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Microstructure studies of AA7150-hBN nanocomposites fabricated by ultrasonic assisted stir casting

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Abstract
For two decades, the Al7XXX series alloys have been playing an extensive role in aerospace and automotive industrial applications due their excellent properties such as toughness, fatigue, strength and low density. However, the current scenario for all these applications, there is a significant improvement at service loads as well as wear resistance properties at elevated temperatures. The main focus of the current investigation is with the microstructure analysis of AA7150-hexagonal Boron Nitride (hBN) nanocomposites which are fabricated through ultrasonic assisted double stir casting process. The Scanning Electron Microscope and Optical Microscope were used to study the particle distribution, grain refinement of the monolithic AA7150 alloy, nanocomposites. The fractured surfaces and wear surfaces were also studied the influence of applied load as well as hBN weight percentage on nanocomposites and compared with base matrix.

1. Introduction

Reinforcement of ceramic nanoparticles in the Metal Matrix Composites (MMCs) are suitable and promising materials for wide range of applications. The fabrication of metal matrix nanocomposites (MMnCs) is facing a crucial problem of low wettability with nano-level fine particles in the molten metal liquid which prone to form agglomeration/clusters during the process. These agglomerations/clusters leads to reduce the uniform distribution of ceramic nanoparticles throughout the molten matrix, result in loss of composite strengthening potential. To avoid this problem during the fabrication process of MMnCs, the ultrasonic assisted stir casting was introduced [1]. Wu *et al* [2], investigated the microstructure as well as mechanical properties of Al356-SiCnp nanocomposites which is fabricated by ultrasonic treatment via squeeze casting. It is noticed that the SiC nanoparticles are homogeneously dispersed and enhancement of tensile strength of the MMnCs compared to base Al356 alloy. Aluminum (Al)-Magnesium (Mg)-Zinc (Zn)-Cupper (Cu) alloy materials are widely used as critical components in automotive and aerospace sectors due to their superior physical and mechanical properties such as strength to weight ratio, higher ductility, high temperature survivability and numerous engineering properties [1, 2]. Yet, they exhibit low abrasive wear under lubricating conditions against the sliding surface making them less futile to tribological applications consequently failure of various components. However, to overcome this problem, solid lubricants were introduced into the aluminium alloys for preparing the MMCs [3–5]. Especially in upper and lower wings, fuselage, stringers and passenger seat tracks of an aircraft. Due to self-lubricating property, the composites accentuated high damping capacity, low thermal expansion [6], low wear and friction [7, 8] an excellent anti-seizure property [9, 10] besides exhibiting reduced temperature rise [11, 12] at mating surface. This research article deals with microstructure analysis of monolithic AA7150 and hBN reinforced nanocomposites for particle distribution through Scanning Electron Microscope (SEM), grain size through Optical Microscope (OM); further, the studies on the surface wear of the AA7150 and hBN

Table 1. The Elemental composition of AA7150 by weight percentage.

Elemental Composition	Zn	Mg	Cu	Fe	Si	Zr	Mn	Al
AA7150	6.37	2.56	2.25	0.12	0.08	0.11	0.009	Balance

Table 2. The base matrix and reinforcement materials properties.

Material	Elastic Modulus (GPa)	Density (g/cc)	Hardness (HV)	Tensile Strength (MPa)
AA7150	70-80	2.83	41	115
hBN	675	2.21	194	620

reinforced nanocomposites surface of the samples at minimum & maximum load conditions and ultimate tensile fractured surface analysis at 1.5%hBN, 2.0%hBN, monolithic material as well.

