Characterization, corrosion and failure strength analysis of Al7075 influenced with B₄C and Nano-Al₂O₃ composite using online acoustic emission

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Abstract
This paper aims to establish the mechanical, corrosion and failure analysis using online acoustic emission of Al7075 alloy, Al7075-B₄C composite and Al7075- B₄C-Al₂O₃ hybrid composite with different Boron Carbide (B₄C) content of 5, 10, 15 & 20% and Nano Aluminium Oxide (Al₂O₃) content of 2% on a weight basis with the high energy stir casting method. The casted samples have been characterized by x-ray Diffraction (XRD), Thermo gravimetric analysis (TGA/DSC), Energy Dispersive Spectrum (EDS), and Scanning Electron Microscope (SEM). In case of hybrid composite, the hardness and the tensile strength decrease when the content of Al₂O₃ increases. However, in the present research, the addition of B₄C with nano Al₂O₃ particles in certain proportions has increased the hardness and tensile strength. In addition, the tensile fractographs of the specimens were analysed using SEM. Acoustic Emission (AE) method was used for monitoring the acoustic energy that are released at the time of deformation process and early crack detection. The influence of the volume fraction of the B₄C particulates on the microstructural and corrosion characteristics of Al7075 - B₄C with nano Al₂O₃ metal matrix composites (MMCs) was also studied. It has been observed from the literature that the direct strengthening of composites occurs due to the presence of hard ceramic phase, while the indirect strengthening arises from the thermal mismatch between the matrix alloy and reinforcing phase during solidification. Based on the database for material properties, the application area of HAMCs has been proposed in the present review. The effects of nanomaterial dispersion in the metal matrix and the formation of interfacial precipitates on these properties are also addressed. Particular attention is paid to the fundamentals and the structure–property relationships of such novel Nano composites.

1. Introduction

Aluminum-oriented particulate reinforced Metal Matrix Composites (MMCs) has been attained considerable attention in terms of high performance materials that are known for light weight, high formability, superior strength, high wear resistance, high electrical conductivity, corrosion resistance and high creep resistance applications. They possess application in the field of aerospace, chemical, transportation, automobile, marine, and mineral processing industries [1, 2]. In general, the aluminium MMCs is developed by semisolid, liquid state, and powder metallurgy techniques [3–5]. Stir casting is generally preferred over the manufacturing methods of MMC. The advantage of this method is its flexibility, applicability, and simplicity to a large production quantity, and in addition, it is attractive due to minimized cost [6]. It is a liquid state technique of composite materials, fabrication, where a ceramic particle is combined homogeneously with a molten matrix
metal using mechanical stirring and solidification of the melt possessing suspended particles to produce the required product [7]. Liquid state processes involve the distribution of the solid dispersed reinforcing agent (e.g. particles) into the liquid matrix metal before allowing the later to solidify. One of the major concerns regarding such technique was the segregation of reinforcing elements due to settling of particles during solidification. The homogeneity of particles distribution within the composite was found to be affected by several factors such as the properties of the particles added, melt temperature, the efficiency of mixing and the cooling rate. Furthermore, and in order to enhance the mechanical properties of the composite, strong interfacial bonding (wetting) between the reinforcing elements and the molten metal matrix should be maintained.

Various ceramic materials which are generally utilized for the reinforcement of the aluminum alloys in Al7075 MMCs [8–12]. Analysis showed that particles of B4C cannot react with aluminium [2, 13] that avoids the development of brittle reaction products in the interface of reinforcement-matrix [12–14]. Aluminium reinforced with B4C, TiC, B4C, SiC is synthesized and their characteristics were compared with the use of powder metallurgy route [7, 15]. It was noticed that B4C enhanced mechanical property compared to other reinforcements [12, 13] and [15]; B4C is very attractive as reinforcement because of its low density (2.52 g cm⁻³), good thermal conductivity (30–42 W m⁻¹ K⁻¹ at 25 °C), superior hardness (Knoop100 g 2900–3580 Kg mm⁻² (only less than diamond, BN and B4C), high Young’s modulus (450–470 GPa), high melting point (2445 °C), high electrical conductivity (140(s) at 25°C), good thermal stability and superior wear resistance [16]. Such unique characteristics make B4C widely used to areas, like engineering ceramics (wear-resistant parts, cutting tools, and armour materials) [17], automotive, armaments, aircraft, and aerospace industry, including the development of the armour of land vehicles, aircrafts, ships, aerospace parts, helicopters, and parts that are subjected to increased temperature and are characterized by high abrasion resistance [18, 19].

