Mechanical Characteristics of WC/Al Metal Matrix Composites with Nanoparticulates

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Abstract :
The addition of reinforcement definitely changes mechanical behaviour of metal matrix composites (MMCs). Hence the objective of the work is to study the effect of nano WC particle content on the mechanical behaviour of Al alloy reinforced composites was studied by using optical microscopy, mechanical properties measurements and scanning electron microscope. The hardness, ultimate tensile strength, compression strength and young's modulus were found higher than those of control alloy. The dislocations which serve as heterogeneous nucleation sites for strengthening precipitates during subsequent solidification compared to control alloy. Higher density of dislocations and higher density of intermediate precipitates was observed.
Key words:
Reinforcement, metal matrix composites, ultimate tensile strength, mechanical behaviour.

I. Introduction

Metal matrix composites (MMCs) have been extensively studied in last two decades [1-5] and are significant for numerous applications in the aerospace, automobile, and military industries. MMC consists of a metallic base with a reinforcing constituent, usually ceramic. The attractive physical and mechanical properties that can be obtained with MMCs include high specific modulus, superior strength, long fatigue life, and improved thermal stability. Normally, micro-ceramic particles are used to improve the yield and ultimate strength of the metal. Nano particulate reinforced MMCs have been studied widely in recent years, essentially due to their promising advanced properties. Specific attention has been focused to aluminium matrices which are widely used in MMCs [6].The advantages of aluminium and its alloys used as the composite's matrix among others are high specific strength and stiffness, good damping capacities, dimensional stability and good machinability [7]. It is of interest to use nano-sized ceramic particles to strengthen the metal matrix, while maintaining good ductility, high temperature creep resistance and better fatigue [8]. However, the ductility of the MMCs deteriorates with high ceramic particle concentration [9]. It is of interest to use nano-sized ceramic particles to strengthen the metal matrix, so-called metal matrix composite (MMC), while maintaining good ductility [10]. With nanoparticles reinforcement, especially high temperature creep resistance and better fatigue life could be achieved [11]. A wide variety of fabrication techniques have been explored for metal matrix composites. These include liquid phase methods, deposition of matrix from a semi-solid or vapour phase, and solid state consolidation. Solid state processes include powder metallurgy, diffusion bonding and deposition technique. Liquid phase processing has attractive economic aspects. Liquid phase processes include squeeze casting and squeeze infiltration, spray deposition, and in-situcomposites.

The objective of this paper was to study the influence of nano WC particulates on mechanical properties of Al/WC composites and also to investigate microstructural changes due to the addition of particles.

II. Experimental Study

The matrix alloy used in the present investigation was Al alloy, which has nano WC particle reinforcement and chemical composition is as shown in Table 1. Nano WC powdered from ball mill and cleaned in distilled water and dried at90°C.

The composites were prepared by adding 0, 5, 10, 15 and 20 wt. %. ofnano WC by liquid metallurgy technique. The nano WC particle were introduced into the molten metal pool through a vortex created in the melt by the use of an alumina-coated stainless steel stirrer. The coating of alumina on the stirrer is essential to prevent the migration of ferrous ions from the stirrer material into the molten metal. The stirrer was rotated at 550 rpm and the depth of immersion of the stirrer was about two-thirds the depth of the molten metal. The pre-heated (773 ^{0}C) nano WC particle were added into the vortex of the liquid melt which was degassed using pure nitrogen gas for about 3 to 4 min. The resulting mixture was tilt poured into preheated permanent moulds.

III. RESULTS ANDDISCUSSIONS:

3.1 MicrostructureStudies

The evolution of microstructure, specifically in terms of the change in the size, shape and spatial distribution of the reinforcing particles during deformation, was quantitatively assessed using a systematic approach. This consisted of metallographic analysis at four different levels of strain, based upon the strain to failure of the MMC at each respective deformation temperature, as determined from the continuous tension tests.In order that the data collected from each different specimen could be compared relative to one another, all quantitative measurements were performed in the central area of each as-deformed tensioncylinder.

Fig. 1 shows the microstructural evolution for the MMC deformed at room temperature. The matrix microstructure of the WC reinforced composite samples revealed four common salient features:

i) The presence of a partially columnar and partially equiaxed matrixmicrostructure.
ii) The presence ofporosity
iii) The presence of an interdendritic Cu-rich phase,and
iv) The incorporation and non-uniform distribution of the ceramicparticulates.