2. Materials and methods

The present investigation, AA7150 (Al-Zinc alloy under 7XXX series) was selected as the matrix material and procured in the form of ingots from M/s. Venuka Engineering Private Limited, Hyderabad, India. The chemical composition of the AA7150 is presented in table 1. The nanoparticle reinforcement material of hexagonal Boron Nitride (hBN: 70 nm size with the laboratory grade purity of 99.5%) was used and procured from Sisco Research Laboratories Pvt. Ltd (SRL) - India. The mechanical properties of matrix and reinforcement materials are presented in table 2. The hBN nanoparticles were added at steps of 0.5 wt% into a molten AA7150 to achieve 0.5% to 2.0% nanocomposites by using ultrasonic assisted liquid metallurgy route. This liquid metallurgy route with mechanical stirrer commonly known as vertex method of casting. Degassing treatment was performed using a degassing tablet Hexachloroethane (C_2Cl_6) and than 1 wt% of Magnesium (Mg) was used as catalyst to improvement of the wettability while mixing the nanoparticles in liquid pool. The fabrication process involves two steps of stirring action, each step takes 10 min of time. Further, ultrasonication was performed for 10 min to achieve uniform dispersion and distribution of nano hBN particles in the molten alloy. The processed molten metal was transferred into preheated cast iron mold which contains cylindrical holes. The solidified blocks were machined according to ASTM E8M, ASTM G99 and ASTM E92 for Ultimate Tensile Strength (UTS), wear and microhardness testing. Cast AA7150-hBN nanocomposite was also machined as per microstructure studies which were subjected to optical, metallographic and particles distribution. The hardness was performed on Vicker microhardness tester (Make: Shimadzu, Model: HMV-G20ST) as per ASTM E92. The UTS was performed on Blue star make WDW-100 S as per ASTM E8M, wear and friction was performed using pin on disc apparatus of Magnum Engineering, wear and friction test model RIG-TE-165-SPOD with a hardened steel counter disk of EN31 with 62 HRC hardness. The size of the specimen was maintained as per ASTM G99 standard with a dimensions of 30 mm in length and 8 mm in diameter. The wear parameter such as applied load (10-40 N) and weight percentages (0.5-2.0 hBN) against 3000 m sliding distance was performed. The coefficient of friction and wear resistance was measured with the help of Linear Variable Differential Transformer (LVDT).

3. Results and discussions

The SEM photographs are shown in figure 1. It is observed that hBN nanoparticles are clearly visible and uniformly distributed in AA7150 matrix. The AA7150-1.5 wt% hBN reinforced composite shows better distribution of nanoparticles in figure 1(c) as compared to other weight percentages of reinforcements. Therefore, there is an enhancement in the hardness of the composites from 151.3 HV to 180.2 HV with an increase in 19.1%, as well as UTS has been enhanced from 115.1 MPa to 181.6 MPa, with an increase in 57.78% of the nanocomposites and the similar type of results were noticed by the several researchers [13, 14]. Figure 2 shows the optical microstructure of monolithic alloy and hBN nano-particulates reinforced composites. From figure 2, it is observed that the grain refinement of AA7150-hBN nanocomposites was increased with increase of reinforcement content. This is mainly due to the uniform distribution of nanoparticles and less particle interface distances which results in enhanced strength and hardness due to Hall-patch and Orowan strengthening mechanism [15].

The Average Grain Size (AGS) can be measured by using Linear Intercept Method and Planimetric (Jeffries) Method [16]. In this article Linear Intercept Method was used to find the average grain size along with principle planes (Transfer and Longitudinal directions) of each microphotograph with the help of ImageJ software. The

