FOUNDRY METALLURGY OF TUNGSTEN CARBIDE AND ALUMINIUM SILICATE PARTICULATE REINFORCED LM6 ALLOY HYBRID COMPOSITES

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ABSTRACT

Hybrid composites are advanced composite materials in which a combination of two or more second phase particulates or fibers are reinforced in a base matrix. In this research paper, liquid metallurgical processing of a new hybrid composite material containing tungsten carbide particulate and aluminium silicate particulate combined at different weight fraction percentage is discussed. Manufacturing of such combined tungsten carbide particulate and aluminium silicate particulate reinforced aluminium-11.8% silicon alloy matrix composites by metal casting technology has some advantages of processing the composites by near net shape techniques. Turbulence generated by the liquid metallurgical vortex mixing technique is the easiest technique for processing these hybrid composites. Aluminium-11.8% silicon alloy hybrid particulate, combined tungsten carbide and aluminium silicate reinforced composites is related to their higher strength, lightweight, hardness, higher temperature resistance and wear resistance than that of any conventional monolithic materials. In this experimental work, aluminum-silicon alloy composites containing tungsten carbide and aluminium silicate combined particulate combination of 2.5%, 5.0%, 7.5% and 10.0% on weight fraction basis are produced by using the liquid stirring method. The size of the tungsten carbide particulate is 47.30 micron supplied by Aldrich, USA and the size of the aluminium silicate particulate is equal to 157.10 micron supplied by Fluka, USA. This paper discusses the vortex stirring process to produce these hybrid composite castings. These are processed in the form of slab containing 2.5%, 5%, 7.5% and 10% weight fraction of the two combination of particulate equally reinforced in LM6 alloy. A grey cast iron metallic mold is used to pour the hybrid composite slurry mixture. Mechanical, electrical and thermal properties are determined and all these aspects are discussed in this paper. The microstructures of the processed hybrid composites are studied at different magnifications and photomicrographs are captured to identify the presence of the two different reinforced particulates and its distribution uniformity. Fracture surface analysis has been performed to study the failure mechanisms.

***KEYWORDS**: Liquid-stirring technique, Aluminium-11.8% silicon alloy, metallography, fracture surface, fractography.*

1.0 INTRODUCTION

Hybrid composites are usually used when a combination of properties of different types of particulates wants to be achieved, or when longitudinal as well as lateral mechanical performances are required [1]. Aluminium oxide and silicon carbide reinforced aluminum alloy matrix composites are applied in the automotive and aircraft industries as engine pistons and cylinder heads, where the tribological properties of these materials are considered important. Therefore, the development of aluminum matrix composites is receiving considerable emphasis in meeting the requirements of various industries. It has also reduced the thermal insulation requirements because of its lower thermal conductivity. Precision components in the missile guidance systems demands dimensional stability and the geometries of the components cannot change during usage [2].

2.0 LITERATURE REVIEW

Today's search is for composite materials with ever-higher service characteristics such as wear and heat resistance, high- temperature strength, antifriction, and cutting properties [3]. Different shapes of particulates are reinforced in the matrix alloy and they are characterized as acicular, irregular rod like, flake, dendritic, spherical, rounded, irregular, angular, sub angular, fibrous, granular, lamellar, nodular, crystalline and porous type. Particle shape has a major influence on processing characteristics [4, 5]. The shape is usually described in terms of the aspect ratio or shape factor [2].

Aspect ratio is the ratio of the largest dimension to the smallest dimension of the particle. This ratio ranges from unity, for a spherical particle to about 10 for flake like or needlelike particles. Shape factor or shape index of the particulate is a measure of the ratio of the surface area of the particle to its volume, normalized by reference to a spherical particle of equivalent volume [2]. The size distribution of particulates is an important consideration, because its affects the processing characteristics of the powder. Normally the fibers have a definite aspect ratio, which is defined by Length/Diameter ratio. Composite materials have found increasingly wider applications in aircraft, space vehicles, offshore structures, piping, electronic, automobiles, boats and sporting good.

On a weight adjusted basis, many aluminium and aluminium alloy based composite materials can outperform the conventional ferrous and non-ferrous materials like cast iron, steel, aluminum, magnesium and virtually any other reinforced metal or alloy in a wide variety of applications [3]. Hence, probably, metal matrix composites will replace the conventional materials in many commercial and industrial applications in the near future. Special interest on particulate-reinforced metal matrix composites is due to the several merits offered by them.

