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Microstructure Exploration of the Aluminum-Tungsten Carbide Composite with different Manufacturing circumstances

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Abstract*— In the last decade, as demand for high quality materials are increased, the development of lightweight aluminum (Al) also increased especially in aerospace and automotive industries. It has been well known that Al based metal matrix composites (MMCs) offers a very low thermal expansion coefficient, high specific strengths, wear and heat resistance as compared to conventional Al alloys. In order to combine all these properties, MMCs have become a very attractive method for various industrial applications. The interest in Tungsten Carbide (WC) as reinforcements for aluminum (Al) has been growing considerably. Efforts have been largely focused on investigating their contribution to the enhancement of the mechanical performance of the composites. The uniform dispersion of Tungsten Carbide in the Al matrix has been identified as being critical to the pursuit of enhanced properties. In this present research paper emphasis, the effect of Tungsten Carbide content on the Physical properties of the composites like SEM, XRD was investigated. The improvement of physical properties for composites of Al/WC has been compared with pure aluminum.

***Keywords*— MMC, SEM, Tungsten Carbide, XR.D.**

I. INTRODUCTION

It is necessary to have high machinery service life, operation reliability low friction in bearings bushes piston rings brake pads driving mechanisms friction clutches couplings gears and moving parts etc.The working condition of these parts differ in various aspects like sliding speeds loads environmental conditions andother parameters.No single metal can meet all the required property so it is necessary to develop a composite material that could have all combinational property satisfying all our engineering requirements. Metal matrix composite have enhanced mechanical properties than pure metal. Metal matrix composite are very attractive for automotive aerospace military and tribological. cemented tungsten carbide is one of the oldest and most successful powder metallurgy products which have its commercial applications in cutting tool industry[1].

Applications due to its high strength, stiffness, wear resistance, thermal conductivity and low density. Although liquid metallurgy is the least expensive technique for composite fabrications, it is difficult to use for synthesizing WC/Al composites due to the extreme gap difference in the thermal expansion coefficients between the two constituents and poor wet ability between molten Al (or Al alloys) and MC.In addition, liquid metallurgy may lead to an undesirable reaction between MC and molten Al, producing brittle phases of Al and MC.In powder metallurgy, composite powders are prepared at room temperature using Mechanical alloying method. The components prepared using this method have merits such as less residual voids, no dissolved gases in products, good interface bonding between inclusions and metal matrix, near-net shape of compacts**.**

A. Why Nano Composites

The Al-WC composites have very small grain size of particles and hence, they have good interface strength and ductility. Nano structured materials are often characterized by a particle size of 1–100*nm*. They have different properties and atomic structure compared to bulk materials.

B. Properties of Aluminum and Tungsten Carbide

Aluminum-matrix composites are not a single material but a family of materials whose stiffness, strength, density, thermal and electrical properties can be tailored. The matrix alloy, reinforcement material, volume and shape of the reinforcement, location of the reinforcement and fabrication method can all be varied to achieve required properties. The aim involved in designing metal matrix composite materials is to combine the desirable attributes of metals and ceramics. The addition of high strength, high modulus refractory particles to a ductile metal matrix produce a material whose mechanical properties are intermediate between the matrix alloy and the ceramic reinforcement. Metals have a useful combination of properties such as high strength, ductility and high temperature resistance, but sometimes have low stiffness, whereas ceramics are stiff and strong, though brittle.

Typical Physical/Mechanical Properties of Al
Density : 2600-2800kg/m^3
Melting Point : 600^{0}C
Elastic Modulus : 70-79GPA
Poisson’s Ratio : 0.33
Tensile Strength : 230-570MPa
Yield Strength : 215-505MPa
Percent Elongation : 10-25%

Henri Moissan (1852-1907),a noble laureate(1906),is best known as the inventor of the electric furnace and for his unsuccessful attempts to prepare artificial diamonds. it was in the laboratory in a school of pharmacy at the university of paris where the two carbide of tungsten were discovered namely W2C(1896) by Moissan and WC (1898) by P.Williams[2].Tungsten carbide compositions range from two to three times as rigid as steel and four to six times as rigid as cast iron and brass. Young's Modulus is up to 94,800,000 psi. strength for a material so hard and rigid.

