SYNTHESIS, MICROSTRUCTURAL AND MECHANICAL PROPERTIES OF FLY ASH AND MARBLE DUST PARTICLE REINFORCED AA7068 MATRIX HYBRID COMPOSITES

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Abstract

Hybrid composites development is essential in the current era to achieve the higher mechanical properties at light weight required for various applications. The selection and optimal inclusion of reinforcing elements are crucial to obtain desirable enhancement in the mechanical properties without any effects. The current research is aimed to develop aluminum hybrid composites and study the influence of reinforcing elements on their mechanical properties through experimental investigations. The stir casting technique is used to produce hybrid composites and fly ash, marble dust selected as reinforced at different weight fractions such as 1, 3, 5 and 7% to the AA7068 metal matrix. The mechanical properties such as hardness, tensile, and impact strength are investigated experimentally and found specimens with 7 wt.% exhibited more significant improvement than the others. The hardness by 44.11%, the tensile strength by 45.87%, and the impact strength by 89.67% when compared to AA7068 without reinforcement. The microstructural analysis is performed by applying EDS, SEM, XRD techniques and obtained results are discussed well with suitable illustrations.

Keywords - fly ash, hybrid metal matrix composite, marble dust, mechanical properties, stir casting process

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1. Introduction

Aluminium alloys are used in a wide range of industries, such as aircraft, automobile, and manufacturing. Aluminium reinforced with industrial waste fabricated by stir casting have potential applications in aerospace and defence industries. These hybrid aluminium metal matrix composites reinforced with industrial wastes are much lighter than their competitors [1,2]. Because of their reduced weight and excellent thermal and mechanical properties, aluminium metal matrix composites reinforced with ceramics play an essential role in engineering research. Industrial waste, such as red mud, fly ash, and marble dust, is commonly utilized as reinforcement in the development of composites, which have demonstrated considerable improvements in the mechanical properties of the composites [3]. the stir casting technique is mostly preferred for the mass production of metal matrix composites at low cost compared to other powder metallurgy techniques. [4-6]. Fabricating composites from aluminium alloys often involves using ceramic reinforcements as SiC, B_4C, TiC, and Al_2O_3 [7]. The particle size and shape of the reinforcement are the most important factors in determining the mechanical properties of MMCs [8]. Soundararajan et al., [9] developed a hybrid composites by reinforcing the 10% fly ash into AA356 and attained the increase in hardness and ultimate tensile strength to 90.35 HV and 329 MPa. It is observed from the microstructure analysis that the even dispersion of reinforcing elements through the matrix prompted to increase the wear resistance by reducing the wear rate 1.42×10^{-3} mg/m compared to base alloy. Sudarshan et al., [10] revealed that the damping capacity is improved by the addition of fly ash particles, as compared to the unreinforced alloy i.e., A356 Al at ambient temperature. The impact and tensile strength were improved in hybrid metal matrix composites with 2 wt% reinforcement of aluminum oxide, boron carbide, and silicon carbide. Sri Ram Murthy et al., [11] also confirmed these improvements through the experimental investigations and stated that reinforcing elements, method, proper dispersion can influence the enhancement of desired mechanical properties. Ashwani Kumar et al., [12] found that the hybrid composites containing

6 wt% SiC and 2 wt% marble dust exhibited superior mechanical properties and wear performance compared to other composites, Ramadoss et al., [13] Al7075 reinforced with B_4C and BN using the stir-squeeze cast method, improved the mechanical and corrosion behaviour of aluminium hybrid metal matrix composites (AHMMCs). Manoj et al. [14], found that incorporating TiB_2 particles into Al 7075 increases its tensile strength, hardness, and corrosion resistance as a result of tightly bound interfaces of the reinforcement particles. Both SEM and EDAX analysis confirm the presence of TiB_2 in the matrix.

Swati Gangwar et al., [15] the primary use of composites made from the ZA-22 alloy is for ball bearings, and marble dust is used as a strengthening filler in these materials. The flexural strength is affected by the addition of marble dust as reinforcement at a weight percentage of 7.5, while the compressive strength is enhanced at 10 wt%. The SEM analysis revealed that there is a formation of inter dendritic fractures which exhibit the mixed (ductile and brittle) fractures. Sujith et al., [16] preferred the ultrasonic stir casting method, and insitu technology for fabrication of Al_3Ti aluminium matrix composites. The mechanical properties including hardness, yield strength, and tensile strength are enhanced with the addition of Ti particles.

