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Effects of Nano B4C Addition on the Solidification Behavior of Al-2219 Alloy Composites

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Abstract

The inclusion of nano B4C particulates in Al-2219-Nano B4C alloy was investigated to understand their impact on hardness and wear characteristics. 500 nm-sized nano B4C particulates are used as reinforcements for structures in the Al2219 alloy matrix. The nanocomposites were fabricated using the two-stage liquid stir melt method with varying weight percentages (2, 4, 6, and 8 wt. %) of Nano B4C in the Al-2219 alloy matrix. Renewable energy dispersive spectroscopy (EDS) and a scanning electron microscope (SEM) were used for analyzing the specimens' microstructure. Hardness and wear strength were assessed in accordance with ASTM standards. The even distribution of nano B4C particles in the Al-2219 alloy was confirmed by SEM images and confirmed by EDS analysis. Moreover, the base Al-2219 alloy's the toughness and wear vitality were enhanced by the addition of nano B4C particles.

Keywords: Al-2219 alloy matrix, scanning electron microscope, energy dispersive spectroscope, nano B4C particles, liquid stir melt method, hardness, wear strength

INTRODUCTION

To maintain a competitive edge in the current market, there is a constant need for product designs that are both lightweight and cost-effective. One practical solution to meet this demand is through the synthesis of composite materials, which offer enhanced material properties. In terms of metallic materials, aluminium alloy is the preferred choice for research and development due to its low density, easy accessibility and production, as well as its ability to form strong bonds with reinforcements [1]. Polymers are created through the incorporation of a variety of materials with varying physical characteristics for the matrix phase (like Al, Zn, Mg, Ti, etc.) and punishment phase (like SiC, B4C, TiC, Gr, Al203, etc.). Various ways of processing are used to combine these two ingredients to produce a novel material with enhanced mechanical and physical qualities [2-4]. a comparison of the matrix component, composites that were can be divided into three categories: metal matrix composites (MMCs), ceramic matrix that's composites, and organic matrix composite substances. Among these, aluminium metal matrix composites (AMMCs) reinforced with nanomaterials exhibit significantly enhanced mechanical properties. These include a favourable strength-to-weight ratio, improved specific modulus, excellent damping capacity, stiffness, and enhanced wear resistance. Over the past two to three decades, AMMCs have emerged as a significant advancement in materials and found widespread use in various engineering applications such as aeronautics, automotive, naval, and civil structures [5, 6]. Reinforcement materials can be classified into four groups based on their shape and size: (i) continuous fibers, (ii) nano-size-reinforced, (iii) short fibers, and (iv) whiskers and particulates. Because of their isotropic in shape qualities and affordability, particulate-reinforced matrix composites (MMCs) with nanoscale reinforcements are especially appealing [7, 8]. Particulate-reinforced aluminum MMCs can be made using a variety of methods, such as liquid phases being

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processed, semi-solid Production and and powdered metal fabrication.. Among these liquid-stage processing techniques, stir casting is preferred due to its numerous advantages, such as simplicity, cost-effectiveness, flexibility, and suitability for mass production [9]. One of the key challenges in the process is to achieve sufficient wetting of the dispersed nanoparticles by the liquid matrix and ensure a uniform and homogeneous distribution throughout the composite. Unsuitable casting technologies can lead to internal imperfections such as porosity molecules of particles, oxide inclusions, and interfacial reactions. The successful casting of aluminium metal matrix composites (AMMCs) has been reported by only a few researchers, highlighting the difficulties involved.

In this particular study, the Al-2219 alloy is reinforced with nano B4C particulates using a liquid stir metallurgy technique with a two-step stirring process. This approach uses regulated variables like steady feed rate, agitation speed, and the temperature of the room cooling and is known to be very successful for a number of programs. These parameters are optimized to achieve better interface bonding and an even distribution of nanoparticles within the composite. This hypothetical study's main goal is to evaluate the hardness and tribological characteristics of the resultant AMMCs, which are made by mixing hard nanoceramic the particles with the metallic aluminum alloy.