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Compressive strength is higher than virtually all melted and cast or forged metals and alloys.High resistance to deformation and deflection is very valuable in those many applications where a combination of minimum deflection and good ultimate strength merits first consideration. These include spindles for precision grinding and rolls for strip or sheet metal.For such a hard material with very high rigidity, the impact resistance is high. It is in the range of hardened tool steels of lower hardness and compressive strength.Tungsten base carbides perform well up to about 1000°F in oxidizing atmospheres and to 1500°F in non-oxidizing atmospheres.Tungsten carbide retains toughness and impact strength in the cryogenic temperature ranges. (-453°F).Thermal Conductivity of the Tungsten carbide is in the range of twice that of tool steel and carbon steel.Electrical Conductivity of the Tungsten carbide is in the same range as tool steel and carbon steel.Tungsten carbide can be fastened to other materials by any of three methods; brazing, epoxy cementing, or mechanical means. Tungsten carbide's low thermal expansion rate must be carefully considered when preforms are provided for grinding or EDM.Tungsten carbide compositions exhibit low dry coefficient of friction values as compared to steels.Specific grades are available with corrosion resistance approaching that of noble metals. Conventional grades have sufficient resistance to corrosion-wear conditions for many applications. Tungsten carbide wears up to 100 times longer than steel in conditions including abrasion, erosion and galling. Wear resistance of tungsten carbide is better than that of wear-resistance tool steels.

The available Literature reveals that most of the studies have been carried out to evaluate the wear behavior of Aluminum based particulate or whisker reinforced composites.*V.Constantin et. al*. [3] investigated the sliding wear behaviour of Aluminum Silicon Carbide metal matrix composites reinforced with different volume fraction of particulate against a stainless steel slider. Their results show that addition of reinforced particles increases the resistance of the composites to sliding wear under dry conditions, even for small volume fraction of particles. It reveals the comparative assessment of the effect of different types of reinforcement. Their results show that in the case of 20% vol. SiC particles Vs 20% Volume SiC-whisker (perpendicular or parallel), the steady state wear rates of the composites were generally independent of the reinforcement geometry (Particulate or whisker) and orientation (perpendicular Vs Parallel)[4].

L. Cao et. al. [5] studied the wear behaviour of a SiC whisker reinforced aluminum composite. Their results show that the SiC whisker–Al composite exhibits a fairly good wear resistance especially for higher sliding velocities and / or higher loads.Scanning electron microscope equipped with energy dispersive X-ray analyzer is used for micro structural characterization and the presence of silicon particles in the composites. Mechanical properties like density and hardness were measured for the composites. As the percentage of RHA particles increases, the density of the composites decreases and there is slight increase in the hardness were observed [6].

II. METHODS AND MATERIALS

A. *Material Used*

The metals identified for the present study are

- Aluminum (Al).
- Tungsten Carbide (WC).

B. *Fabrication techniques*

1. POWDER MIXING

Required amount of Aluminum and tungsten carbide were measured and taken as per the required composition and aspect ratio based on volume and mass calculation. The powders were mixed thoroughly in a mixing bowl, manually for obtaining homogeneity.

2. *DIE PREPARATION*

The composite powder has to be compacted into cylindrical perform of diameter 20mm and varying heights. The performs were prepared for two different aspect ratios. A split was performed from mild steel in order to meet the above requirements. It basically consists of the die walls containing the cavity for the cylindrical perform. There are two lower punches, one of length 80mm and other length is 120mm. The reason for having two lower punches is to provide the varying height in the compaction process. Six Allen screws and a bed to hold them together in the bottom, hold the two die walls together. Molybdenum disulphide was used for the die wall lubrication for the easy removal of the compacted perform.

3. SINTERING

The compacted performs were then placed in a muffle furnace for sintering. Sintering is usually carried out below the melting point of the lowest melting metal which in this case is aluminum (melting point=660ºC). Sintering is essentially a process of bonding solid bodies by atomic forces. Sintering forces tends to decrease with increase in temperature.