Santosh et al., [17] used marble dust as reinforcing elements in copper alloys and observed the significant improvement in the mechanical and tribological properties, such as wear. It was shown that the improvement in the mechanical properties of copper alloys can be improved by adding marble dust up to 4.5 wt% and further increase can create decrement due to cluster porosity.

Abhinay et al., [18] fabricated a composite using marble dust and basalt fibre as the reinforcement in epoxy resin and found that the mechanical properties of the material enhanced up to 7.5 wt% of marble dust and basalt fibre. it was observed from the wear analysis that the inclusion of marble dust and basalt fibre of all compositions, causes the specific wear rate to decline at the velocities greater than 4.19 m/s. The wear analysis reveals that the relationship between the speed and the wear rate improves for both regular and atypical loads.

Ayalew Abede Emiru et al., [19], the ultimate tensile strength of an Al6061 metal matrix composite reinforced with MoS_2, SiC, and B_4C using stir casting process increased by 12%, which they attributed to the addition of 4 wt% B_4C and 12 wt% MoS_2. Similarly, the hardness value is rose to 114.03 HV.

Mohammad Alipour et al., [20], the addition of graphene nanoplatelets to aluminium alloy samples subjected to T6 heat treatment results in an increase in the ultimate tensile strength by 8%, to 582 MPa. It was observed that formation of crack growth is due to the presence of higher graphene nanoplatelet content on the grain boundaries.

Rajan et al., [21] analysed three distinct stir casting processes which include liquid stir casting, compocasting, and squeeze casting. It stated that the squeeze casting method yields the best results in the mechanical properties when compared to the other processes. The microstructure analysis confirmed that the homogeneous distribution of fly ash particles reduced the void formation in the composites.

Vardharajan [22] reported that the mechanical characteristics of concrete, such as compressive, flexural, and tensile strength, improved with the reinforcement of fly ash and marble dust.

John Joshua et al., [23] fabricated AA7068 composites reinforced with different percentages of Nano TiO_2 (3, 6 and 9 wt%) using powder metallurgy technique and reported that maximum of 68 VHN is obtained by addition of 9% Nano TiO_2 particles.

Rohini Kumar et al., [24] investigated the addition of ceramic particles SiC and TiB_2 in Zn-Al-Cu alloy-based composites and reported that the addition had a greater impact on modern bearing applications because of its reliable mechanical performance the findings revealed noticeable increase in the mechanical performance in terms of hardness, tensile strength, young's modulus, and impact strength. From the literature review, it is evident that numerous researchers had focused on individual reinforcements of industrial wastes and reported the improvement in mechanical properties of metal matrix composites. The current research aims to study the influence of reinforcing elements on the mechanical and microstructural characteristics of the hybrid metal matrix composites developed from aluminum alloys.

2. Materials and Methods

The hybrid metal matrix composites (MMC)s is aimed to fabricate through stir casting technique.

AA 7068 is taken as the base alloy and the fly ash, marble dust is selected as the reinforcing elements for the fabrication of hybrid MMC.

2.1. Material selection

The base alloy AA7068 is procured from Vision Castings & Alloys Pvt Ltd, Hyderabad, Telangana. The chemical constituents of the alloy are listed in Table 1. Marble dust is collected during the crushing of marbles at Anjani Stone Crushers, Autonagar Visakhapatnam and fly ash is collected from Vijayawada Thermal power station (APGENCO) Vijayawada, Andhra Pradesh. Table 2 and 3 enlists the chemical composition of fly ash and marble dust taken in the study. Ball milling process is applied to obtain the finely grinded particles of the reinforcing elements and a sieve examination is performed to analyze the size of the particles according to ASTMC136 standards. Figure 1 (a), (b) represents the SEM images of reinforcing elements after grinding process. It is observed that average size is found as 47μm for both the elements and the structure of fly ash particles appears as small, spherical, or irregularly shaped particles with rough surface as shown in figure 1 (a). However, marble dust possesses rough and irregular shape with varying particle size as shown in figure 1 (b)