MATERIAL USED

Aluminium

For the current experimental study, the matrix phase is based on an aluminium-copper (Al-Cu) composition combination, specifically using the aluminium alloy Al-2219. After silicon and oxygen, metallic is the third most common element in the uppermost layer of the Earth. Al-2219 is characterized by its low density of 2.8 g/cm3 compared to other aluminium composites. It offers a favourable combination of strength, high corrosion resistance, excellent ductility, and good machinability and weldability. Table 1 provides the chemical composition of Al-2219 as determined through Spectro analysis.

Table 1. Shows the Chemical Composition of Al2219 Alloy by wt%.

Al	Cu	Fe	Mg	Mn	SiC	Ti	V	Zn	Zr	Others
Bal	6.8	0.3	0.02	0.4	0.2	0.10	0.10	0.1	0.20	0.15

Nano B4C

Among the most resistant materials that are readily accessible are nano-sized bore carbide (B4C) particulate matter. They possess high purity, a narrow particle size distribution, and a large specific surface area while having a low density of 2.52 g/cm3. B4C has an impressive melting point of up to 2350˚C and a boiling point exceeding 3500˚C. It exhibits exceptional hardness, measuring up to 2800 BHN (Brinell Hardness Number), and flexural strength of ≥ 400 MPa. B4C also offers excellent oxidation resistance, high-temperature resistance, exceptional strength, efficient granulation, high modulus of elasticity, outstanding wear resistance, and self-lubricating properties. Additionally, it possesses a significant thermal neutron capture cross-section, excellent neutron absorption capabilities, and remarkable anti-radiation performance.

EXPERIMENTAL PROCEDURE

Liquid metallurgy stir-casting is the first step in the preparation of nano-reinforced metallic matrix composites (MMCs). The rationale behind selecting this particular method is its capacity to produce a nanotechnology with enhanced durability and a strong interfacial bonding (wetting) between the liquid structure and the nano support phase. In this particular study, the matrix alloy, Al-2219, is placed in a graphite crucible within an electric furnace capable of reaching a maximum temperature of 1300˚C. An elevated temperature of 750˚C melts the entire matrix that is alloy. To eliminate unwanted slag content and volatile gases, a degassing tablet known as solid hexachloroethane is added to the molten melt. To guarantee a strong bond using the matrix's solid phase, the nano B4C particles are preheated to 600˚C before being added to the currently molten state matrix [10]. Mechanical equipment, such as the zirconium-coated stirrer and the mould, is preheated at temperatures between 350-400˚C to remove any moisture. Next, at a consistent feed rate, 2% weight fraction of nanoparticles are added to the resulting melt, and vigorous mixing is continued for about ten hours at a speed of 400 rpm.

Subsequently, the complete molten evaporate was transferred into the heated mold cavity and permitted to cool down to ambient temperature. Likewise, the identical procedure was carried out again for different percentages of body weight (4, 6, & 8%).

TESTING

Hardness

The Brinell hardness test, conducted according to ASTM E-10 standard, is employed to assess the hardness of Al-2219-Nano B4C alloy composite specimens. For this purpose, samples with a diameter of 12 mm and thickness of 5 mm are prepared from the as-cast conditions and their surfaces are polished. During the Brinell hardness test, a load of 500 kgf is applied to the Nano aluminium alloy specimen. The indenter used in this test is a hardened-steel round ball with a diameter of 10 mm.

Wear

The dry sliding wear characteristics of the composite material are examined using a pin-on-disc model (Model: TR-201CL, made by Ducom in Karnataka, India) in accordance with ASTM G99-95 standards. The wear specimen, in the form of a pin, is machined from the as-cast samples and has dimensions of 8 mm in diameter and 25 mm in height. The weight of the specimen is accurately measured using a digital microbalance weighing machine with a precision of 0.1 mg, and the initial weight of the model is recorded. In the examination, as shown in Figure 1, the pin is pressed up against a rotating disc of 65 HRC hard EN32 steel. The specimen is removed and weighed to calculate the decreased weight due to wear having going through a predetermined slide.. The difference between the weight measured before and after the test provides the sliding wear of the nanocomposite specimen, from which the volume and weight loss can be calculated.