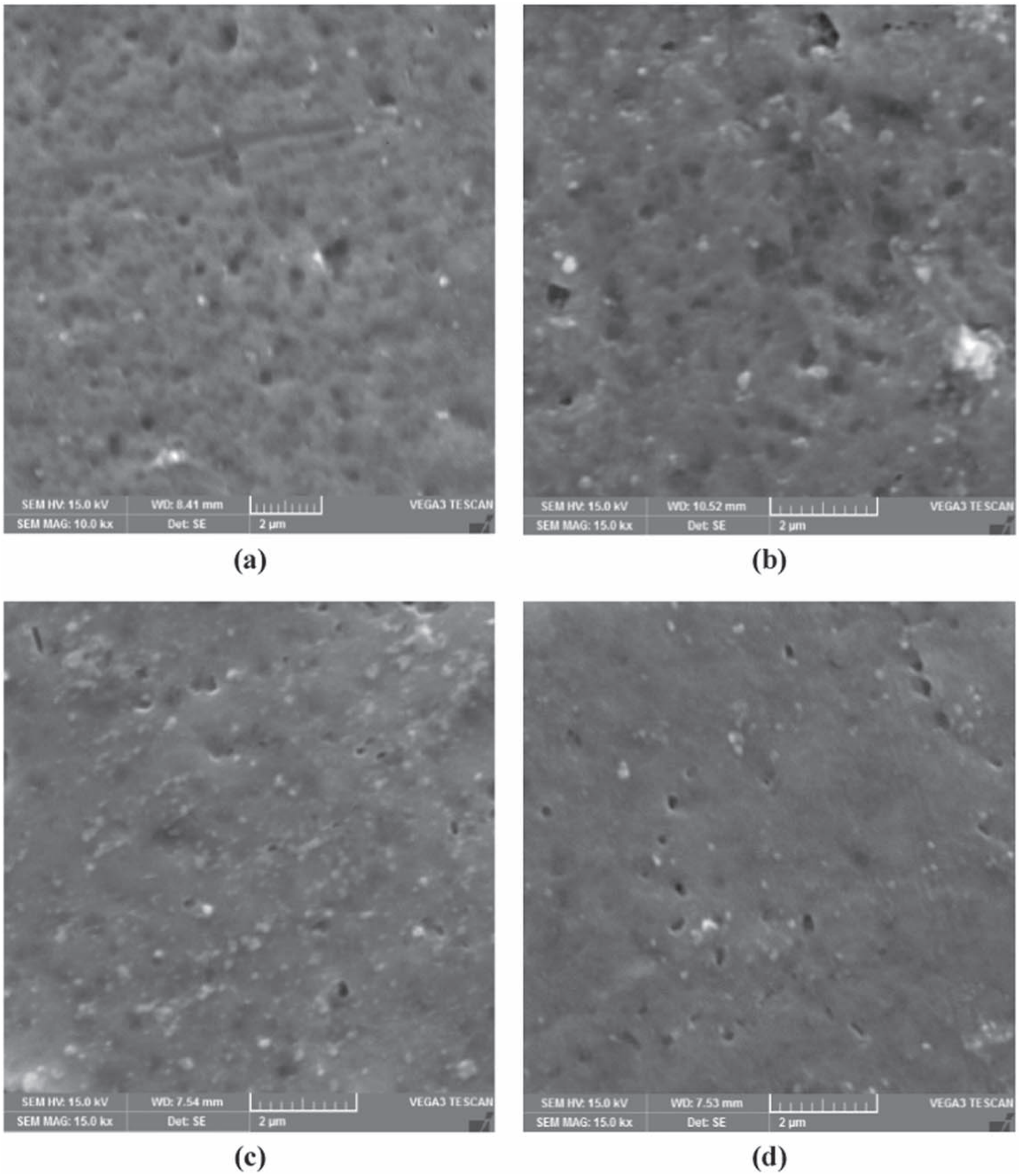

Figure 1. SEM images of AA7150-hBN nano particulates filled MMC with (a) 0.5 wt% hBN (b) 1.0 wt% hBN (c) 1.5 wt% hBN and (d) 2.0 wt% hBN.

measured values are calculated by equation (1) to get the size of grain. The calculated results for AA7150 (76 μm) and 0.5%-2% nanocomposites are 53 μm, 33 μm, 17 μm, 26 μm respectively.

$$AGS = \frac{\text{Length of line}}{\text{Number of grains}} \quad (1)$$

From the results, the finer grain size was confirmed in 1.5 wt% hBN nanocomposite matrix when compared to their counter parts and exhibits superior mechanical properties. The corresponding results are shown in figure 3 for better understanding.

The wear test was carried out for various compositions and worn out test specimen surfaces were analyzed with SEM photographs for base material, 1.5 wt% and 2.0 wt% hBN reinforced nanocomposites at 40 N load, as shown in figure 4. Visual observation of images confirm that the wear mechanism was the abrasive type and it is a function of load at constant Sliding Distance (SD) (3000 m). It was also observed that the wear height loss of the matrix alloy and composites increased with an increase in applied load due to frictional temperature of the