Table 1. Chemical composition of AA7068

Element	**Zn**	**Mg**	**Cu**	**Mn**	**Pb**	**Fe**	**Zr**	**Al**
Wt.%	8.09	2.65	2.25	0.03	0.02	0.02	0.14	86.8

Table 2. Chemical composition of marble dust

Element	CaO	Al_2O_3	SiO_2	Fe_2O_3	MgO
Wt.%	44.55	0.65	27.45	10.40	1.58

Table 3. Chemical composition of fly ash

Element	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**TiO_2**	**CaO**	**MgO**	**Na_2O**	**K_2O**	**IL**
Wt.%	59.5	29.39	8.45	2.65	1.30	1.45	1.0	1.98	2.5

Table 4. Composition of hybrid composites

S. no	**Sample no's**	**Composition of reinforcements**	**Marble dust wt.%**	**Fly ash wt.%**
1.	Sample-1	AA7068	0	0
2.	Sample-2	AA7068+1% Marble dust & Fly ash	0.5	0.5
3.	Sample-3	AA7068+3% Marble dust & Fly ash	1.5	1.5
4.	Sample-4	AA7068+5% Marble dust & Fly ash	2.5	2.5
5.	Sample-5	AA7068+7% Marble dust & Fly ash	3.5	3.5

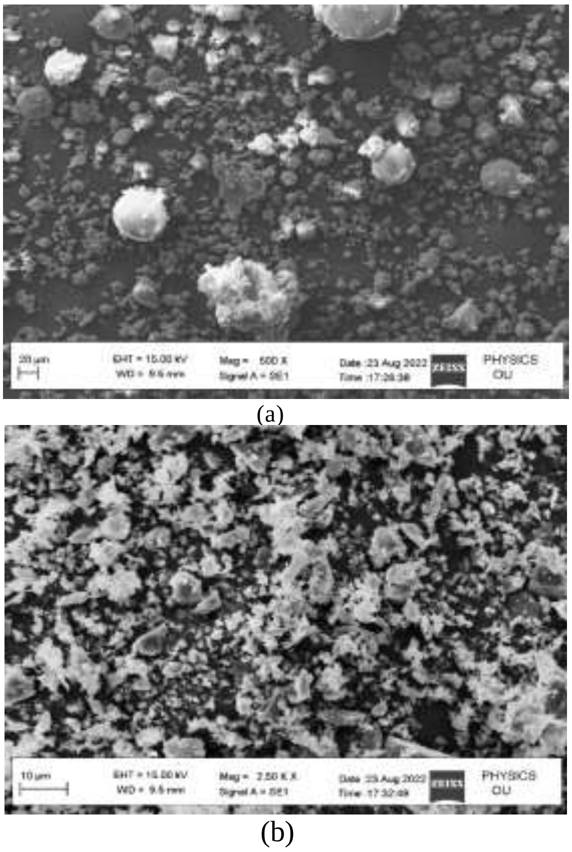


Fig 1. (a) SEM Image of Fly ash particles and (b) Marble dust

2.2. Fabrication process

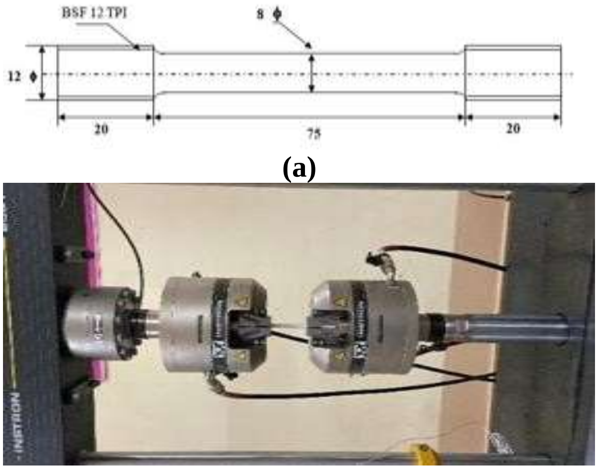
The specimens are fabricated through stir casting technique by using different proportions of the reinforcing elements in the base alloy. Table 4 enlists the different kinds of samples that are fabricated in the study. It can be observed that the equal weight proportions of fly ash and marble dust reinforced into the AA7068. The furnace is heated up to 700^0C and kept idle for the 15 minutes before the process initiation in order to the avoid the trap of undesirable moisture content in the specimens. After examining the smoke pattern, the temperature is raised to 800^0C. The reinforcing elements are preheated and added to the cut ingots of AA7068 at this temperature. The FOSECO Nitral C19 degassing tablets of 0.2 wt% are added in the completely processed crucible melt to eradicate the porosity in the hybrid MMCs formed by the gases entrapped during the melting process. FOSECO ALSPEK-H probe is immersed into melt pool to measure the hydrogen concentration and the process is continued to obtain a melt quality index of 3. Reading was taken at 100 and 150 mm in the melt. The melt is continuously stirred at 450 rpm for 10 min before pouring to obtain cast specimens. The cast specimens are machined as per ASTM standards to perform mechanical tests.