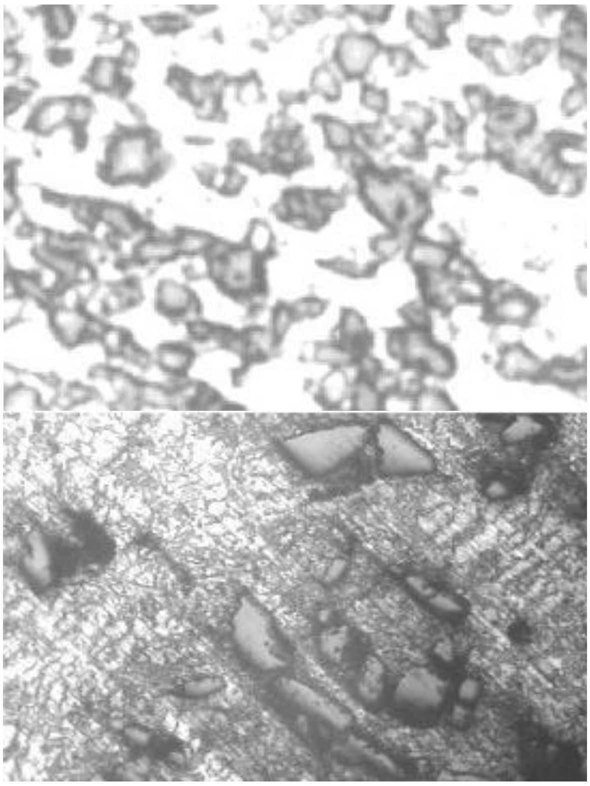

Fig 1: Microstructure of Al/WC MMCs

The partially columnar and partially equiaxed structure, commonly referred to as an 'ingot'type structure, indicates that the temperature of the liquid remaining after the onset of solidification from the mould wall stayed above the nucleation temperature and the underlying principles behind the development of 'ingot' structure types are well established and can be found elsewhere. Another important microstructural feature observed in case of the WC reinforced samples investigated in the present study was the presence of non-interconnected and randomly distributed porosity. Two types of porosity were observed in the presentstudy:

i. Microporosity in the bulk metallicmatrix
ii. Porosity associated with the individual and clusteredparticulates

The formation of microsporosity in the bulk matrix was inevitable, primarily as a result of the columnar equiaxed type of solidification structure observed in the present study. The presence of porosity associated with particulates can be attributed primarily to the physical properties of the metallic material containing the suspended particulates and the solidification associated distribution of the particulates in the metallic matrix.

The development of porosity at the sharp corners of ceramic particulates, for example, can be attributed to the inability of the high-viscosity particulate containing metallic slurry to negotiate sharp corners, whilst the presence of voids within clusters of ceramic particulates can be attributed to the inability of the liquid metallic alloy used in the present study to infiltrate the microscopic-sized crevices in the inefficiently packed clusters of ceramic particulates formed ahead of the moving solidification front using conventional casting.

Table 1: Mechanical properties of Al and Al composites specimens

	Density	Hardness	Young's Modulus E (Gpa)	Ultimate Tensile Strength (Mpa)	Yield Strength (Mpa)	Ductility
Al	2.691	65.0	75.0	238	207	15.60
Al/5WC	2.740	80.2	85.9	240	219	6.30
Al/10 WC	2.776	81.6	88.9	265	221	5.20
Al/15 WC	2.841	87.1	96.9	280	233	5.75

Al/20 WC	2.909	89.9	90.6	260	220	3.06

3.2 MechanicalProperties

Synthesis of monolithic and reinforced Al composites containing different amounts of WC particulates composites was carried out using a disintegrated melt deposition technique. A complete description of the method of composite fabrication is provided. A summary of the compositions and important mechanical properties of the materials used in this study is given in Table 6.1 and represented in Fig. 2 to 7. Fig. 2 demonstrates the effect of WC. By increasing the ratio of the nano sized particulates, the density first increases slightly.