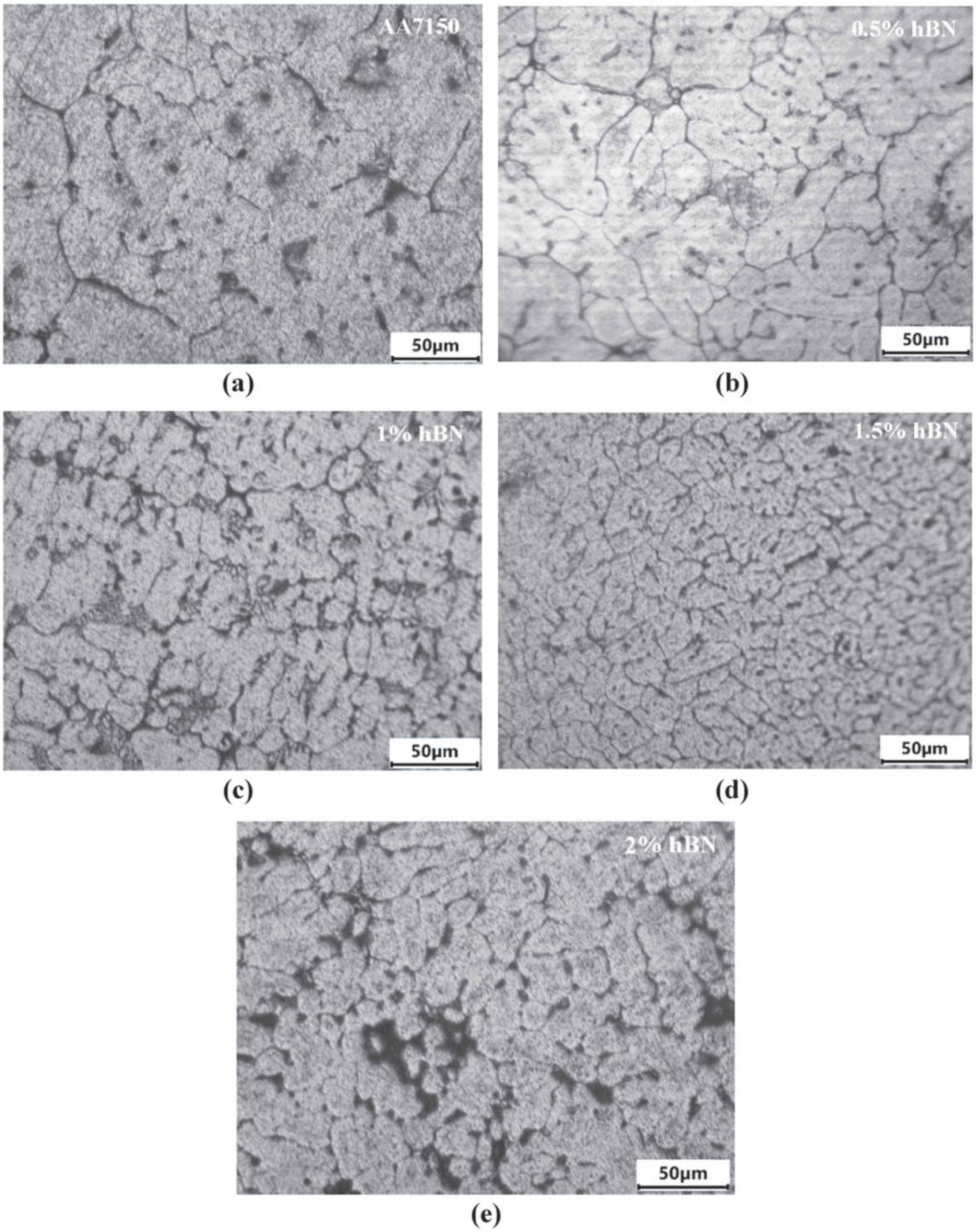

Figure 2. Optical microstructures of (a) AA7150 and composites with (b) 0.5 wt% hBN (c) 1.0 wt% hBN (d) 1.5 wt% hBN (e) 2.0 wt% hBN.

material softening at the couple surface which in turn leads to increase in wear loss [17]. However, increasing wt% of hBN tends to decrease the wear loss because of solid-lubricating property and its slips over a speed [18]. Furthermore, the coefficient of friction increased by increasing load due to grain size improvement at higher frictional temperatures [19], while it decreased with increasing wt% [20]. Similarly, the temperature increased with increasing SD, load because of friction and decreased with increasing of wt%, due to hBN solid lubricant property [11, 12]. The corresponding results for influence of load on wear, coefficient of friction and temperature at 1.5 wt% hBN with constant sliding distance (3000 m) as well as sliding speed (2 m s^{-1}) as shown in table 3.