Fig 3. Preparation of samples
(a) AA7068 ingots (b) Fly ash (c) Marble dust (d-e) Melting of composites (f) Cast specimens (g) Machining operation (h) Test specimens

3. Experimental procedure

3.1 Tensile Testing

Instron fatigue testing machine servo 8801 coupled with a system and a capacity of 20kN, the tensile behaviour of stir-casted Marble dust/Fly ash/AA7068 metal matrix composites is investigated. As shown in Fig 3(h), samples are made and evaluated in accordance with ASTM E8 [25], and the results are provided as mean and standard deviation. The strain rate of 3 mm/min is considered throughout the test.



(a)

(b)

Fig 4. (a) Standard tensile test specimen geometry (b) Instron Fatigue Machine

3.2 Hardness Test

The hardness test was performed on a MicroVickers hardness tester in accordance with ASTM E384-04a standards [26], which performs a maximum load of 100 KgF and a minimum load of 10 KgF to determine the hardness of materials. For each composite, the mean of six readings was used to calculate hardness. A diamond cone indenter was used for hardness testing,

Fig 5. Micro -Vickers hardness

3.3 Impact strength

The impact strength was measured using a Charpy impact test (according to ASTM E23 standard) with specimen dimensions as shown in Fig. 6 and a V -notch in the middle with a depth o f 3 mm and a 45 angle of lean was considered.

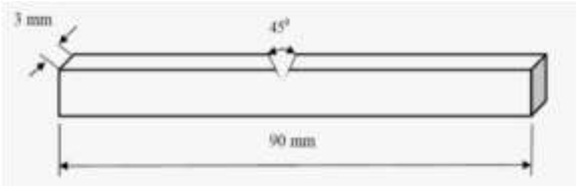


Fig 6. Impact test specimen as per ASTM standard

4. Results and Discussion

Scanning electron microscopy (SEM) is used to comprehend the particle uniform mixing as shown in Fig 7.

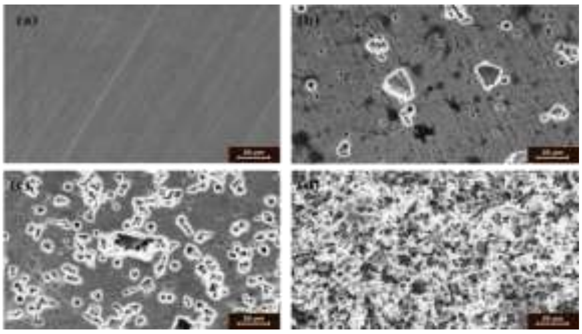


Fig 7. SEM micrographs of (a) AA7068 (b) AA7068+ 3% Marble dust and Fly ash (c) AA7068+5% Marble dust and Fly ash (d) AA7068+7% Marble dust and Fly ash

It was observed from fig. 7 that fly ash and marble dust are irregular in shape and consist of minute particles. Marble dust and fly ash appear to be dispersed evenly throughout the sample, as seen by the SEM study. The SEM micrographs show that there is good adhesion between the reinforcements and matrix. The micrographs do not show any evidence of aggregates of the marble dust and fly ash.