The ceramic reinforcements possess superior strength than any other type of reinforcement and because of the fact; these are used as a primary reinforcement for development of hybrid composites. However, the secondary reinforcements reduces the cost as these are readily available and weight as they lower density of the hybrid composites [8, 9]. The properties of the hybrid reinforcements (primary and secondary) can be combined to achieve optimization of material properties [20, 21]. Due to these enhanced properties, coupled with the capability to be operated at high temperatures, hybrid MMCs compete with ceramics, super-alloys, plastics and re-designed parts of steel in various automotive and aerospace applications [22].

Aluminium oxide particulate MMCs developed by the solidification methods indicates a class of tailor-made materials that are inexpensive for various applications, like automotive components [23]. Due to the property of solid lubrication, graphite in the particle form possesses a large number of applications in the composite materials. They are utilized in making the components requiring great wear resistance and tensile strength, like pistons, piston rings engine bearing, and cylinder liners [24–26]. This leads to the increased research attention in the evaluation of the influence of the weight fraction and type of reinforcement and for the various alternative steps used in the production of MMCs [27, 28].

Acoustic Emission (AE) method is a powerful nondestructive testing method for the real-time structural analysis of damage that is present in composite structures under dynamic-cyclic and quasi-static loading [29]. AE method is widely used in the characterization of the behavior of various engineering materials [30–32]. The need of an AE system is to obtain the energy that are released from the specimen under test at the time of deformation and the analysis of the characteristics of the material is highly reliable compared to the calculations that are made theoretical, especially in case of heterogeneous material, due to the fact that the theoretical estimations depending on an assumption that it uses only homogeneous specimen [33]. The capturing of AE energy does not depend on the deformation of the testing machine and the corresponding energy absorbing issues [33]. Corrosion characteristics are important in the assessment of the application potential of composites as the structural materials [34]. Researchers have stated that the pits originate from the secondary particles within the matrix, and thus the composites normally contain more pits than monolithic matrix. For instance, the development in corrosion resistance is declared with the decrease in the volume rate of Al₂O₃ particles in Al–4 wt% matrix composites of Mg alloy [35].

Even though various researchers tried Al with B₄C, the characterization, mechanical and failure analysis using online AE are not clear. In this analysis various composites of Al7075 were developed by reinforcing various weight fractions of B₄C and with nano Al₂O₃ particulates and their mechanical and failure analysis with the use of online AE of hybrid composite were analyzed. Literature from number of existing works in Al7075-B₄C-nano Al₂O₃ composite stated that no work was performed to determine the tensile test with the AE in Al7075-B₄C-nano Al₂O₃ hybrid composite. Hence, this research mainly aimed on the analysis of tensile testing with AE and in addition emphasizes the hardness of Al7075–B₄C- Nano Al₂O₃ hybrid composite.
2. Material and methods

The materials utilized in the current study were identified as Al7075, B4C and Al2O3, and the information related to their compositions are shown separately in table 1. The reinforcing ingredient B4C powder has the particle size of about 10 μm and the nano Al2O3 particle size is 25 μm.

The hybrid composites and composites of Al7075 were produced by stir casting method with the addition of 5, 10, 15 and 20 wt% of B4C and 2 wt% of Al2O3 [34]. The detailed fabrication procedure, SEM, EDS and XRD analysis of the Al7075 alloy, B4C and Al2O3 particles are available elsewhere [35]. It is designed to prepare the cast samples of the Al7075, Al7075-based composites and Al7075-based hybrid composites with different compositions on the basis of the needs of all microstructural, mechanical and tribological analysis [36].

2.1. Mechanical properties

2.1.1. Hardness test

Hardness was estimated with the Vickers micro hardness tester, and a test of micro hardness was performed as per ASTM: E384–10 on the mirror finish polished samples of the Al7075 alloy and its composites, successively with the finer diamond abrasives to produce a 0.25 μm surface finish. The samples are applied to a load of about 300 g for duration of 10 s. The tests were performed at five various locations to reduce the possible influence of the indenter that is placed on a hard reinforcement particles, and the averages of entire readings were recorded.

2.1.2. Tensile test

The specimens of tensile test were developed as per the ASTM standard (E8/E8M-13a) in a cylindrical shape and are tested in a FIE servo controlled universal Testing Machine (UTM) named (UNITEK 94100-100 kN, FIE Pvt Ltd, Yadrav) in the presence of a cross head speed of about 8.33 × 10⁻⁶ ms⁻¹ at the room temperature.