Since bonding particles is greatly affected by surface films, the formation of undesirable surface films, such as oxides, must be avoided. To prevent oxidation the compacted performs are sintered by placing them in foundry sand. But there are obstruction to sintering such as incomplete surface contacts, presence of surface films and lack of plasticity, all decrease more rapidly with increase in temperature. Sintering was done at 550± 10ºC. The performs were cooled in furnace itself.

C. SCANNING ELECTRON MICROSCOPE

The scanning electron microscope (SEM) is a type of electron microscope that images the sample surface by scanning it with a high-energy beam of electrons in a raster scan pattern. The electrons interact with the atoms that make up the sample producing signals that contain information about the sample's surface topography, composition and other properties such as electrical conductivity.

The types of signals produced by an SEM include secondary electrons, back-scattered electrons (BSE), characteristic X-rays, light, specimen current and transmitted electrons. Secondary electron detectors are common in all SEMs, but it is rare that a single machine would have detectors for all possible signals. The signals result from interactions of the electron beam with atoms at or near the surface of the sample.

In the most common or standard detection mode, secondary electron imaging or SEI, the SEM can produce very high-resolution images of a sample surface, revealing details about less than 1 to 5 nm in size. Due to the very narrow electron beam, SEM micrographs have a large depth of field yielding a characteristic three-dimensional appearance useful for understanding the surface structure of a sample. This is exemplified by the micrograph of pollen shown to the right. A wide range of magnifications is possible, from about 10 times (about equivalent to that of a powerful hand-lens) to more than 500,000 times, about 250 times the magnification limit of the best light microscopes. Back-scattered electrons (BSE) are beam electrons that are reflected from the sample by elastic scattering. BSE are often used in analytical SEM along with the spectra made from the characteristic X-rays. Because the intensity of the BSE signal is strongly related to the atomic number (Z) of the specimen, BSE images can provide information about the distribution of different elements in the sample. For the same reason, BSE imaging can image colloidal gold immuno-labels of 5 or 10 nm diameter which would otherwise be difficult or impossible to detect in secondary electron images in biological specimens. Characteristic X-rays are emitted when the electron beam removes an inner shell electron from the sample, causing a higher energy electron to fill the shell and release energy. These characteristic X-rays are used to identify the composition and measure the abundance of elements in the sample.

All samples must also be of an appropriate size to fit in the specimen chamber and are generally mounted rigidly on a specimen holder called a specimen stub. Several models of SEM can examine any part of a 6-inch (15 cm) semiconductor wafer, and some can tilt an object of that size to 45°.

For conventional imaging in the SEM, specimens must be electrically conductive, at least at the surface, and electrically grounded to prevent the accumulation of electrostatic charge at the surface. Metal objects require little special preparation for SEM except for cleaning and mounting on a specimen stub. Nonconductive specimens tend to charge when scanned by the electron beam, and especially in secondary electron imaging mode, this causes scanning faults and other image artifacts. They are therefore usually coated with an ultrathin coating of electrically-conducting material, commonly gold, deposited on the sample either by low vacuum sputter coating or by high vacuum evaporation. Conductive materials in current use for specimen coating include gold, gold/palladium alloy, platinum, osmium, iridium, tungsten, chromium and graphite. Coating prevents the accumulation of static electric charge on the specimen during electron irradiation.

Two reasons for coating, even when there is enough specimen conductivity to prevent charging, are to increase signal and surface resolution, especially with samples of low atomic number (Z). The improvement in resolution arises because backscattering and secondary electron emission near the surface are enhanced and thus an image of the surface is formed.

An alternative to coating for some biological samples is to increase the bulk conductivity of the material by impregnation with osmium using variants of the OTO staining method. Nonconducting specimens may be imaged uncoated using specialized SEM instrumentation such as the "Environmental SEM" (ESEM) or field emission gun (FEG) SEMs operated at low voltage. Environmental SEM instruments place the specimen in a relatively high pressure chamber where the working distance is short and the electron optical column is differentially pumped to keep vacuum adequately low at the electron gun. The high pressure region around the sample in the ESEM neutralizes charge and provides an amplification of the secondary electron signal. Low voltage SEM of non-conducting specimens can be operationally difficult to accomplish in a conventional SEM and is typically a research application for specimens that are sensitive to the process of applying conductive coatings. Low-voltage SEM is typically conducted in an FEG-SEM because the FEG is capable of producing high primary electron brightness even at low accelerating potentials. Operating conditions must be adjusted such that the local space charge is at or near neutral with adequate low voltage secondary electrons being available to neutralize any positively charged surface sites. This requires that the primary electron beams potential and current be tuned to the characteristics of the sample specimen.