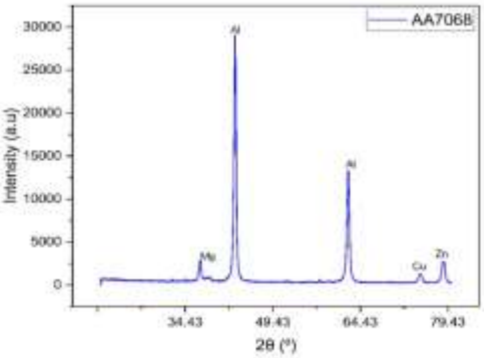


Fig 8(a). XRD pattern of Aluminium alloy 7068

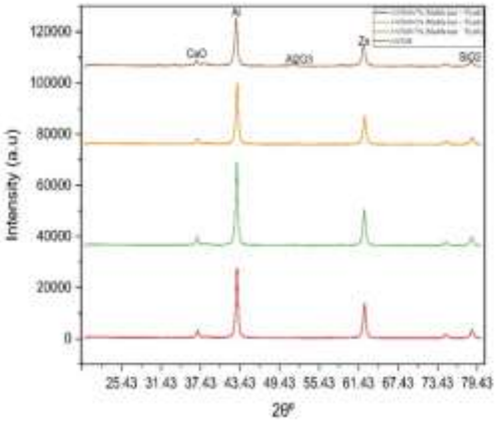


Fig 8(b). XRD pattern of Hybrid composites

Fig 8(a) depicts the XRD pattern of AA7068, with peaks at about 39.110, 45.390, 63.940, and 78.160 indicating the presence of alloy components in AA7068. The peaks at 36.950, 43.320, 62.580, and 79.320 in fig 8(b) indicate the presence of marble dust and fly ash in metal matrix composites.

4.1 Tensile test

From Fig 9, the graphical representation shows the enhancement of ultimate tensile strength. The weight percentage of reinforcement in the matrix material primarily determines the maximum strength of the composite. AA7068/Marble dust/Fly ash MMCs samples were subjected to tensile load as per ASTM standards. For each component of the hybrid composite, four samples were tested to increase the repeatability of experimentation. The variation of tensile strength with different wt. % of fly ash and marble dust content is seen to be increasing gradually. It has been noticed that the tensile strength is increased by 18.38%, 22.48%, 40.25%, and 45.87%, respectively, for 1, 3, 5, and 7% addition of reinforcement elements compared with the base metal of AA7068 matrix material. This is attributed to the strain-hardening effect of the composite due to the addition of particles when fly ash is used in aluminium matrix composites [8, 9]. Due to their smaller size and irregular shape, fly ash and marble dust particles can create a particle bridging effect that helps to prevent crack propagation during tensile loading.

This may lead to an increase in the tensile strength of a material. It was observed by SEM that the addition of fly ash and marble dust created a micro-crack in the materials, which can act as a stress concentrator and lead to the creation of new fracture surfaces.

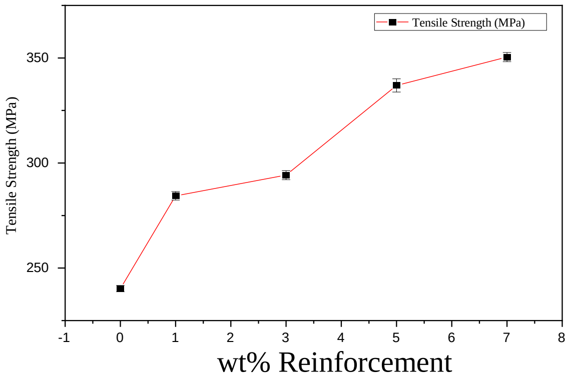


Fig 9. Tensile strength and wt % reinforcement

4.2 Hardness

Hardness studies were conducted on the refined specimens of AA7068 alloy and obtained composites as per ASTM E-384-04a standards. A load of 0.5 kgf was applied with dwell time of 15 sec. Fig 10. represents that the addition of fly ash and marble dust particles in AA7068 matrix increases the hardness significantly. The Mean of six evaluations were noted down for each hardness value at different possible areas to study the influence of particle discrimination. The Vickers hardness number of a metal matrix reinforced with fly ash and marble dust was increased compared to the parent material. The enhancement in rigidity may be attributed to the inflexible and rigid CaO, SiO_2 and Al_2O_3 available in the fly ash and marble dust. The addition of fly ash and marble dust can also lead to grain refinement in the matrix. The smaller size of the reinforcement particles can act as nucleation sites for new grains, leading to a finer microstructure with a high density of grain boundaries which can improve the hardness of the material. The homogenous particle distribution is also one of the reasons for the increase of hardness observed in SEM micrographs from fig 7.