2.2. Characterization

2.2.1. Scanning electron microscope

Scanning Electron Microscope (SEM) images are generated from EVOLS15, Carl Zeises at 9.0 kx and 15.0 kV were utilized in the investigation of the fracture morphology with increased magnification views of tensile tested specimen of Al7075%-10% B4C-2% Al2O3 and Al7075-20% B4C-2% Al2O3 of reinforced composites.

2.2.2. Energy dispersive spectrum (EDS)

EDS (Bruker) is an analytical technique utilized in the elemental analysis of a sample. EDS elemental study confirmed the availability of titanium, aluminium, boron, carbon and magnesium. X-ray mapping with EDS in the electron microscopes develops based on the qualitative microanalysis of x-ray with the provision of a visual indication of the presence of the elements. Mapping routines possess long elements that are identified within a sample and showed the element distribution in the image map of the sample area often, the visual comparisons of various element maps, side-by-side or overlaid depicts where the combinations of elements arise, which provide a deeper idea about the chemical characteristics of material.

2.2.3. X-ray diffraction (XRD)

XRD analysis of prepared samples was performed with the (Analytical, Model: XPERT-PRO). The outcomes of XRD of the prepared Al7075- B4C composite and Al7075- B4C- Al2O3 hybrid composite are depicted.

2.3. Acoustic emission test

Acoustic Emission (AE) is the sound wave developed whenever a material is subjected under stress due to external force. This characteristic arises inside the material whenever the mechanical loading produces the sources of elastic waves. The emissions are due to small displacement of surface of material, developed due to the stress waves developed during the rapid release of energy. The tests were carried out using electro-mechanical

| Table 1. Chemical composition of Al7075, B4C& Al2O3. |
|---------------------------------|
| **Element** | **Weight %** | **Element** | **Weight %** | **Element** | **Weight %** |
| Al7075 | Zn | Mg | Cu | Si | Fe | Mn | Cr | B | Al |
| 4.8 | 2.4 | 1.4 | 0.78 | 0.28 | 0.04 | 0.18 | 0.03 | Remainder |
| B4C | Element | B | C | O | Fe | Si |
| 78.64 | 20.42 | 0.26 | 0.42 | 0.26 |
| Al2O3 | Element | Al | O |
| >95.00 | <0.50 |
controlled UTM interfaced in the presence of an AE recorder as in figure 1. In addition, the true energy produced is directly proportional to the area that is under AE waveform [36].

The activities of AE is observed with the AE sensors, mechanical signals that can be then converted as pre-amplified electrical signals and then as a post-amplified count of AE after conducting the process of filtration. The filter must possess necessary range of frequency for the suppression of noise signal that are unwanted. Then, the filtered signals of AE are fed to comparator in addition to the value of threshold that further avoids the unwanted noise signals [31].

AE was monitored in continuous manner during tensile tests with an AE platform acquisition system of Physical Acoustic Corporation (PAC). The piezoelectric- micro 80 model sensor in the presence of 175 kHz − 1 MHz resonance frequency capacity AE was utilized in measurement. The frequency response of AE was 10 kHz − 2.1 MHz ± 1.0 db. The presence of ambient noise was filtered out with a threshold value of about 40 dB. The specimen was placed in between the holding grips of UTM-UNITEK-94100 and the AE recorder was placed nearly in the centre of tensile specimen [34]. The specimen was developed at a constant rate of $0.5 \times 10^{-3} \text{m/s}$ for the two ends in a tensile testing machine continuously and simultaneously for the measurement of stress characteristics and the instantaneous applied load of the specimen. The tests were performed with minimum cross head speed of about $8.33 \times 10^{-6} \text{ms}^{-1}$ at the room temperature [37]. Each nano second was saved using the AE recorder and the plots were produced with ultimate load, yield load, and the breaking load. In the same way, all the five sets of specimens were analyzed for the details to be recorded.