The wear resistance of AA7150- hBN nanocomposites was observed to be better with increase in hBN content as compared to base material. This can be attributed to the following reasons. The hardness of the nanocomposites enhances with the content of hBN percentage up to 1.5 wt% and it leads to reduction of

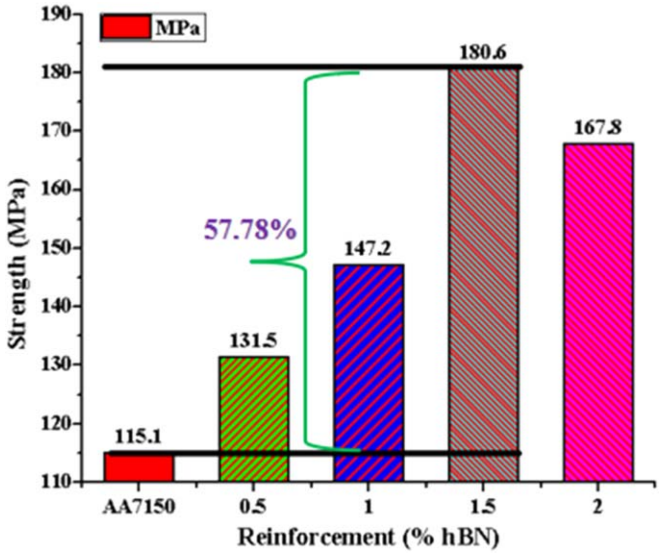

Figure 3. Reinforcement (wt% hBN) versus Strength.

wear loss of the nanocomposite material as well as the grain size. Increasing reinforcement particle beyond this threshold leads to increased formation of clusters, agglomeration and void like defects [21]. This can be observed in figures 1 and 2. The wear studies were examined by varying applied loads and reinforcement content. The SEM photographs for the wear surfaces of base material, AA7150-1.5% hBN nanocomposite (optimal properties) and AA7150-2.0% hBN nanocomposites (cluster/agglomerations) at higher load were represented in figure 4. It was noticed that the wear debris and delamination of the AA7150 and its hBN reinforced nanocomposites increased with the increase in hBN wt% [22, 23] on wear surface were identified.

Figures 5(a)–(c) shows the SEM photographs of tensile fractured surfaces at 200-micron scale for base AA7150 alloy, AA7150-1.5 wt% hBN and AA7150-2.0 wt% hBN reinforced nanocomposites and also enlarged at 20-micron scale to analyze the fractured surfaces. Figure 5(a) shows a lot of grape-liked dendrites, micro-cracks, micro-voids and the enlarged image attributes of the grain to grain detachment; it also shows the nature of fracture as mixed kind of fracture. Figure 5(b) shows the image of AA7150-1.5 wt% hBN reinforced nanocomposite which results in superior properties, with fewer voids, cracks, facets and grape-liked dendrites. The enlarged scale shows the facets, step-wise dendrites and its attributes in B-N strong bonding between adjacent layers of crystal structure, which elevate the surface energy as well as interface friction required to detach. Figure 5(c) shows AA7150-2.0 wt% hBN reinforced nanocomposites SEM image with larger cracks and voids as compared with other two, which may be attributed to the reduction in strength and other properties.

4. Conclusions

AA7150-hBN nanocomposite has been fabricated successfully through ultrasonic assisted double stir cast technique. The microstructure of monolithic, hBN reinforced nanocomposites were investigated through SEM and OM and the following conclusions were made.

- The OM studies state that the finer grains were observed in a composites containing 1.5 wt% hBN (17 μm) as per grain refinement theory.
- The SEM studies confirmed that the particle distribution at 1.5 wt% hBN nanocomposites is uniform when compared to the other nanocomposites considered in the present study.
- The worn out surfaces of SEM images indicates that 1.5 wt% hBN has low debris and less delamination due to higher hardness of the nanocomposites and this leads to higher resistance to the wear.