Embedding in a resin with further polishing to a mirror-like finish can be used for both biological and materials specimens when imaging in backscattered electrons or when doing quantitative X-ray microanalysis.

D. X-RAY DIFFRACTION

XRD is a technique that is widely used in the nano-technology. Applications range from phase identification, quantification and determination of crystallite and particle size, all on nano-scale level. We will explain typical advantages using XRD in this technology over other techniques such as the non-destructive nature, averaging of properties, proper statistics and fast measurements. Also we present Small Angle X-ray Scattering, used to determine nano-sized particles, that is now available on a standard laboratory-scale diffractometer.

III. RESULT AND DISCUSSIONS

A. SEM Analysis for Al – WC Composition

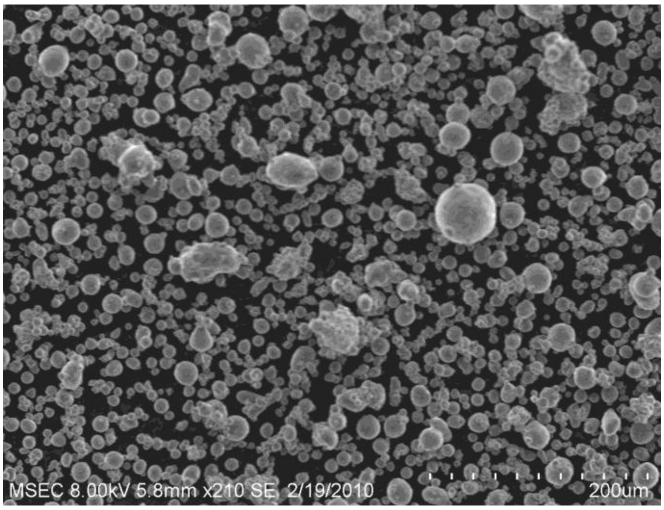

Figure1: Sem Image For Coarse Aluminum Powder

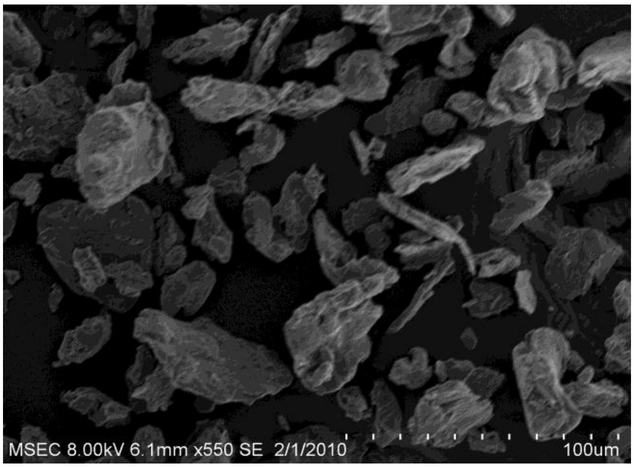

Figure2: Sem Image For 5% Tungsten Carbide With Aluminum

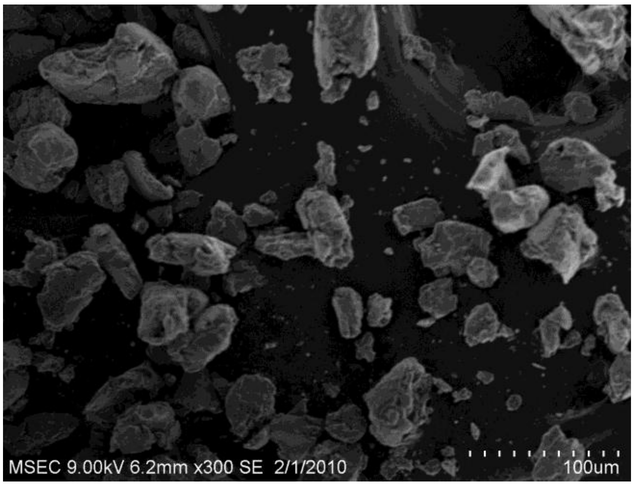

Figure3: Sem Image For 10% Tungsten Carbide With Aluminum

The scanning electron microscope (SEM) is a type of electron microscope that images the sample surface by scanning it with a high-energy beam of electrons in a raster scan pattern. The electrons interact with the atoms that make up the sample producing signals that contain information about the sample's surface topography, composition and other properties such as electrical conductivity. Good retention of tungsten carbide particles was clearly seen in the microstructures of Al/WC composites.

B. *X-RAY DIFFRACTION*