Researchers have reported that some composites exhibit a higher compressive strength than tensile strength due to the dominance of the presence of the reinforcement phase since the compressive strength of the reinforcement particulate is very high. In the processing of metal matrix composite, one of the subjects of interest is to choose a suitable matrix and a reinforcement material. It influences the mechanical properties, shear modulus and shear strength and its processing characteristics.

Reinforcement phase is the principal load-carrying member in a composite. Therefore, the orientation, of the reinforcement phase decides the properties of the composite. The reinforcing phase may be a particulate or a fiber, continuous type or discontinuous type. The size of the particulate is expressed in microns, micrometer. But the discontinuous fiber is defined by a term called as 'Aspect Ratio'. It is expressed as the ratio of length to the diameter of the fiber. To improve the wettabilty with the liquid alloy or metal matrix material, the reinforcement phase is always preheated [4].

The interface between the matrix and the reinforcement plays an important role for deciding and explaining the toughening mechanism in the metal matrix composites. The interface between the matrix and the reinforcement should be organized in such a way that the bond in between the interface and the matrix should not be either strong or weak. While the load is acting on the composite, it has been distributed to the matrix and the reinforcement phase through the matrix interface.

The reinforcement is effective in strengthening the matrix only if a strong interfacial bond exists between them [5]. The interfacial properties also influence the resistance to crack propagation in a composite and therefore its fracture toughness.

The two most important energy-absorbing failure mechanisms in a composite are debonding and particle pull out at the particle matrix interface [3]. If the interface between the matrix and reinforcement debonds, then the crack propagation is interrupted by the debonding process and instead of moving through the particle, the crack move along the particle surface allowing the particle to carry higher load. Particles can be spherical, disk-shaped, rod shaped, and plate shaped [5].

3.0 MATERIALS AND METHODS

In this work, hybrid composite slab castings of dimension 190 mm* 30mm*20mm and weighing approximately 302.10 grams are produced. The processed hybrid composite castings are subjected to various testing to assess its mechanical properties, hardness, impact resistance and microstructure. Then electrical and thermal properties are determined and metallographic analysis has been performed to study the tungsten carbide particulate and aluminium silicate particulate distribution uniformity. Besides, fracture surface analysis has been conducted to study the failure and interfacial reaction characteristics. Permanent grey cast iron metallic mold is used to pour 2.5%, 5%, 7.5% and 10% weight fraction of combined tungsten carbide particulate and aluminium silicate particulate reinforced LM6 alloy hybrid composite slurry mixture to make hybrid composite slab castings. The mold material used in this process is grey cast iron and it is reused to process more number of test castings. Testing for mechanical properties, thermal properties and electrical properties of the newly developed combined tungsten carbide particulate and aluminium silicate particulate reinforced aluminium-11.8percentage silicon alloy matrix hybrid composites has been performed by using standard equipments and hence data are generated. Electrical resistivity and electrical conductivity values of the processed hybrid composites are calculated by finding the resistance in between the hybrid composite slab casting material. An indigenously designed circuit is used to determine the resistance value and hence the electrical conductivity and resistivity values are determined. Thermal diffusivity of the processed hybrid composites are measured by photo flash method and hence thermal conductivity values are determined. Metallographic analysis has been performed with the aid of a metallurgical microscope to study the tungsten carbide and aluminium silicate particulates distribution uniformity and hence to characterize the phases present in the processed new type of hybrid composites. Lastly, fracture surface analysis has been conducted to study the failure of composites and interfacial reaction characteristics [6].