2.4. Corrosion test
The static immersion corrosion analysis was performed at three varying temperatures, such as room temperature, 50 and 75 °C. Loss in weight was estimated to find the corrosion rate of Al7075-B4C-Al2O3 composites with the use of a digital accuracy for an accuracy of about 0.1 mg. All the specimens are initially weighed before they are immersed in 3.5 wt% solution of NaCl and then taken out later after 24, 48, 72, 96 and 120 h, respectively. After thorough drying, all the specimens are again weighted. The loss in weight was estimated and is converted as rate of corrosion that is expressed in mm penetration per year (mm/year). The surfaces that are corroded were analyzed with the use of SEM, and the corrosion analysis were performed with the suspension of composite samples of Al7075-B4C in a still solution of about 3.5 wt% aqueous solution of NaCl. The outcomes of the corrosion analysis were estimated with the measurements of weight loss that are carried out following the ASTM G31 recommended practice as stated in [38]. Before the immersion in 3.5 wt% aqueous solution of NaCl, the composite samples of Al7075-B4C were ground to 1000 grit and then cleaned using the deionized water that is followed by rinsing using methanol and finally dried. In case of elevated temperatures corrosion analysis (i.e. accelerated tests), a 3.5 wt% solution of NaCl was prepared, and heated to about 50 ± 1 and/or 75 ± 1 °C with an electric heater. All the specimens were placed in the warm solution and using a glass cover on the top of vessel avoids evaporation.
The corrosion rate $CR$ (from the mass loss) \( \left[ 34 \right] \) was estimated with expression given as,

$$CR = \left( K \times W \right) / \left( A \times D \times T \right)$$ \hspace{1cm} (1)

where $CR$ indicates the rate of corrosion in mm/year, $K$ represents a constant equal to $8.766 \times 10^4$, $T$ indicates the exposure time ($h$) to the nearest 0.01 h, $A$ represents the area in cm$^2$, $W$ indicates the loss in weight in the nearest 1 mg and $D$ represents the material density in g cm$^{-3}$.

3. Results and discussion

3.1. Analysis of micro hardness

The outcomes of the micro hardness analysis performed in the Al7075 alloy and composite possessing 5, 10, 15 and 20 wt\% of the B$_4$C particles with 2 wt\% of particles of Al$_2$O$_3$ are depicted in figure 2. They depict the changes in micro hardness with the variation in the reinforcement content of B$_4$C and Al$_2$O$_3$. The Al7075 alloy possesses the reduced hardness of 62 HV and the aluminium-based composite with Al7075%-5% B$_4$C indicates 66.7 HV and this leads to increasing content of B$_4$C. It is found that the wear resistance and hardness properties have been found to increase upon of maximum reinforcement addition. It is identified that the hardness of the composite with Al7075%-20% B$_4$C is 78.21 HV, which is more than the base alloy Al7075. It is noticed that the hardness of Al7075%-5% B$_4$C with 2% Al$_2$O$_3$ is 65.45 HV. It is observed that the hardness lowers with the increase in content of Al$_2$O$_3$ in the Al7075- B$_4$C composite. The hardness of Al7075 based composite and hybrid composite, the hardness of Al7075%-20% B$_4$C with 2% Al$_2$O$_3$ is 81.25 HV \( \left[ 36 \right] \).

In general, the addition of Al$_2$O$_3$ lowers the hardness \( \left[ 37, 39 \right] \), but the current analysis depicts that, while adding B$_4$C with Al$_2$O$_3$ particles the hardness increases to certain proportions \( \left[ 5, 40 \right] \) mainly by the transference of hardness from aluminium matrix to the reinforced particles of B$_4$C. The hardness of hybrid composites was considerably higher compared to base alloys, because of hard B$_4$C particles. A considerable increase in the hardness is noticed due to the addition of B$_4$C and Al$_2$O$_3$ particles \( \left[ 36 \right] \). The wear resistance of boron carbides is very high; therefore the wear resistance of material obtained should increase. So, the hardness of the composite will increase at 20% B$_4$C + 2% Al$_2$O$_3$ than 10% B$_4$C + 2% Al$_2$O$_3$. Al oxides will prevent the increase of the grain size; therefore the hardness of the composite decreased. The increase in hybrid composite hardness was because of the increased hardness of reinforcement particles of B$_4$C, uniform distribution of B$_4$C particles and the higher density. \( \left[ 8, 17, 30 \right], \left[ 40 \right] \).

3.2. Tensile strength

3.2.1. Tensile strength of various composites

The variations in the ultimate stress, tensile stress, and elongation of Al7075 alloy & composites with 5, 10, 15, 20 wt\% of B$_4$C were analyzed with the computerized curves which indicate the stress with displacement, and are depicted in figures 3(a)–(d). Figures 3(a)–(d) represent that the increase in ultimate tensile strength is strongly related with the increased amount of the B$_4$C particles. In addition, the tensile test, which increases in the reinforcement rate, increases the tensile strength with reduced ductility.

The considerable development in the mechanical characteristics of the composite on comparison to Al7075 is attributed to the particles of B$_4$C in the matrix increases when the wt\% of B$_4$C increases. Over this, there arise a...
rapid increase because of hard nature and better bonding characteristics of B₄C. The deformation of plastic in the base metal is very faster than the composites produced with reinforcement. This is due to the transferring of load to the reinforcement from the matrix [13, 18] and [41].