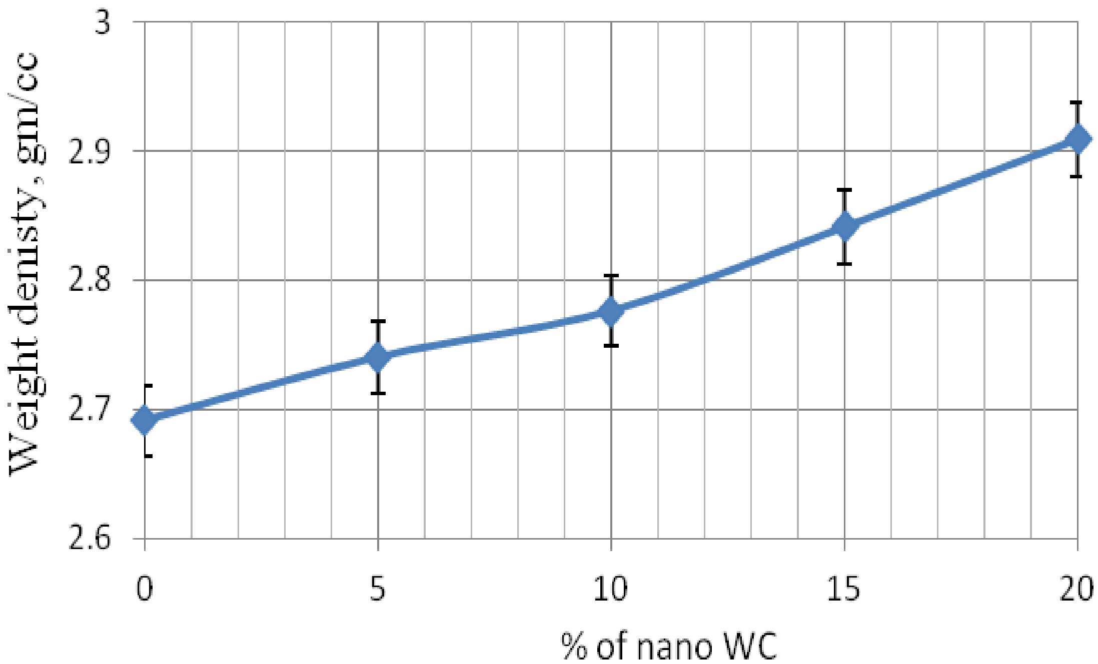

Fig 2: Effect of wt. % of Nano WC on density of Al/WC Nano MMCs

The reinforcement particles which are smaller than the matrix particles situate themselves among the matrix particles, filling pores. This causes an increase in the density of the composites compared with the pure aluminum. However, the increase in agglomeration of the particles with an increase in the nano-sized WC particulates leads to pores retained in the agglomerated zones, this causes a decrease in the density.

Adding the nano WC to the aluminium alloy results in increased Young’s modulus, ultimate tensile strength (UTS) and yield stress as shown in Fig.3, Fig. 4 and Fig.5 respectively. However there is a decrease in the percentage elongation as shown in Fig.6.