Figure 1. Pin on Disc.

RESULTS AND DISCUSSIONS

Microstructural Studies

Microscopic studies were conducted to characterize the prepared composites. Cutting from the center of the casting produced specimens with a diameter of 12 mm and a thickness of 5 mm for use in SEM/EDAX microanalysis investigations.

The Al-2219 composite, cast with 8% weight percentage of nano B4C particulate composites, is depicted in the SEM microphotographs in Figure 2(a-e). The B4C particles are distributed uniformly, there is little agglomeration, and the porosity and particle isolation are well-executed. Figure b demonstrates the homogeneous dispersion of nano B4C particles within the Al-2219 composite matrix, indicating the absence of particle clustering. Notably, there is no evidence of defects commonly associated with flawed castings, such as porosity, shrinkages, slag incorporation, or cracks. The wetting effect between the particles and the liquid Al-2219 alloy matrix impeded the clustering of nano B4C particles. Consequently, the particles can remain suspended in the melt for an extended period, facilitating their uniform dispersion.

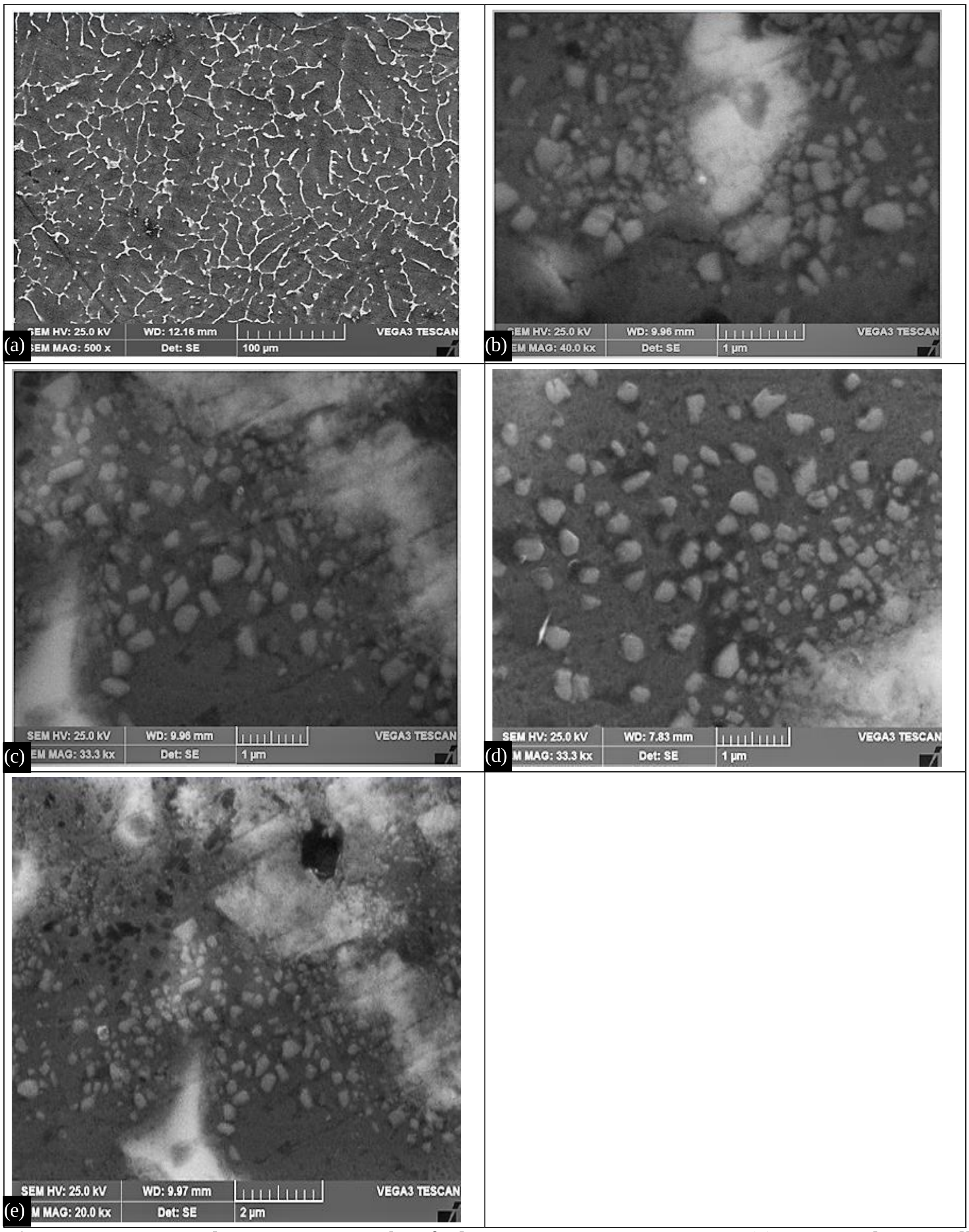

Figure 2. Scanning Electron Micrographs of Al-2219 nano B_4C composites, (a) As cast Al-2219 Alloy, (b) Al-2219-2%B_4C, (c) Al-2219-4% B4C, (d) Al-2219-6% B4C

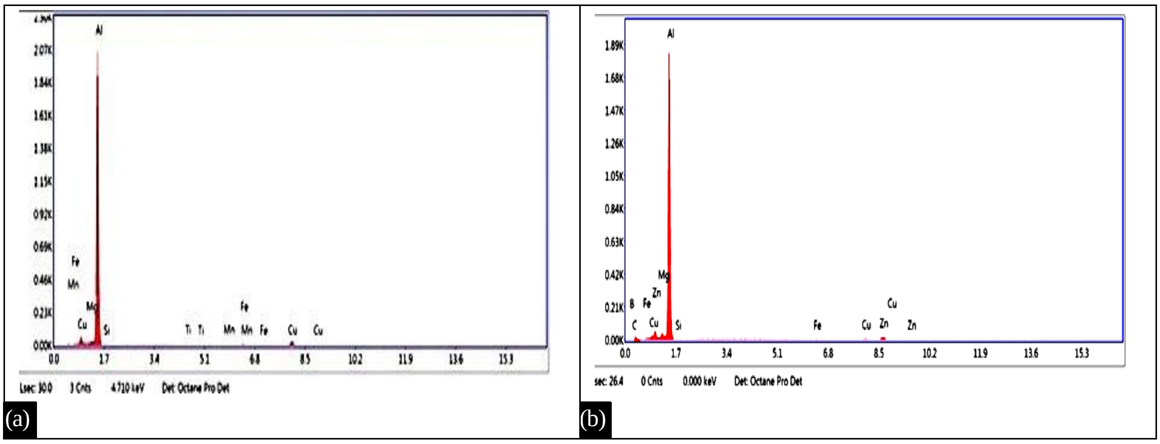

Figure 3. EDS spectrum of (a) Al2219 Alloy and (b) Al2219-8%nano B_4C composites

Figure 3 shows and reveals the chemical composition of Al-2219 alloy without adding reinforcement. Figure 3b indicates the presence of nano B4C particles in the aluminium matrix in the form of Boron (B) and Carbon (C).

HARDNESS MEASUREMENTS

Figure 4 demonstrates the changes in the hardness of Al-2219 alloy when incorporating 2, 4, 6, and 8 wt. % nano B4C particulate reinforcements. The inclusion of these nano reinforcements in the Al-2219 matrix leads to an enlargement of the surface area of the reinforcement particles and a reduction in the grain sizes of the matrix. Consequently, the presence of these tough nano B4C materials results in enhanced resistance to plastic deformation, ultimately elevating the hardness of the nanocomposites.