4.0 PROPERTIES DETERMINATIAON, MICROSTRUCTURAL CHARACTERIZATION, AND FRACTURE SURFACE STUDIES

Testing for mechanical properties, thermal properties and electrical properties of the newly developed combined tungsten carbide particulate and aluminium silicate particulate reinforced aluminium-11.8percentage silicon alloy matrix hybrid composites has been performed by using standard equipments and hence data are generated. Tensile specimens are carried out by using an Instron universal testing machine 8500 to determine the tensile properties of the material such as tensile strength, yield stress, fracture stress, Young's modulus, percentage of elongation, ductility, specific strength and specific stiffness. MITUTOYO ATK-600 MODEL hardness testing machine is used to determine the hardness values of the hybrid composites expressed in Rockwell Superficial scale with 15 N-S by applying a load of 100kg. In this innovative project, impact charpy values of the machined samples from the processed hybrid composite castings are determined from the reading taken in an impact testing machine. Electrical resistivity and electrical conductivity values of the processed hybrid composites are calculated by finding the resistance in between the hybrid composite slab casting material. An indigenously designed circuit is used to determine the resistance value and hence the electrical conductivity and resistivity values are determined. Thermal diffusivity of the processed hybrid composites are measured by photo flash method and hence thermal conductivity values are determined. Metallographic analysis has been performed with the aid of a metallurgical microscope to study the tungsten carbide and aluminium silicate particulates distribution uniformity and hence to characterize the phases present in the processed new type of hybrid composites. Lastly, fracture surface analysis has been conducted to study the failure of composites and interfacial reaction characteristics [6].

5.0 RESULTS AND DISCUSSIONS

Results and data are obtained from the tested samples taken from the combined tungsten carbide and aluminium silicate particulate reinforced LM6 alloy slab composite castings made in grey cast iron mold. The values are reported for the mechanical, thermal and electrical properties as well as the density, hardness, impact strength and microstructural features of the tungsten carbide and aluminium silicate particulate distribution for each weight fraction percentage addition to the LM6 alloy matrix. In this section, the above composites made in the grey cast iron are analyzed and the results are presented. It is found that the two combined tungsten carbide particulate and aluminium silicate particulate reinforced LM6 alloy matrix hybrid composite casting properties are superior to the LM6 alloy with and without grain refiner addition and no particulate reinforcement. In this innovative hybrid composite material development research work, the two combined particulates are reinforced in the alloy matrix are processed by liquid vortex metallurgical melt stirring technique. Microstructures of the processed hybrid composites based on the metallographic studies have confirmed the uniformity of tungsten carbide particulate and aluminium silicate particulate distribution in the aluminium-11.8% silicon alloy matrix. Sufficient amount of turbulence during the mixing of the particulates with the liquid alloy is necessary to get uniform particulate distribution during its solidification processing. The impeller blade type and its rotational speed have not shown any effect on the distribution uniformity. But, faster pouring of the hybrid composite slurry mixture into the grey cast iron mold immediately after the mixing by vortex method has played a significant role in the distribution of the particulates used in this project. A small amount of tungsten particulate segregation has been observed due to its higher density. But, due to combination with aluminium silicate particulate, the effect of segregation is protected. In this section, the above composites made in the grey cast iron are analyzed and the results are presented in the corresponding graphs that are shown in **Figure 1** to **Figure 7**.

5.1 Mechanical properties

The tensile strength, yield stress and fracture stress values of combined tungsten carbide and aluminium silicate particulate composites are determined. The tensile strength of 10% and 2.5% weight fraction of the above combined particulate composite is 89.16 MPa and 173.63 MPa respectively. From this, it is clear that the tensile strength value decreases with the increase on the weight fraction % of combined tungsten carbide and aluminium silicate in the alloy matrix. The tensile strength value decreased gradually when above combination of particulate weight fraction addition of LM6 alloy matrix is increased and it is shown in the graph as **Figure 1**.

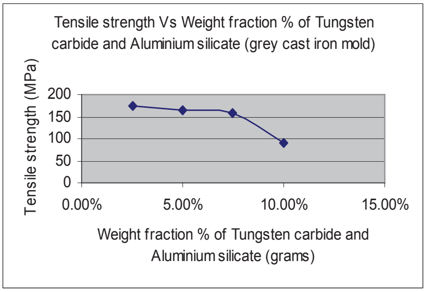

Figure 1 Tensile strength vs Weight fraction % of combined tungsten carbide and aluminium silicate

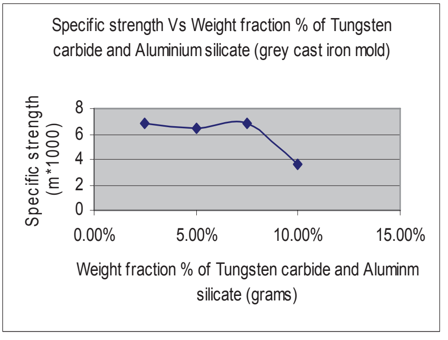

Figure 2 Specific strength vs Weight fraction percentage of combined tungsten carbide and aluminium silicate