From the fig 10, it is noticed that the hardness values of the developed composites are increased to 17.66%, 22.87%, 40.54% and 44.11%, compared to the parent metal. The maximum hardness value obtained is 151.66 HV at 7 wt% reinforcement

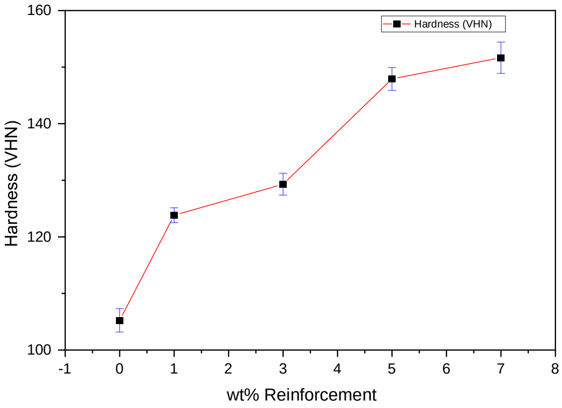


Fig 10. Hardness and wt % reinforcement

4.3 Impact Strength

The influence of fly ash and marble dust on the impact strength of the developed composite of AA7068 is shown in fig. 11. As wt. % reinforcement increases, the impact strength also increases. The inclusion of fly ash and marble dust particles in the matrix can improve the interfacial bonding and lead to an increase in impact strength. It can be observed from the SEM analysis that the particles are uniformly distributed. The impact strength is 30.98 J which is increased up to 89.67% for AA7068+ 7% Marble dust & Fly ash when compared to the base alloy.

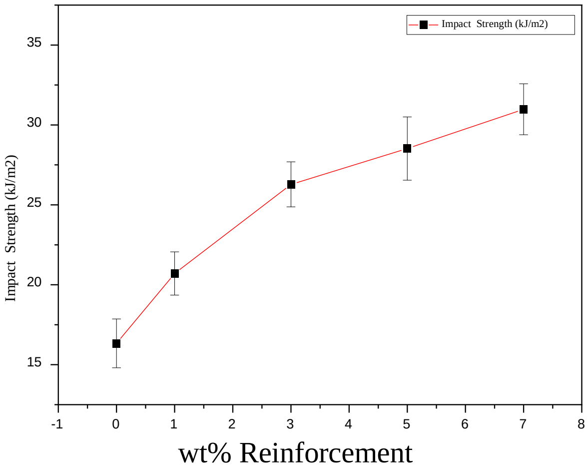


Fig 11. Impact strength and wt. % reinforcement

5. Fractography and surface analysis

The phenomena of fracture in the composites is influenced by various factors such as the method of reinforcement, size of specimens, type of reinforcing element, porosities, coarseness and interfacial properties [27].

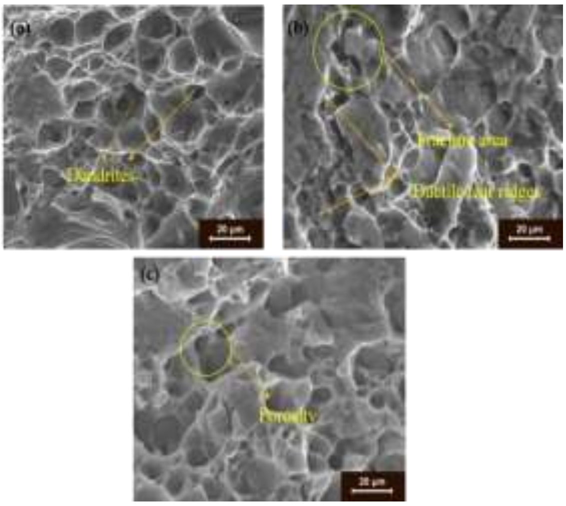


Fig 12. SEM micrographs of (a) AA7068 (b) AA7068/3 wt% Marble dust & Fly ash (c) AA7068/5 wt % Marble dust & Fly ash fractured surfaces

Fig 12. represents the SEM images of the base alloy, 3%, and 5% reinforcement subjected to tensile testing. From the fig 12(a), interdendritic cracking can be observed as primary mechanism of fracture. It may be due to cluster formation of secondary phases. While the solidification process is taking place, the interdendritic zone becomes more concentrated with alloying elements. This particular area is responsible for initiation and propagation of cracks when the material is subjected to stress, leading to the eventual failure of the specimen. And also, the presence of voids may be the reason behind the formation of micro-cracks under low levels of stress.