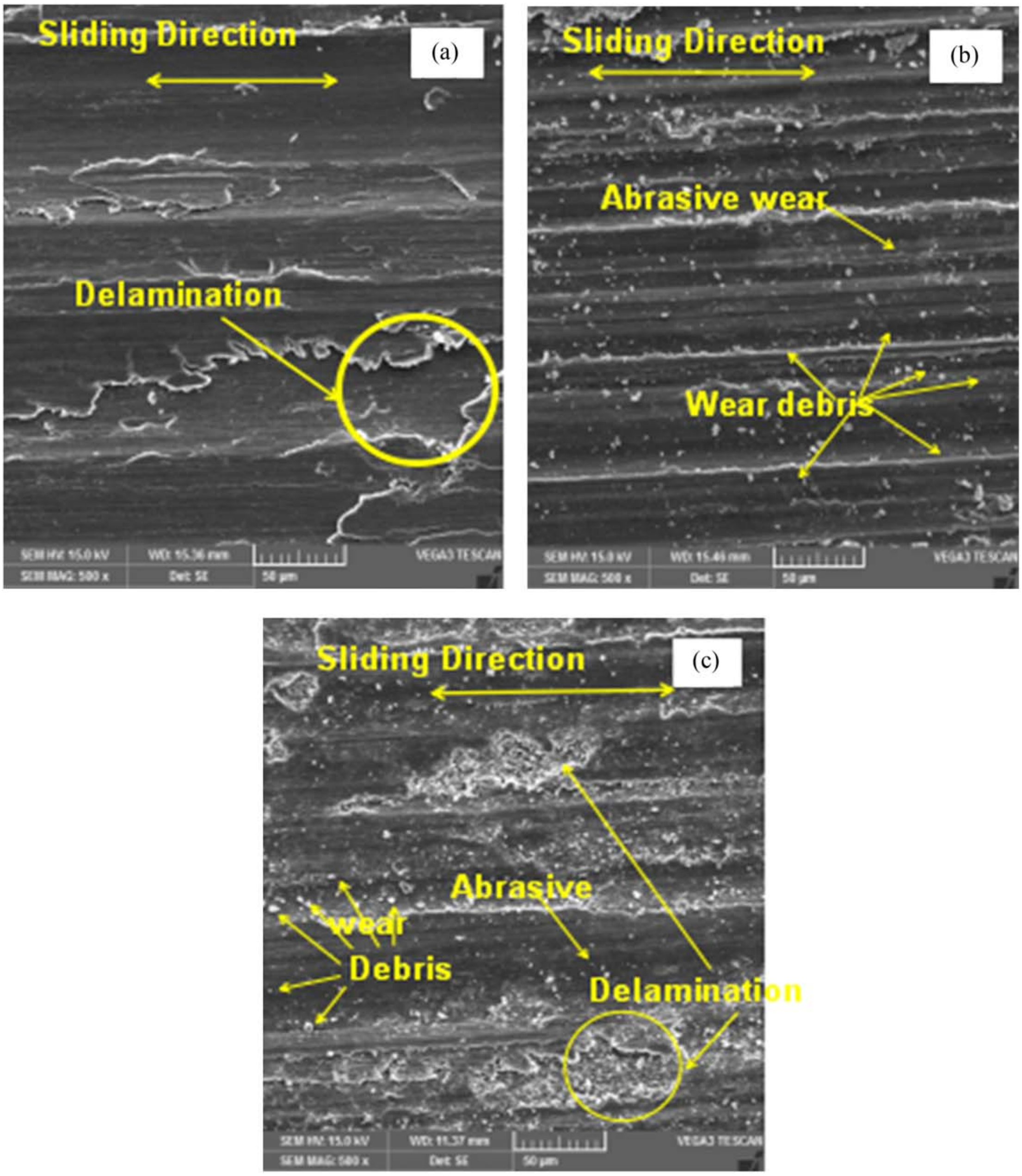

Figure 4. SEM Images of (a) AA7150 Alloy (b) 1.5 wt% hBN (c) 2.0 wt% hBN at 40 N load.

Table 3. Influence of applied load on wear, coefficient of friction and temperature at 1.5 wt% hBN.

S. No.	Applied Load (N)	Wear (μ)	Avg. COF	Temperature (C^o)
1	10	57	0.445208	40
2	20	87	0.461823	44
3	30	99	0.487902	47
4	40	130	0.496464	51

- The SEM photographs of UTS test fractured surfaces imply that the increase of reinforcement particles beyond threshold i.e., 1.5 wt% hBN leads to increased formation of clusters, agglomeration, cracks and void like defects.