From the graph shown in **Figure 2**, it is observed that the values of specific strength gradually increase with an increased addition of combined particulate up to the addition of 7.5% weight fraction, after which the values start decreasing. Therefore, it is understood that the optimum value of adding the combined particulate to the alloy matrix is 7.5% by weight fraction. Data on the hardness of combined particulate reinforced composites made in grey cast iron mold is analyzed. It is found that the hardness value increases gradually with the increased addition % by weight and it is shown below in the graph as **Figure 3**. The maximum hardness value based Rockwell superficial 15N-S scale is 67.13 for 10% weight fraction addition.

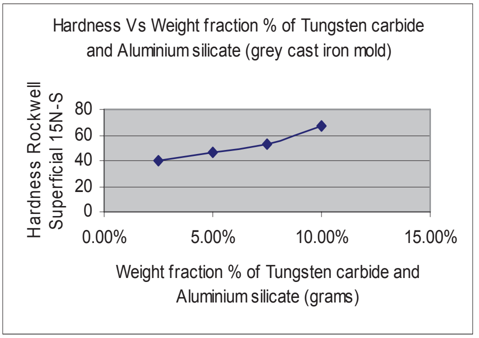

Figure 3 Hardness vs Weight fraction percentage of combined tungsten carbide and aluminium silicate

The density values of the combined particulate composite castings poured grey cast iron mold is observed from the data. Based on the plotted graph as shown in Figure 4, it is found that there is no remarkable variation or changes observed in the determined density values of the processed combined particulate hybrid composite casting from the grey cast iron mold.

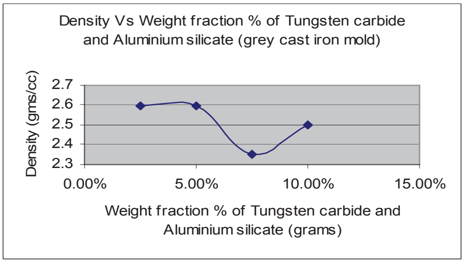

Figure 4 Density vs Weight fraction % of combined tungsten carbide and aluminium silicate

Impact strength values of the hybrid composite castings processed in grey cast iron mold is determined. From the analysis and plotted graphs, it is found that the impact strength values are gradually increasing up to a certain extent and then starts decreasing sharply, with the increasing addition of the two different particulates in the alloy matrix. Based on the plotted graph as shown in **Figure 5**, it is found that the optimum amount of tungsten carbide and aluminium silicate to be added is nearly 5 % weight fraction and further addition is not effective in the impact strength improvement due to the reinforcement. The optimum value of impact strength is 8.838 N-m for 5% weight fraction addition of combined particulate to the alloy matrix.

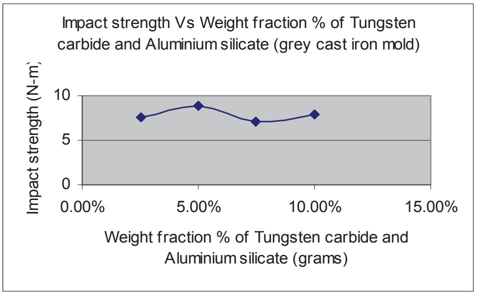

Figure 5 Impact strength vs Weight fraction % of combined tungsten carbide and aluminium silicate

5.2 Electrical properties

The processed hybrid composite castings made in grey cast iron metal mold are tested for electrical properties. Graph is plotted between the weight fraction % addition of combined particulate and electrical resistivity and it is shown in **Figure 6**. From the analysis, it is found that the electrical resistivities of the hybrid composites are decreased with the increased addition in the alloy matrix.