These voids create a path with a low energy barrier along the grain boundaries that allows for the propagation of cracks. The higher level of porosity and an uneven distribution of reinforcement are mainly responsible for failure of the hybrid composite. As the amount of reinforcement is increased, the reinforcement fills the porous structure and leaves no room for porosity. Moreover, this may decrease the chance of coagulation and promotes even distribution. Fig 13(a)–(c), displays the EDS pattern of hybrid metal matrix composites contains 3 to 7 wt.% marble dust and fly ash, there are peaks of aluminum, alloying element, and reinforcing elements that confirmed the presence of the marble dust and fly ash. The uneven distribution at some portions in the hybrid MMCs may leads to ductile fracture.

The de-cohesion between the reinforcing elements with base alloys can also be responsible for the initiation of a fracture. It is observed that from the comparison of 12 (a) with 12 (b) the appearance of the dendrite structure is more apparent in the hybrid MMCs than in the base alloy. It is revealed that the fracture mode has appeared as a combination of ductile and brittle in 3 wt% reinforcement. In contrast, the fracture mode exhibits ductile behavior that correlates with the gradual rise in the quantity of reinforcement with 5% reinforcement. The presence of voids may be responsible for microcrack formation at 5% reinforcement, as depicted in figure 12 (c).

From the above, it can infer that the higher weight fractions of filler material and proper mixing during the stirring process can help prevent the formation of porosities.

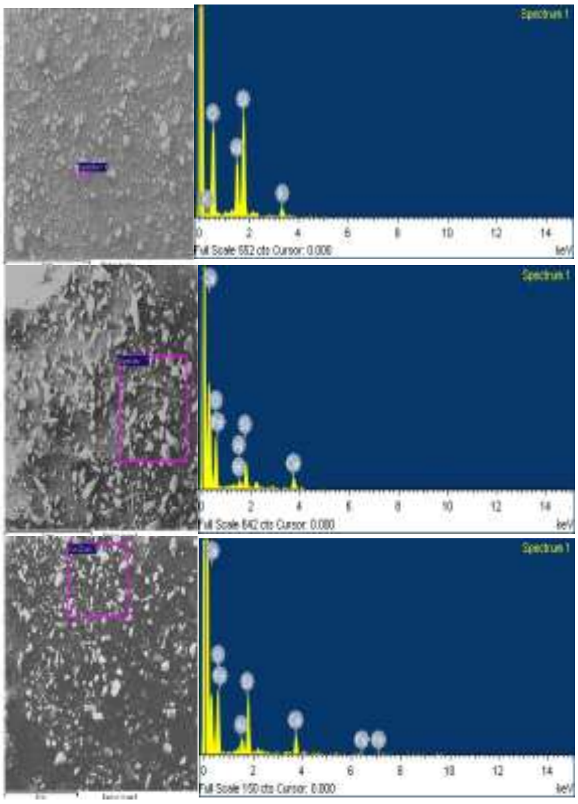


Fig 13. Eds spectrum of (a) AA7068+3% Marble dust and Fly ash (b) AA7068+5% Marble dust and Fly ash (c) AA7068+7% Marble dust and Fly ash.

6. Conclusion

In this research, a hybrid MMC is fabricated by reinforcing the fly ash and marble dust into the AA7068 aluminium alloys through the molten metallurgical stir casting. The influence of reinforcing elements on mechanical properties is studied through experimental analysis, and microstructure characteristics are observed through EDS, XRD, and SEM techniques. The major conclusions drawn from the performed investigations are summarized:

- The hybrid composites exhibited higher mechanical properties for every inclusion of reinforcing elements than the AA7068 without reinforcement.
- The inclusion of reinforcement gives the enhancement of tensile strength by 45.87%, hardness by 44.11%, and impact strength by 89.67% for 7 wt% reinforcement to the base alloy.
- The EDS spectrum and XRD phase analysis confirmed the non-existence of any foreign materials rather than the reinforcing elements in the hybrid MMC.
- The fractography analysis revealed that the hybrid MMC is exhibiting ductile behaviour due

to the presence of filler particles with random distribution in the coarser areas of the base alloy.

Conflict of interest

The authors have no conflict of interest

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