive mixed with base alloy, 54% of Cu mixed with AA-6063, double particle size, 12 minutes of stirrer time, 50% of brick powder for making the mold and 30 minutes cooling time can give the best result for the compressive strength. The following reasons can be summarized:

1. It has been already discussed that 5% of binder provides better collapsibility and compactness of the mould. That's why, 5% of binder to make the mold, gives better compressive strength.
2. As the compressive strength of TiO_2 and ZrO_2 are same, 50% of ZrO_2 + 50% of TiO_2 gives the highest compressive strength value.
3. From the literature review it has been found that if percentage of abrasive decreases compressive strength increases. From the figure, it is found that the minimum amount of abrasive in the composite is showing the maximum compressive strength which may be due to the clustering of the reinforcements in the composite.
4. From the figure it has been observed that with the increase in wt% of copper the compressive strength of the composite is also increasing. 54% copper with aluminium is giving better compressive strength value as from the three levels this is the highest wt% of copper which has been added in the composite as compressive strength of copper is better than aluminium.
5. After the investigation, it has been observed that DPS particle size is affecting the compressive strength property more than SPS and TPS. For same weight percentage, SPS has greater quantity of abrasive but in case of compressive strength DPS is giving better result as greater quantity may introduce agglomeration of the abrasive in the base matrix.
6. The figure shows that 12 minutes of stirring time is giving the better result of compressive strength than the other two levels of stirring time. This is happening due to the distribution of abrasive particles into the base matrix as explained in the above section.
7. Mixing of 50% of brick powder is showing better compressive strength value among the all three levels. Brick powder has greater grain size than the sand particles as a result permeability of mould increases and compressive strength decreases. However, 50% of brick powder shows better compressive strength than 25%, this is due to the increment of refractiveness of the mould which increases with the increase in grain size.
8. The figure also shows that 35 minutes of cooling time is providing the highest compressive strength value as compared to the other two levels of cooling time. This may be due to the formation of porosity which can take place at cooling time beyond the limit of 35 minutes.

Effect of Abrasive on Mechanical Properties

Mixers of TiO_2 and ZrO_2 abrasive particles of different proportions and different sizes have been employed to get the new composites with better mechanical properties. The effect of adding abrasive particles into the base matrix has been discussed below:

1. It has been found that 7.5% of hybrid abrasive gives the highest hardness. So addition of abrasive particle into the base matrix improves the hardness property of the composite material.
2. Addition of 10% of abrasive particle is the maximum amount of particle reinforced into the base matrix which improves the tensile strength of the composite.
3. Due to the addition of the abrasive particle upto a certain limit improves the compressive strength of the base matrix.

Thus reinforcement of abrasive particle has a significant effect on the mechanical properties of the newly developed composite.

Confirmation Test

From the S/N ratio graph the optimum parameters settings which are mentioned in the above sections, one sample of the composite Al-Cu-TiO_2-ZrO_2 for one each mechanical property has been prepared and accordingly the experiments for the mechanical properties has been carried out once again. The results of these experiments are shown in Table 3.

Table 3 — Observations of confirmation test

Hardness (HV)	Tensile Strength (MPa)	Compressive Strength (MPa)
107.67	281.33	674.67

The error percentage can be find by using the following formula:

$$\delta = \left| \frac{\nu_A - \nu_H}{\nu_H} \right| \times 100\%$$

δ= Percent error

ν_A= actual value observed

ν_H= highest value obtained from the table no. 2

For these different mechanical properties (Surface hardness, tensile and compressive strength), the error percentage are 5.57%, 2.68% and 0.70% respectively.

Conclusions

Aluminium-Copper alloy composites have been successfully developed by combining stir casting and sand molding processes where sand mold was prepared by using starch as binder. Aluminium-Copper alloy composites reinforced with hybrid abrasives ZrO_2 and TiO_2. Surface hardness, compressive and tensile strength were the output responses in this present work. The specimens were prepared and also tested by maintaining ASTM standards. The conclusions are as bellow:

a) A broad range of surface hardness (79.27–101.99) HV, tensile strength (212–274) MPa and compressive strength (618–673) MPa have been observed from the experimental data.

b) The percentage of copper has a strong influence on the mechanical properties of the composites. It has been observed that casting prepared with 54% copper exhibit better hardness value and compressive strength and casting prepared with 20% of copper exhibit better tensile strength.

c) Percentage of hybrid abrasive particle reinforced into the base alloy is an important factor which improves the mechanical properties of the composites. It has been noticed that 7.5% of reinforcement into the base alloy shows the highest surface hardness value and tensile strength whereas 5% of reinforcement gives better compressive strength value. However, a significant improvement has been observed on the mechanical properties of all composites due to the reinforcement of hybrid abrasive particles.

d) In case of particle size of the hybride abrasive materials, SPS particle size shows the better surface hardness and tensile strength value as SPS has greater quantity of abrasive for same weight percentage. However, in case of compressive strength, DPS shows the better result as greater quantity may introduce agglomeration of the abrasive in the base matrix.

e) Stirrer time and cooling time also plays an important role on the mechanical properties of the composites. It has been observed that maximum stirrer & cooling time, both shows the better result for surface hardness property and for the better value of tensile & compressive strength properties, both the stirrer and cooling time must be lower down.

f) Binder and brick powder also contributes a significant role in preparing of aluminium-copper alloy composites. 5% binder and 50% brick powder, both was found to increase the mechanical properties. Due to increase in compactness and permeability, hardness and compressive strength increases whereas 25% of brick powder gives the better tensile strength as greater permeability causes lower tensile strength.

g) Microscopic image, SEM micro-graphs and EDS analysis along with the X-ray elemental mapping and XRD proved the existence of abrasive particles comprising of ZrO_2 and TiO_2 on the composite. An homogeneous distribution of reinforcements with fine grain structure and good bonding between the base alloy (AA6063-Cu) and hybrid reinforcement particles has been obtained from the micro-structural analysis.

h) From the present study, it has also been observed that the surface hardness, compressive and tensile strength value of the Al-Cu alloy composite is 4 to 5 times better than the base material.

This newly developed Al-Cu-TiO_2-ZrO_2 composite can be used for electronic appliance of aeroplane. Besides this composite is suitable for making connectors and bearings. Due to better mechanical properties these composites are widely used for valves, heat exchangers and underwater parts.

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