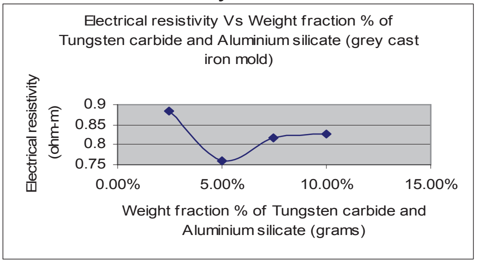

Figure 6 Electrical resistivity vs Weight fraction % of combined tungsten carbide and aluminium silicate

The average electrical resistivity value for 10 percentage weight fraction of combined particulate addition to the alloy matrix is 0.825765 ohm-m and the electrical conductivity value is 1.2124911/ (ohm-m).

5.3 Thermal properties

The processed combined hybrid composite castings made in grey cast iron mold are tested for thermal properties. Graph is plotted for the weight fraction % addition of combined tungsten carbide and aluminium silicate particulate between thermal conductivity values. From the analysis, it is found that the thermal conductivity of the combined composites is decreased with the increased addition of combined particulate in the alloy matrix. The data for thermal conductivity of grey cast iron mold is analyzed and this is illustrated in the plotted graph as shown in **Figure 7**.The thermal conductivity values for 10% weight fraction addition is 21.035 W/ m K respectively.

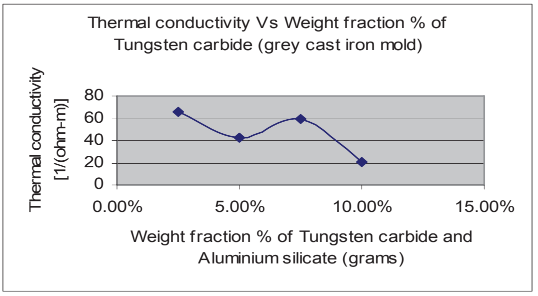

Figure 7 Thermal conductivity vs Weight fraction percentage of combined tungsten carbide and aluminium silicate

5.4 Metallography of combined tungsten carbide and aluminium silicate particulate Reinforced aluminium-11.8% silicon alloy hybrid composites

Microstructural observation at different magnifications of the processed combined tungsten carbide and aluminium silicate particulate reinforced LM6 alloy composite test specimens made in grey cast iron mold are analyzed by a metallurgical microscope and hence it is employed to obtain some qualitative evidences on the combined tungsten carbide and aluminium silicate particulate distribution in the alloy matrix and bonding quality between the two particulates and the matrix. Metallographic samples of the combined composites are prepared under the standard procedures and HF, Hydrofluoric acid is used as an etchant to reveal the phases present in the LM6 alloy matrix. The samples are viewed at different magnifications such as at 50x, and 100x and photomicrographs are captured to predict the confirmation of the presence of the two particulates in the alloy matrix. Then, it is further studied to identify the particulate distribution. From the in-depth research on this, it is confirmed the presence and distribution of embedded two particulates in the matrix is uniform. The alloy matrix grains are finer and the bonding between particulate surface and the matrix material is satisfactory. It is found that, the morphological distribution of combined particulate for every weight fraction % addition increases. No interfacial reaction products are observed superficially. From this analysis, it is confirmed that the two different particulates reinforced LM6 alloy hybrid composite casting properties are superior to the LM6 alloy with and without grain refiner addition and no particulate reinforcement. In this section, a number of captured photomicrographs are shown in the **Figure 8 to Figure 10** for better understanding.

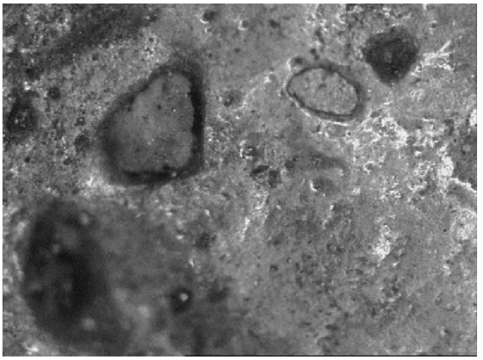

Figure 8 2.5 % Tungsten carbide and aluminium silicate mixed particulate hybrid composite magnified at 50x

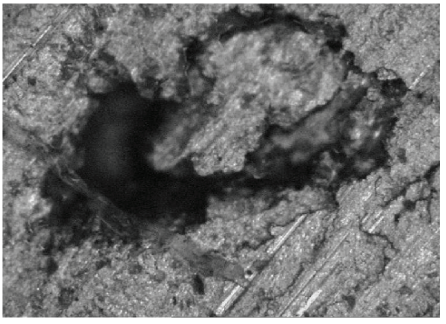

Figure 9 5 % Tungsten carbide and aluminium silicate mixed particulate hybrid composite magnified at 50x