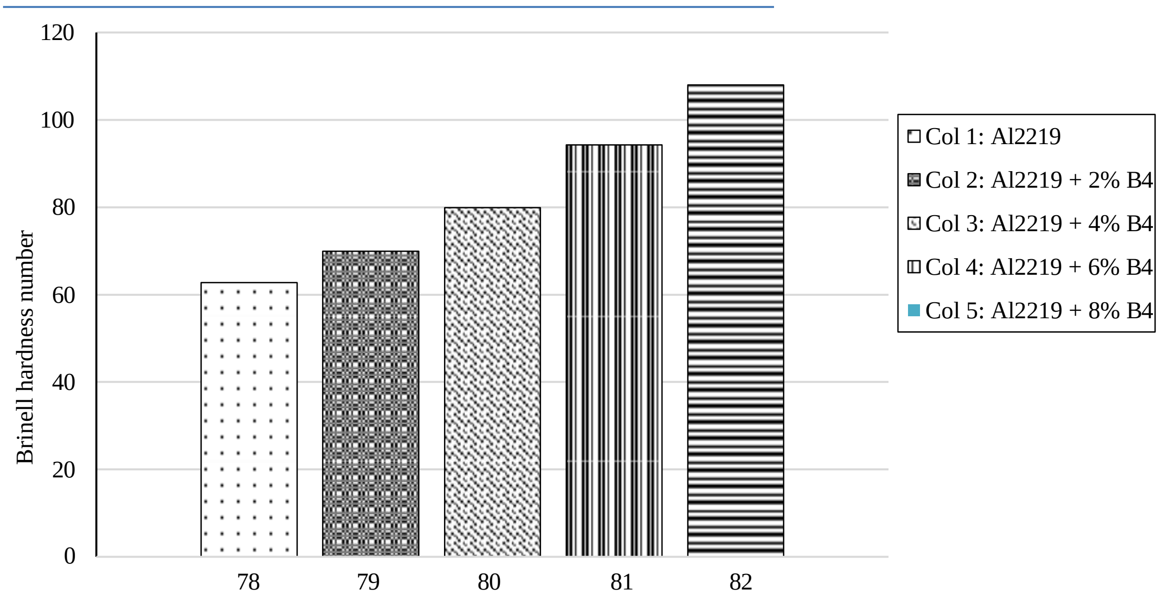

Figure 4. Shows the variation in Hardness of Al-2219 alloy and nanocomposites.

WEAR STRENGTH

The wear test outcomes for both the as-cast Al-2219 alloy and the nano B4C composites are displayed in Figures 5 and 6. The graphs illustrate that the wear resistance of the Al-2219 alloy is significantly improved by incorporating nano B4C particles, particularly as the weight percentage increases from 2 to 8 wt.%. This enhancement in wear strength can be attributed to the high hardness of the ceramic particles present in the Al-2219-B4C composites. Typically, these particles possess exceptional hardness and exhibit substantial strength even after wear [11, 12].