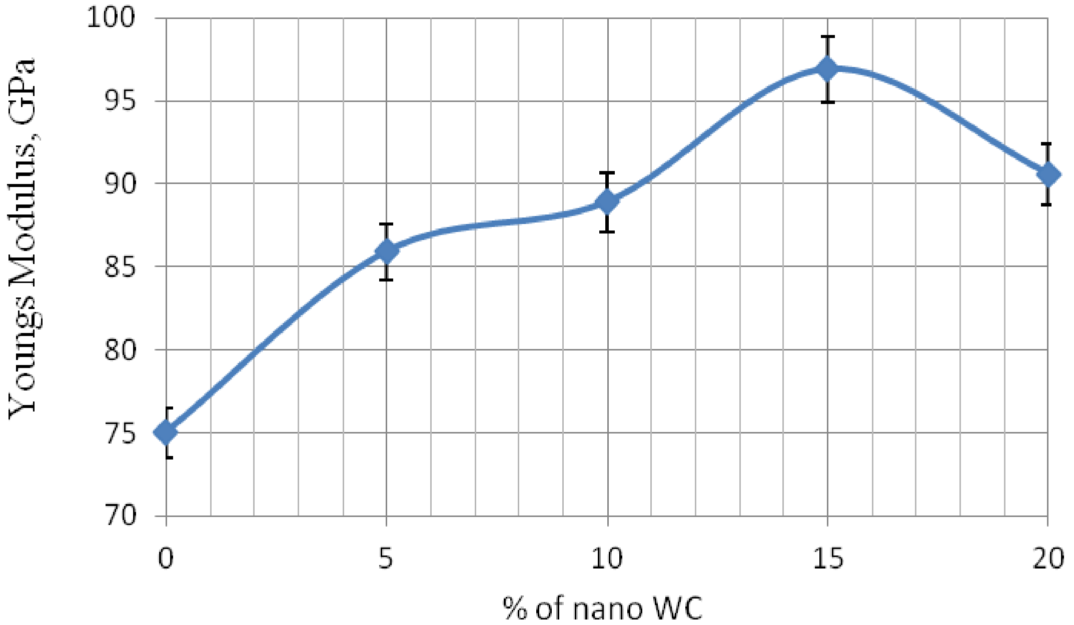

Fig: 3 Effect of wt.% of nano WC on Youngs Modulus of Al/WC nano MMCs

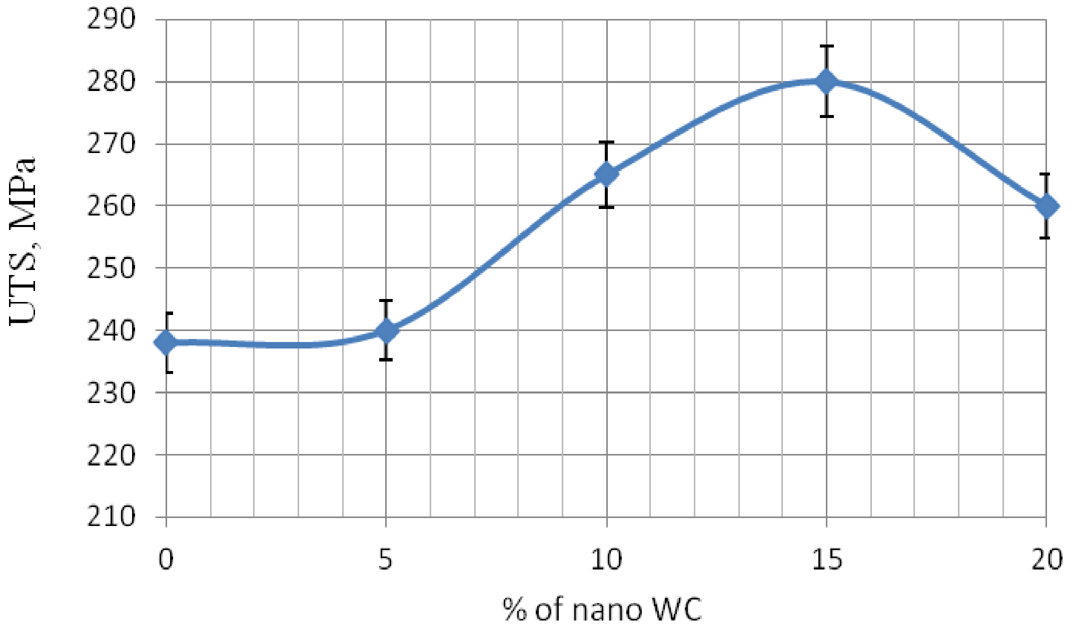

Fig 4: Effect of wt. % of nano WC on UTS of Al/WC nano MMCs

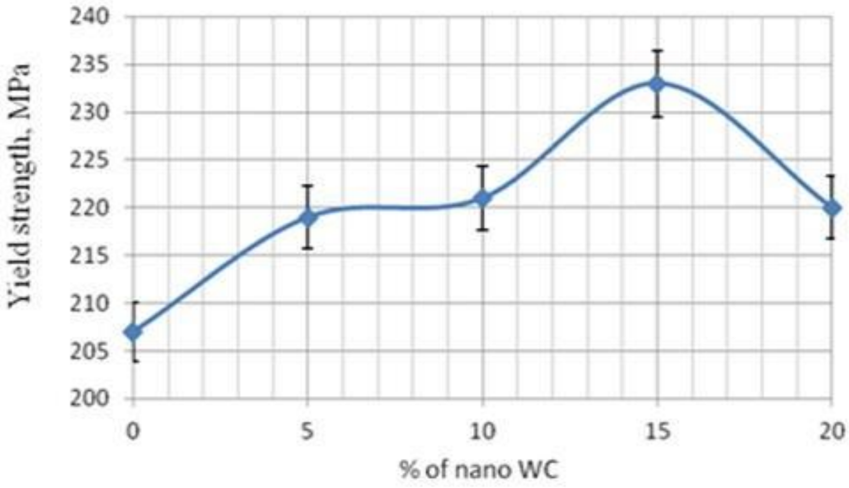

Fig 5: Effect of wt.% of nano WC on yield strength of Al/WC nano MMCs

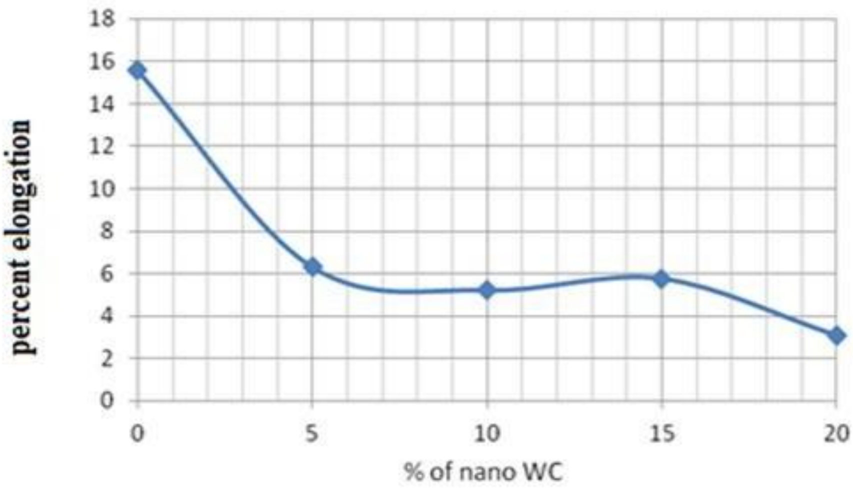

Fig 6: Effect of wt.% of nano WC on ductility of Al/WC nano MMCs

A decrease in elongation with an increase in the content of nano WC is observed for all the different wt. % of nano WC investigated. The yield stress, ultimate tensile strength and the Young's modulus increases with the growing amount of nano WC up to some critical reinforcementconcentration.

This depends on the actual nano WC particle size through which the maximum values decrease due to the formation of nano WC clusters in the composites. Among the characteristics studied, the yield stress seems to be least sensitive to reinforcement clustering, since its dependence on the reinforcement content which shows the most monotonic trend over the whole range of reinforcementconcentrations.

A comparison of the data for the composites reinforced for the concentrations where the reinforcements are distributed sufficiently uniformly (10 wt.%) leads to the conclusion that small nano WC particle provide a higher increase of the yield stress and the ultimate tensile strength, where as the composites containing large nano WC particles possess higher elongation to fracture and Young's modulus.

The obtained results show that, using reinforcements with small particle size provides higher strength, comparable to Young's modulus and elongation to fracture and obviously better fabricability of the material if the reinforcement concentration does not exceed the critical value. Therefore, it is preferable to use small-size reinforcements for optimization of the properties of the material where low reinforcement concentrations are sufficient.

However, in cases where an increase in Young's modulus is the main factor that can be implemented into the material goal, large reinforcement particles should be preferred, because of the higher critical content of the reinforcements. The increase of the mean particle size of the reinforcement leads to a poorer distribution which in turn leads to lowering of the mechanical properties.