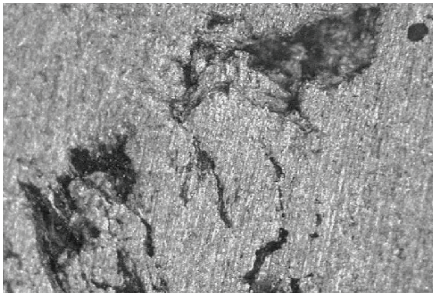

Figure10 10 % Tungsten carbide and aluminium silicate mixed particulate hybrid composite magnified at 50 x

5.5 Fracture surface analysis and interfacial bonding characterization by SEM

Investigation of hybrid composite test samples is performed by using the LEO VARIABLE PRESSURE SEM 1455 VP Series. By using it, the fractures surfaces of the tensile tested samples are observed at higher magnifications to characterize the failure. Then, studies on the interphase and bonding are performed to observe the formation of interfacial reaction products and to predict the type of bonding between the particulate surface and the matrix surface. This research consists of two parts.

1. Fracture surface analysis of tensile tested composite samples by SEM.

2. Interphase studies and bonding characteristics between the particulate surface and the matrix by SEM.

5.5.1 Fracture surface analysis of tensile tested composite samples by SEM

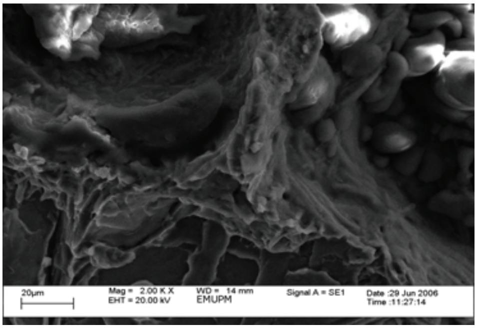

Figure 11 Tensile fracture surface of 2.5% weight fraction of combined tungsten carbide and aluminium silicate particulate reinforced hybrid composite magnified at 2000 x

Figure 11 shows the fractograph of the tensile fracture surface of 2.5% weight fraction of combined tungsten carbide and aluminium silicate particulate hybrid composite magnified at 2000x by SEM. The fracture is of brittle type and the particle is pulled out due to poor debonding. A cluster of aluminium silicate particulates are seen in the top right side of the fractograph. A few silicon needles with undeformed condition are also visible. Cleavage of the matrix is observed and the tungsten carbide particulate is covered by the silicon particles.

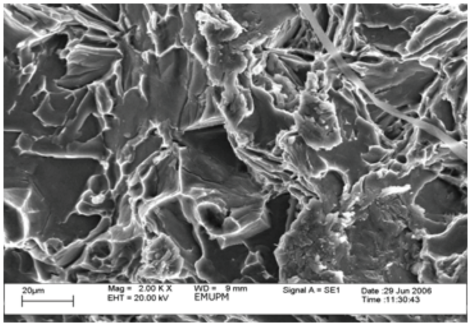

Figure 12 Tensile fracture surface of 5% weight fraction of combined tungsten carbide and aluminium silicate particulate reinforced hybrid composite magnified at 2000-x

The above **Figure 12** shows the fractograph of the fracture surface of 5% combined hybrid particulate composite and it is magnified at 2000x. It reveals the uniform distribution of the two particulates in the LM6 alloy matrix and the fracture has taken place along the interface region of the particulates. A very low deformation zone is seen in the fractograph.

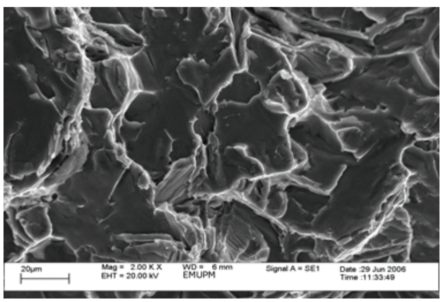

Figure 13 Tensile fracture surface of 10% weight fraction of combined tungsten carbide and aluminium silicate particulate reinforced hybrid composite magnified at 2000-x

The above **Figure 13** shows the fractograph, which reveals the fracture surface of a tensile tested 10% weight fraction of combined particulate hybrid composite. The uncracked long deformed silicon needles are observed. Transgranular type of fracture is observed and an interphase region is clearly visible from the fractograph.