Figures 3(a)–(d) depicts the variation in ultimate stress, tensile stress, and elongation of 10, 15 wt% of B₄C with 2 wt% of Al₂O₃ is interpreted using the curves that show the stress with displacement. The mechanical strength is affected with the addition of Al₂O₃ and to improve it, the particles of B₄C were added. The ultimate tensile strength of hybrid composites increases with the addition of B₄C [41].

In figures 3(c), (d) the tensile strength decreases with increasing content of B₄C and Al₂O₃. The addition of Al₂O₃ usually lowers the strength, however while adding the particles of B₄C it increases the mechanical properties. This is due to the fact that hybrid composites changes tougher with the increased particles of B₄C, and exist till the matrix lodges the particle without any distortion and possess better agreement with as stated in [41]. Reinforcement is an important factor which controls the strength of Al- B₄C-Al₂O₃ hybrid composites. The hard B₄C particles result in the dispersion hardening of matrix. In addition, it showed that the strength of fracture increases with Al₂O₃, compared to the alloy of Al7075 and the composite of Al7075- B₄C [36].

3.2.2. SEM fractography
The fracture morphology with increased magnification views of tensile tested Al7075 with 10 and 20 wt% of B₄C and 10 and 20 wt% of B₄C with 2 wt% of Al₂O₃, reinforced composites is depicted in figures 4(a)–(e). Figure 4(a) depicts the SEM image of Al7075 alloy that cleared the fact that the alloy of Al7075 are uniformly distributed voids, however in 10 B₄C and 20 B₄C composites they are minimal as depicted in figures 4(b)–(e). The evidence of the ductile fracture could be noticed in both the morphologies; however it was more in the alloy of Al7075 and medium in composite. The % of elongation lowers with increased % of B₄C, which is due to the hard nature of B₄C particles [42].

The fracture morphology specimen of Al7075 alloy that are tensile tested with 10 and 20 wt% of B₄C and 2 wt% of Al₂O₃ reinforced composite is depicted in figures 4(b)–(e). It revealed the ductile mode of fracture with de-cohesion of reinforcing particles. In most cases, the fracture of B₄C can be readily observed, leading to particle pull-out and associated micro voids. However, in the composites 10 and 20 wt% of B₄C with 2 wt% of Al₂O₃, they were less and present inside the dimples, the particles of B₄C are harbored well. This showed the better existing of bonding among the matrix and of B₄C particles as stated in [34]. The evidence of the ductile fracture could be noticed in the fracture morphology; however it was more in Al7075 alloy and medium in case of composite [8]. The particles of B₄C and Al₂O₃ stayed intact in various place that possess surety for the presence
of better bonding among the matrix of aluminium and the particles of B₄C and Al₂O₃. These trends were noticed by various other researchers [43].

3.3. SEM Analysis
Figures 5(a), (b) shows the distributions of B₄C were analyzed and found non uniform with Al₂O₃ particles. It discloses the fact that Al7075 alloy has voids that are uniformly distributed. The evidence of ductile fracture is present in the fracture morphologies; however the ductile fracture is very high in the alloy of Al7075 and it is marginal in the composite. It proves that the percentage of elongation lowers when the percentage of B₄C increases. This is because of the hard nature of B₄C particle [2].

3.3.1. EDS Analysis
Figure 6 shows the SEM micrographs and the corresponding B, Al, O, Ti, C, Mg and Si composition maps produced by EDS analysis of composites reinforced in the presence of 10 wt% of B₄C particles. Figures 6(a)–(d) depicts the EDS pattern of different composites after casting. Figures 6(a), (b) depicts the spectrum of EDS of
Al7075-10 & 20 wt% of B4C composite with aluminium and titanium peaks. Figure 6(c) depicts the EDS spectrum of Al7075%-10%B4C-2% Al2O3 hybrid composite and figure 6(d) shows the Al7075%-20% B4C-2% Al2O3 hybrid composite with peaks of boron, aluminium, carbide, and aluminium oxide. Figure 7 presents the elemental distribution map of the homogeneous distribution of the particle of B4C in Al matrix. A map overlay of all seven elements depicts where B (green), Al (red), O (blue), Ti (violet), Mg (dark green), Si (lavender) and occurs with C (light green). It is also evident that there are some areas where the elements are not in any combination with other elements.