A linear decrease of the mechanical properties with increasing mean particle size of the matrix alloy is observed. The results reveal that the addition of the reinforcement to the Al matrix generally increases values of the mechanical properties of the composites. This increase is a consequence of the dispersion of the WC particles in the matrix. The mechanical properties of the composites increases initially then decreases at 20% nano WC particles

3.3 Fracturestudies

Fig. 7 shows the fracture surface of a specimen WC reinforced Al composites. Agglomeration of sharp edged WC particulates in the matrix can be easily observed. Large dimples can be seen in the Al matrix due to the ductility of the matrix material and the relatively large powder particle size. The same phenomenon was also observed in the specimens of short duration composites as depicted in Fig. 7. The fracture surface analysis suggests that fracture was due mainly to the segregation of WC particulates and/ or debonding at the matrix particle interfaces in conventional blending and at shorter duration of composites where a uniform distribution of WC particulates had not been achieved. Microvoids could also be observed. Generally, in particulate reinforced MMCs, microvoid coalescence is the predominant fracture mode. The stages of microvoid coalescence consist of void nucleation, growth, and coalescence. The void nucleation process can be influenced by a variety of factors including the total volume fraction and the local volume fraction of the particulates, the matrix deformation characteristics and the interfacial bond strength. It has been demonstrated by previous studies on particulate reinforced materials exhibiting some degree of ductility that void nucleation and the final ductility may be sensitive to both the size and distribution of the particulates. In particular, it has been suggested that the local volume fraction as opposed to the average volume fraction may be an important parameter in determining the fracture of materials containing dispersions of particulates at high volume percentages.

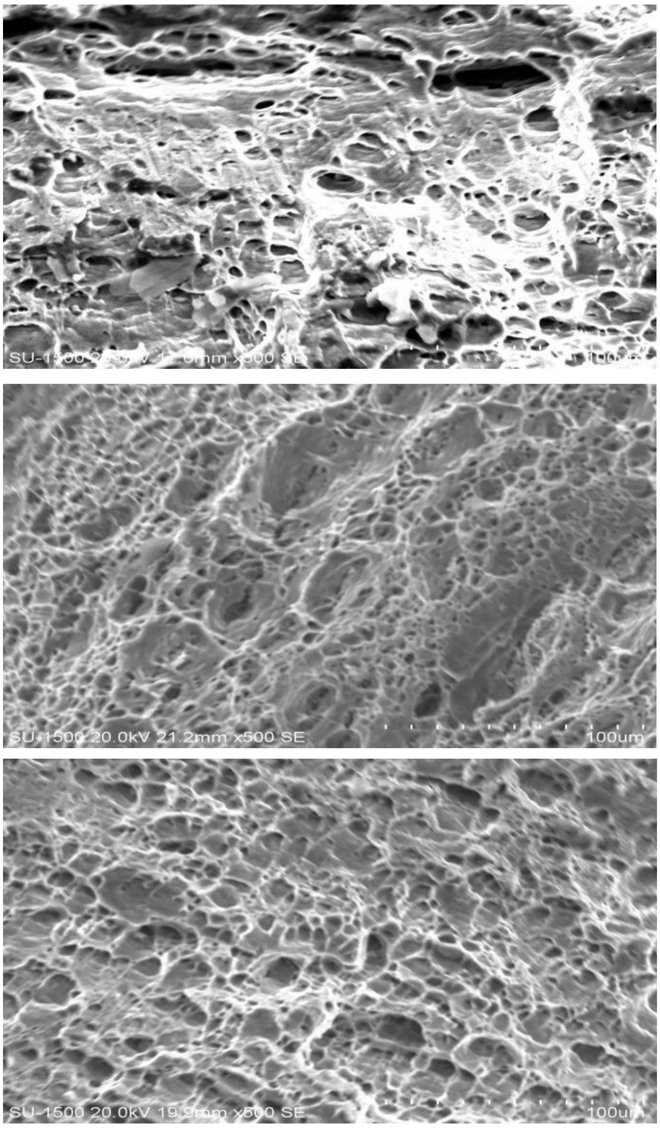

Fig. 7 (a) and (b) Fracture studies of Al/WC composites

IV. Conclusion

Mechanical properties on overall results show that the appropriate choice of the reinforcement particle size for particulate reinforced MMCs prepared by the liquid metallurgy route have important effect. Larger nanoWCparticulateshouldbeusedwhereYoung'smodulusismorecritical.Itwasfoundthatlargerparticle reinforcement provides higher Young's modulus for equal wt.% and in addition, higher nano WC particulate wt.% are possible while the particles are uniformly distributed in the matrix. Decreasing the nano WC particulate size allows higher yield stress and tensile strength to be obtained and better material fabrication on the assumption of a uniform nano WC particulatedistribution.

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