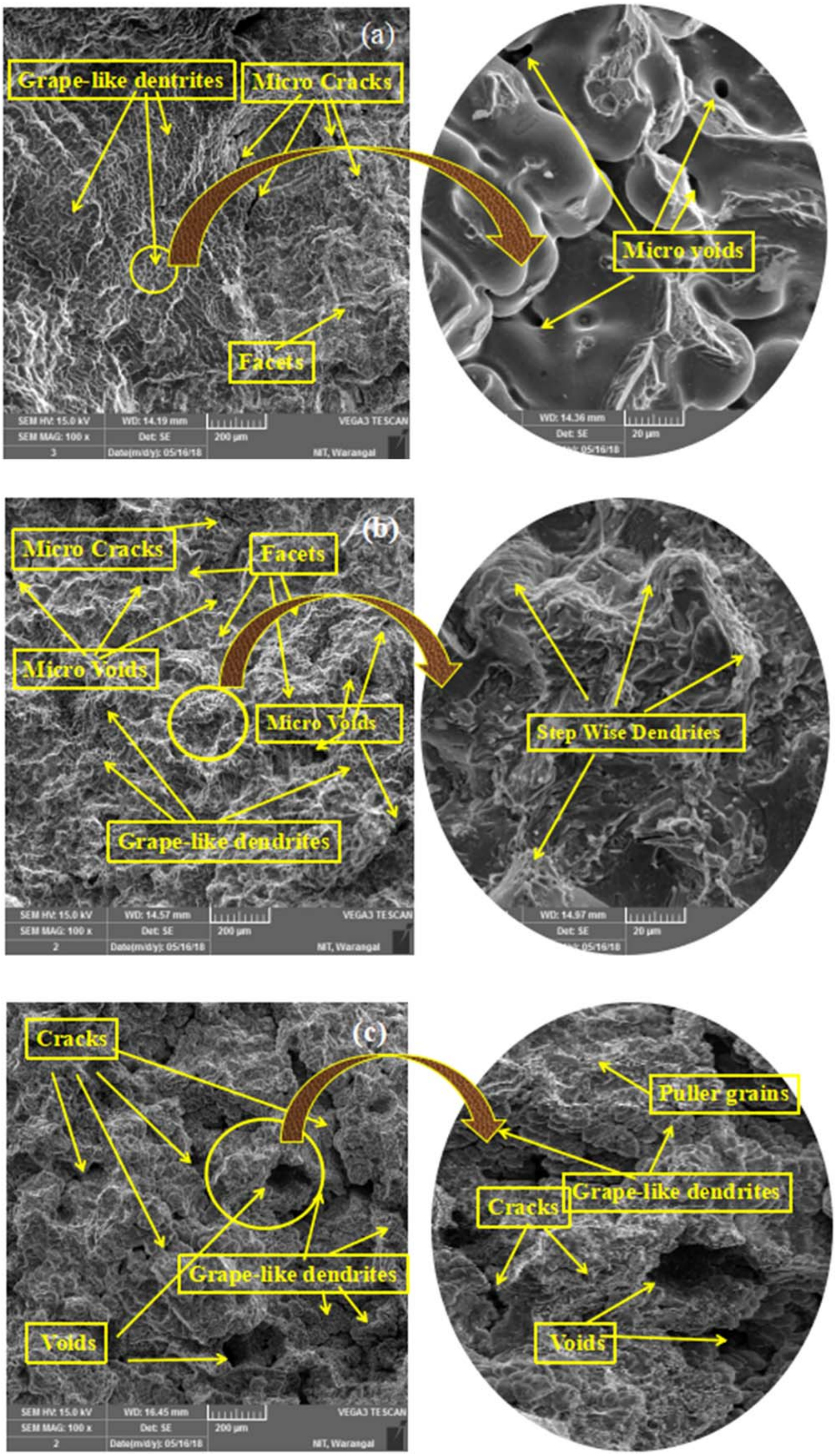

Figure 5. SEM image of fracture surface (a) AA7150 (b) AA7150-1.5 wt% hBN (c) AA7150-2.0 wt% hBN.

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