5.5.2 Interphase studies and bonding characteristics between the particulate surface and the matrix by SEM

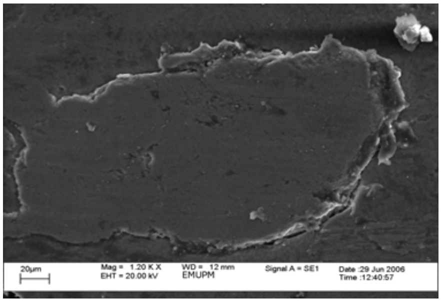

Figure 14 Interface and bonding in 2.5% weight fraction of combined tungsten carbide and aluminium silicate particulate reinforced composite magnified at 1200-x

The above displayed **Figure 14** shows the microstructure of 2.5% combined particulate hybrid composite magnified at 1200x. A small aluminium silicate particulate is visible at the top right side of the micrograph and a bigger tungsten carbide particulate is seen clearly and well embedded in the LM6 alloy matrix. The bonding between the tungsten carbide particulate is excellently seen in the micrograph and it is not surrounded by any interfacial reaction products.

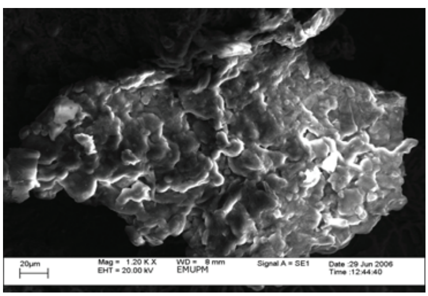

Figure 15 Interface and bonding in 5% weight fraction of combined tungsten carbide and aluminium silicate particulate reinforced composite magnified at 1200-x

The above **Figure 15** shows the microstructure of 5% weight fraction of combined particulate hybrid composite magnified at 1200x and it reveals the tungsten carbide particulate covered by the dissolute silicon particles from the matrix alloy.

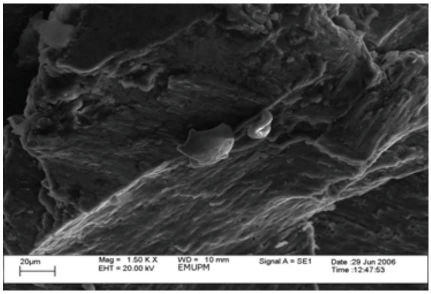

Figure 16 Interface and bonding in 10% weight fraction of combined tungsten carbide and aluminium silicate particulate reinforced composite magnified at 1500-x

The micrograph shown in **Figure 16** shows the microstructure of 10% weight fraction of combined tungsten carbide and aluminium silicate particulate hybrid composite. It reveals the presence of aluminium silicate particulates in the matrix material. A void is present at the center and it contains a cluster of particulates embedded on it.

6.0 CONCLUSION

It is concluded that the two combined tungsten carbide particulate and aluminium silicate particulate reinforced LM6 alloy matrix hybrid composite casting properties are superior to the LM6 alloy with and without grain refiner addition and no particulate reinforcement. In this innovative hybrid composite material development research work, the two combined particulates are reinforced in the alloy matrix are processed by liquid vortex metallurgical melt stirring technique. Microstructures of the processed hybrid composites based on the metallographic studies have confirmed the uniformity of tungsten carbide particulate and aluminium silicate particulate distribution in the aluminium-11.8% silicon alloy matrix. Sufficient amount of turbulence during the mixing of the particulates with the liquid alloy is necessary to get uniform particulate distribution during its solidification processing. The impeller blade type and its rotational speed have not shown any effect on the distribution uniformity. But, faster pouring of the hybrid composite slurry mixture into the grey cast iron mold immediately after the mixing by vortex method has played a significant role in the distribution of the particulates used in this project. A small amount of tungsten particulate segregation has been observed due to its higher density. But, due to combination with aluminium silicate particulate, the effect of segregation is protected and future research work on this mentioned problem can be continued by a metallurgical engineering researcher.

7.0 REFERENCES

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