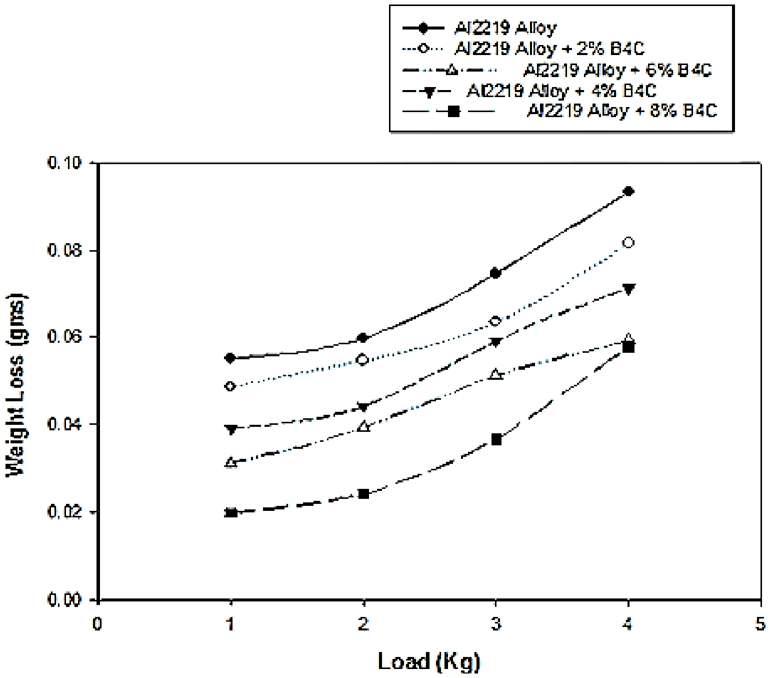

Figure 5. Shows the Weight Loss of Al-2219 alloy and nanocomposites with varying load and Constant Speed.

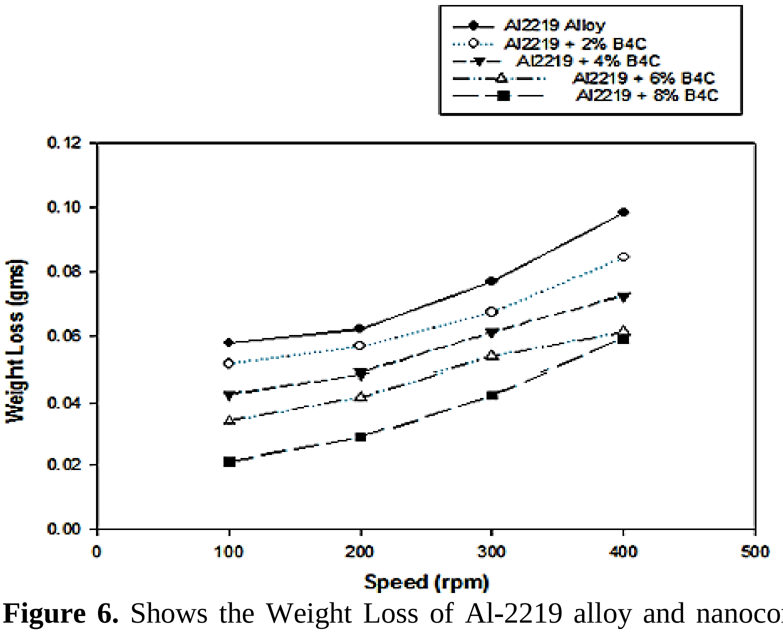

Figure 6. Shows the Weight Loss of Al-2219 alloy and nanocomposites with Varying Speeds and Constant Load

Figure 6 illustrates the weight losses observed in Al-2219 under both as-cast conditions and when reinforced with 2 to 8 wt. % B4C. The dry sliding wear test results indicate that adding B4C reinforcements enhances the alloy's wear resistance. This improvement in wear resistance is particularly noticeable in the Nano Composites. The reduction in wear can be attributed to forming a stable B4C layer on the worn surface.

WEAR DEBRIS AND WORN SURFACES

Scanning electron microscopy (SEM) was used to examine the the specimens' worn surfaces following the examination for wear. Analysis of the morphology of the worn surfaces reveals that the debris generated from the Nanocomposite specimen is characterized by a fine and smooth texture. In contrast, the worn surfaces of the Nanocomposites (as depicted in Figure 7) exhibit deeper and wider grooves and craters, accompanied by coarse and rough debris.