3.3.2. XRD analysis

The characteristic peaks in XRD patterns were consistent with the JCPDS files No. 89-2837, 07-0275 and 89-8487 for Al7075, B4C and Al2O3 respectively. Peak values are obtained at 2θ ranges of 10°–100° with a step size of about 0.0170° and step time of about 20.3142 s. All samples possess wide peaks of diffraction that are indexed to Al7075, B4C and Al2O3 structure. Figures 8(a)–(d) depicts the XRD outcomes of the prepared composites with the intensity peaks at about 10 and 20 wt% of B4C & 10 and 20 wt% of B4C with 2 wt% Al2O3. Figures 8(a), (b) shows that the B4C intensity was higher in the (1 0 1) plane (2θ = 44.6714°, JCPDS 07-0275). In addition, the B4C intensity was noted at various peaks and guaranteed through the software of JCPDS and increased using the...
weight percentage of B₄C, notably at 2θ = 65.0960°, JCPDS 89–4746 (TiO₂ 125). Figures 8(c), (d) depicts the availability of aluminium (at largest peaks), notably at 2θ = 38.7618°, 65.3376°, 78.4779°, 82.7099° of (1 1 1), (2 0 0), (3 1 1), (2 2 2) of the diffraction peaks of Al7075, related to JCPDS 89–2837 file. The availability of the B₄C particles (represented by minor peaks), was related to 2θ angle 45.0223°, 61.3770°, 78.3867°, 88.6000° of (1 0 1), (1 1 0), (2 0 1), (1 1 2) of the diffraction peaks of B₄C related to file no. (JCPDS 07–0275) and the carbon (represented by minor peaks), are identified using the 2θ angle 26.9314°, 61.4688°, 68.5539° of (2 0 0), (2 2 0), (1 1 3), JCPDS software (89–8487), (89–8498), (89–8493). A visible peak of carbon is noticed in the hybrid composites. The intensity of Ti was noticed at the various peaks and verified using JCPDS software, notably at Ti, 2θ = 55.2646°, 82.8910° of (2 0 0), (2 0 1), JCPDS (89–4913, 89–4893). A gradual marginal shift of Al peaks to

Figure 7. Elemental distribution map of the composite with 5 wt% of the B₄C reinforcement (a) B (b) Al (c) O (d) Ti (e) C (f) Mg (g) Si.
increased angles, with the increased weight % of the content of B₄C and Al₂O₃ in the hybrid composite is also noticed [39].

### 3.4. Effect of thermo gravimetric analysis

Figures 9(a), (b) shows the thermo graph of TGA/DTA analysis. It is reported that the peak temperature touched throughout material diverse amongst 620 °C and 650 °C with 20–40 mm min⁻¹. From thermo graph heat stability of aluminium oxide added composite is increased that Al₇₀₇₅-B₄C composites [44]. Even though Al-B₄C phase possess better thermal stability, and its point of dissolution is very much greater than 650 °C. So the Al-B₄C-Al₂O₃ phase with improved thermal stability can be engaged in the prepared composite compositions. During DTA analysis there is mass reduction is about 0.1% in weight due to the B₄C-Al₂O₃ addition [40].

### 3.5. EBSD analysis

Figures 10(a), (b) reveals that EBSD study of Al-B₄C-Al₂O₃ composites which show its controlled reinforcement fractions and color scheme reflects its grains orientation from the surface [27]. The composites possess the maximum particle size of about 112 μm and 98 μm respectively and a purity of 98.5%. The images extent the confirmation on no deformation is found using morphology interface area by the yellow, green, and red colors indicates the increasing levels of internal orientation across the composites. The hybrid composite has no clear grain refinement because of metallic matrices does not promote the formation of strong texture.

### 3.6. Acoustic emission

#### 3.6.1. Analysis of acoustic emission

The study of the data of AE were done with the AT post software, which indicated that the signals of AE were send over the specimen, which is prepared by the sensors. The different parameters of AE that are produced from test setup are time, hits, count, amplitude and voltage. Continuous and transient signals are the types of AE signals, where the continuous signals possess variations in time and the voltage, but the signals never end, and the transient signals possess the burst starting and end points that varies from the background noise clearly. The required signals to test the AE at different percentage of weight of the composite materials are the burst signals that originate from the crack growth or the fracture.

#### 3.6.2. Distribution of AE for number of composites (time versus amplitude)

Figures 11(a)–(e) depicts the distribution of AE for Al7075 and other Al7075 based composites with 10, 20 wt% of B₄C and 2 wt% of Al₂O₃ with respect to time versus amplitude. It depicts the signal detect ability and effect of
reinforcement of particles of B\textsubscript{4}C and Al\textsubscript{2}O\textsubscript{3} on the activity of AE. It is clear that there occur a noticeable increment in amplitude above 20 $\mu$s, due to the rate of particles of B\textsubscript{4}C and Al\textsubscript{2}O\textsubscript{3} as stated in [36].