Crystallite size can also cause peak broadening. The well known Scherrer equation explains peak broadening in terms of incident beam divergence which makes it possible to satisfy the Bragg condition for non-adjacent diffraction planes. Once instrument effects have been excluded, the crystallite size is easily calculated as a function of peak width (specified as the full width at half maximum peak intensity (FWHM)), peak position and wavelength. Warren and Averbach's method takes not only the peak width into account but also the shape of the peak. This method is based on a Fourier deconvolution of the measured peaks and the instrument broadening to obtain the true diffraction profile. This method is capable of yielding both the crystallite size distribution and lattice microstrain. The XRD analysis was carried out at a voltage of 40 kV and 30 mA current intensity. The XRD pattern of the purified rice husk ash sample is shown in figs.

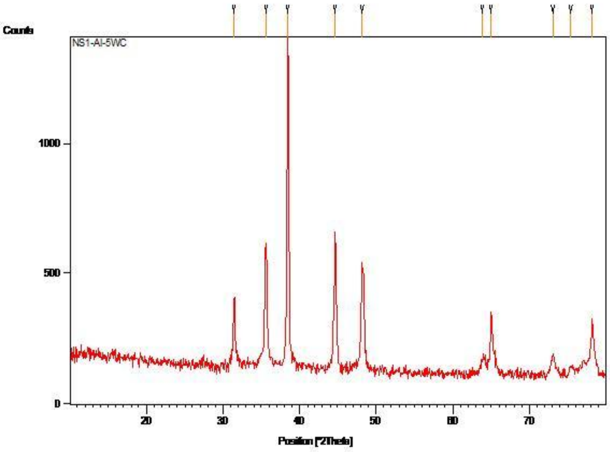

Figure5: XRD Test For 5% Wc With Al

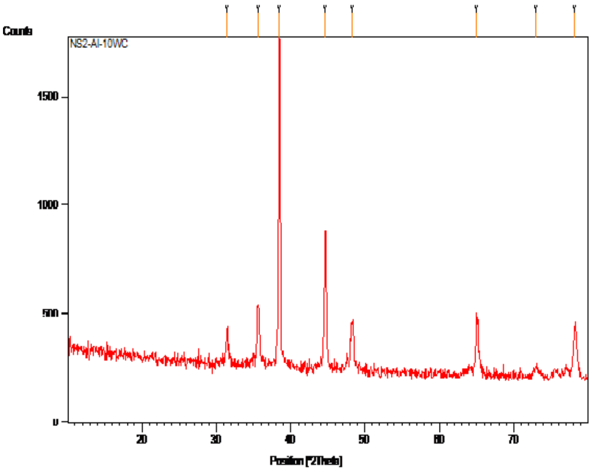

Figure6: XRD Test For 10% Wc With Al

IV. CONCLUSION

- Micro structure analysis shows the uniform distribution of tungsten carbide particles in the Aluminum. The microstructure also revealed good interfacial bond between matrix and tungsten carbide particles.
- Composite Al/Wc Material Powders that we have fabricated shows the tine Grain Structure as compared to Pure Aluminum.
- The addition of tungsten carbide with Al, increases the impact resistance of the reinforced Al by reducing the cracks and voids in the crystal lattice which was observed in the XRD analysis.

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