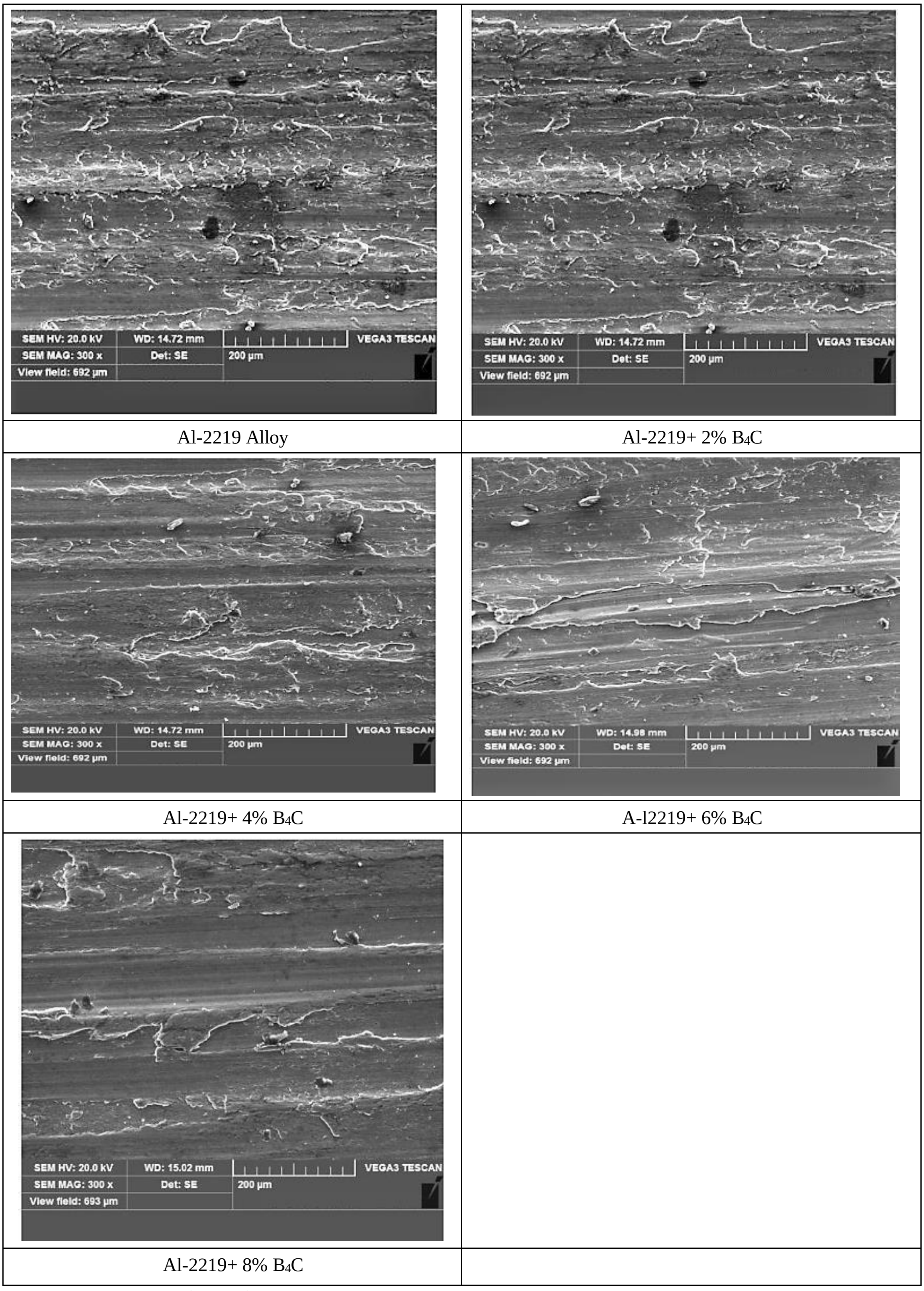

Figure 7. Worn surface of Al-2219 Nano Composites.

CONCLUSION

The stir casting method was employed to fabricate nano B4C/Al2219 composites with varying weight percentages of 2, 4, 6, and 8 as reinforcement. We looked at the samples' the level of hardness resistance to wearing, and structure. The matrix exhibited minimal porosity and displayed a uniform dispersion of nanoparticles, as observed in SEM microphotographs. The existence of nano B4C particles within the Al alloy matrix was verified by EDS evaluations. The abrasive action occurred along the sliding direction, but the wear debris from the nanocomposites was finer and smoother than conventional composites. The composites became harder after the nano B4C particles were added. Furthermore, the wear properties of Al2219-nano B4C composites surpassed those of the unreinforced material.

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