3.7. Corrosion characteristics of Al/B\textsubscript{4}C-Nano Al\textsubscript{2}O\textsubscript{3} composites

Figure 12 represents the variation in rate of corrosion of the Al7075- B\textsubscript{4}C composites for the duration of exposure of 3.5 wt% solution of NaCl at the room temperature. In general, it is observed that the Al7075- B\textsubscript{4}C composites possess better resistance to corrosion than pure Al matrix. When the volume rate of the B\textsubscript{4}C and nano Al\textsubscript{2}O\textsubscript{3} particulates increases the corrosion resistance of the composites of Al7075- B\textsubscript{4}C- Al\textsubscript{2}O\textsubscript{3} also increases. In addition, increase in the exposure duration lowers the rate of corrosion. These results show that the materials resistance to corrosion which are under analysis increases when the duration of exposure increases. The strategy of lowering the rate of corrosion in terms of the duration of exposure represents some passivation of matrix alloy. The development of resistance to corrosion of Al-MMCs with the volume fraction increment in B\textsubscript{4}C as stated by more number of workers [45, 46]. The experimental outcomes cleared that the increase in loss of weight of the composites increases with the exposure time. In addition, the results revealed that intermetallic due to reaction among Al7075 and B\textsubscript{4}C particle possess a considerable influence on the resistance to corrosion of the composites in the presence of interruption of matrix channel continuity within the pressure infiltrated.

**Figure 9.** TGA D$^{-1}$T$^{-1}$A$^{-1}$ thermo graph (a) Al7075%-10% B\textsubscript{4}C; (b) Al-10%B\textsubscript{4}C-2% Al\textsubscript{2}O\textsubscript{3} Composite.
composites. In addition, the loss in weight of composites still 3.5 wt% solution of NaCl increases with the increase in exposure time.

Figures 13(a), (b) depicts the variation in rate of corrosion of the composites of Al7075- B₄C-Al₂O₃ with a temperature after its exposure to 3.5 wt% solution of NaCl for about 24 h and 120 h. In contrast to the outcomes produced at the room temperature, it is seen that the composites of Al7075- B₄C possess higher rates of corrosion than Al7075 matrix at the elevated temperatures. Increasing the volume fraction B₄C decrease the corrosion rates of the Al7075- B₄C- Al₂O₃ composites. The rate of corrosion of composites of Al7075 and the Al7075- B₄C increases in linear manner with the increase in temperature. For fixed duration of exposure, the Al7075- B₄C composites always possess higher rate of corrosion at 75 °C than that at 50 °C.

Figure 14(a) depicts the SEM micrographs of the corroded surface for Al7075 matrix and the composites of Al7075%-15% B₄C-2%Al₂O₃ after its exposure to 3.5 wt% solution of NaCl for about 96 h at the room temperature. It is evident that a considerable rate of damage is found on matrix surface of Al7075. Large pits on the surface represent the material susceptibility over the pitting corrosion in the medium of NaCl. On the other hand, the composites of Al7075%-15% B₄C corroded surfaces possess less damage compared to the Al7075 matrix. It is evident from figure 14(b) presented that unreinforced Al7075 matrix surface suffered from severe degradation, considerably over the grain boundaries that offers preferential sites of initiation of corrosion due to discontinuity as a result of modification in structure. In the composites of Al7075- B₄C, pitting arise at the sites where the particulates of B₄C agglomerate in addition to the grain boundary attack. Figure 15 depicts SEM micrograph of high magnification of corroded surface for the composites of Al7075%-15% B₄C-2%Al₂O₃ after its exposure to 3.5 wt% solution of NaCl for about 24 h at the room temperature.

The enhanced corrosion resistance of Al7075- B₄C composites at room temperature on comparison with Al7075 matrix may result in a fact that B₄C particulates are the ceramics and the oxides stays inert in the solution of NaCl, and are affected hardly with the aqueous medium of NaCl. Even though the rate of corrosion of the Al7075- B₄C-Al₂O₃ composites is less as compared to the Al7075 matrix metal, the composites of Al7075- B₄C depicts the creation of pits. But, the rate of pits decreases while adding the B₄C particulates compared to Al7075 matrix metal. It is evident that the increase in volume of B₄C particulates lowers the pits. In addition, there is a pitting corrosion and grain boundary corrosion in Al7075- B₄C-Al₂O₃ composites as shown in figure 16.

Figure 16 depicts the SEM micrographs related to the corroded surface of both Al7075 matrix and Al7075%-15%B₄C-2%Al₂O₃ composites after its exposure to the 3.5 wt% solution of NaCl for about 96 days at 50 °C. It is clear that the rate of degradation of surface increases with the increase in temperature with these images. In addition, the increases in temperature of NaCl solution boost up the severity of damage of Al7075.
matrix and the composites of Al7075- B₄C- Al₂O₃. However, the composites of Al7075- B₄C possess more damage surfaces as compared to the Al7075 matrix. In general, the severity of damage in the composites of Al7075- B₄C- Al₂O₃ and the Al7075 matrix increases with increased duration of exposure and temperature of NaCl solution. The size of pits and the number per unit area increases with the increase in temperature of the solution of NaCl. There are only few literatures related to the corrosion characteristics of composites in 3.5 wt% NaCl medium at elevated temperatures.

Figure 11. AE distribution for various composites (time versus amplitude) (a) Al7075 (b) Al7075%-10%B₄C (c) Al7075%-10%B₄C-2%Nano Al₂O₃ (d) Al7075%-20%B₄C (e) Al7075%-20%B₄C-2%Nano Al₂O₃.

Figure 12. Variation in the corrosion rate with the exposure duration for Al7075-B₄C-Al₂O₃ composites after static immersion in 3.5 wt% NaCl aqueous solution in laboratory room temperature.
Figure 13. (a) Variation in the corrosion rates with the temperature for Al7075-B$_4$C-Al$_2$O$_3$ composites after immersion in 3.5 wt% NaCl solution for 24 h, (b) Variation in the corrosion rates with the temperature for Al7075-B$_4$C-Al$_2$O$_3$ composites after immersion in 3.5 wt% NaCl solution for 120 h.

Figure 14. SEM micrographs of Al7075 matrix (a) and Al7075%-15% B$_4$C-2%Nano-Al$_2$O$_3$ composites and (b) after exposure in 3.5 wt% NaCl solution for 96 h at room temperature.
4. Conclusions

In the proposed work, Al7075 based hybrid composites and composites were prepared with the use of stir casting with different B4C & Al2O3 content, and the characterization was carried out using SEM, EDS, XRD, TGA and EBSD. On the basis of the proposed experimental research, the conclusions are obtained as follows,

- The crystalline structure is confirmed by the XRD pattern and the results of EDS proved the availability of functional elements in Al7075 alloy, Al7075- B4C composite and Al7075- B4C - Al2O3 hybrid composite with various peak intensity using JCPDS and various other elemental peaks.
- The hardness of the Al7075- B4C - Al2O3 composite raised mainly as a result of weight percentage of B4C and Al2O3. The hardness increased while adding the reinforcements of B4C&Al2O3 with Al7075 matrix and the hardness of composites lowered with the increase in % of Al2O3.
- The ultimate tensile strength, tensile strength and the elongation improves while addingB4C and Al2O3. The Al2O3 addition, decreased the strength, however while adding theB4C particles, the strength was improved. The ductility was known to be little less for a composite as compared to the Al7075 alloy. The fracture morphology of specimen was analyzed using SEM.

Figure 15. SEM micrograph of the corroded surface for Al7075%-15%B4C-2%Nano Al2O3 composites after exposure in 3.5 wt% NaCl solution for 24 h at room temperature.

Figure 16. SEM micrographs of Al7075 (a) Al7075%-15% B4C-2%Nano Al2O3 composites (b) after exposure in 3.5 wt% NaCl solution for 96 days at 50°C.
• The Al7075- B4C composites possess better resistance to corrosion as compared to pure Al matrix at room temperature in 3.5 wt% of aqueous solution of NaCl.

• While the volume rate of B4C particulates increases, the corrosion resistance of Al7075- B4C-Al2O3 composites gets increased. In addition, the increase in the duration of exposure lowers the rate of corrosion.

• The Al7075- B4C-Al2O3 composites possess reduced corrosion resistance as compared to the Al7075 matrix at the elevated temperature in 3.5 wt% of aqueous solution of NaCl. The corrosion rates of the Al7075 and Al7075- B4C-Al2O3 composites increases linearly with the increase in temperature.

• The extent of the Al7075- B4C- Al2O3 hybrid composite was noticed using AE that helps the engineers to reduce failure at the time of MMC manufacture.

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