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Evaluation of fatigue and impact behavior of titanium carbide reinforced metal matrix composites

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ABSTRACT

The objective of this work is to evaluate the load bearing behavior of titanium carbide reinforced aluminum matrix composites and their suitability for automotive application. Three different weight percentages of TiC particulates: 10, 12 and 15, in the size of 325 meshes were prepared by stir casting process to study the effect of particulates for load bearing application. Tensile, fatigue and impact tests were conducted on the ASTM standard test samples to investigate the effect of titanium carbide in Al–Si matrix alloy. XRD analysis shows various intermetallic phases present in the composites cast at 750 °C. Crack propagation and failure mechanism of the fabricated composites were examined using SEM. The steering knuckle used in automobile suspension system is a critical structural component subjected to both fatigue and impact load during its service and it is considered in this study. The steering knuckle made of Al/TiC, unreinforced alloy and spheroidal graphite (SG) iron was tested and compared for the performance in real time load conditions. The results show that performances of samples and component knuckle were remarkably increased in the presence of TiC reinforcement. Fractographs show that cyclic load starts the crack initiation from the matrix region and particle breaking mechanism occurs during impact load.

1. Introduction

The life of structural components in automobile industry is predicted by the fatigue life and impact resistance of the material. This results in a design with higher-level factors of safety which in turn increases the weight of the component. Recent developments in aluminum alloys make it the ideal candidate to replace heavier materials like iron and steel in the car for weight reduction demand within the automotive industry [1]. In the recent past, the metal matrix composites (mmcs) paved the way in reducing the weight of the component with improved fatigue and impact performance [2–4]. Al-matrix composites with ceramic TiC reinforcing particles show good mechanical strength, stiffness, fatigue resistance, wear and creep resistance [5–7]. LLorca [8] reviewed the literature of fatigue of reinforced composites in a detailed manner and reported that many automobile industries started to replace their products with composite material. Vijayarangan [9] experimentally proved that Al/TiC mmc could safely replace spheroidal graphite iron which is used in critical automotive component steering knuckle. Vyletel [10] investigated an Al–Cu alloy reinforced with 15 vol% of TiC and observed stable cyclic response at ambient conditions. Sharma et al. [11] investigated the fatigue behavior of Al/SiC mmc and found superior performance compared to unreinforced 7075-T6 alloys. Chawla [12] reported that aluminum based mmc exhibited superior fatigue life and endurance stress compared to their unreinforced alloy under high cycle fatigue mode. Kaynak [13] reported that SiC particulates improved the fatigue resistance of the specimen over unreinforced specimens and also presented SN data. Despite these good fatigue properties of mmc, high impact strength and toughness at room temperature is a critical issue in many structural applications on automobiles [14]. The impact strength of mmc has been investigated using different materials, which is reported in literature [15]. Zahedi et.al [16] reported the impact behavior of Al–SiC mmc fabricated by pressureless melt infiltration technique. The results showed that the mmc fabricated with 90 μm SiC powder withstands more plastic deformation and also absorbs higher impact energies. The impact behavior of SiC particle on reinforced Al matrix composites was studied in the temperature range −176 °C to 300 °C by Sedat [17]. The results indicated that the impact strength of the composites increased with particle size and extrusion ratio. However, the test temperature variation did not affect the impact strength of the mmc samples. Lopez [18] investigated wettability and reactivity aspects of mmc made of

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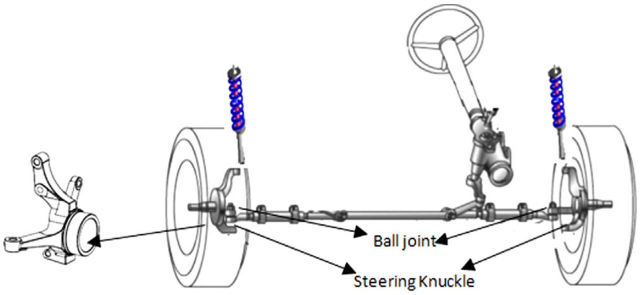

Fig. 1. Steering knuckle assembly.

Table 1
Mechanical properties of TiC.

Properties of TiC	
Density	4900 kg/m^3
Ultimate tensile strength	258 MPa
Modulus of elasticity	450 GPa

Table 2
Composition of unreinforced alloy.

Alloy designation	**Chemical composition (wt%)**				
LM6 alloy	Si	Mg	Cu	Mn	Fe
	12	0.8	0.1	0.3	0.2

Table 3
Mechanical properties of SG iron.

S no.	**Material**	**UTS[a]** **MPa**	**YS[b]** **MPa**	***E*[c]** **GPa**	**Elongation** **%**	**Fatigue strength** **MPa**	**Impact strength** **J**
1	SG iron	418	276	170	15	180	10

[a] Ultimate tensile strength.
[b] Yield strength.
[c] Modulus of elasticity.

inexpensive reinforcements like SiC, Al_2O_3. Recently, attention has been focused on Al-based mmc reinforced with TiC particles due to good wettability and epitaxy between two phases. This results in strong interfacial bonding and the resulting composites show better strength and stiffness compared to SiC additions [19].

It is inferred from the literature that fatigue and impact properties of Al/SiC composites were studied separately. The fabrication technique and characteristics of Al/TiC composites have also been studied at laboratory level and reported by many researchers. The fatigue and impact behaviors of structural components made of particulate reinforced composites were not explored much in the literature. Moreover, the design of automobile components requires real time test data instead of laboratory test data. One such critical auto-component taken for this current study is an automotive steering knuckle. The details of a steering knuckle and its position in an automobile are shown in Fig. 1 [20]. Hence the plan is to study the real time fatigue and impact behavior of a structural component, steering knuckle, made of Al/TiC composites.

2. Experimental procedure

In the present study, the microstructure and mechanical properties of Al/TiC standard specimens are discussed. To study the behavior of mmc at a product level, automobile structural component steering knuckles are manufactured and tested for fatigue and impact behavior. Three different materials Al/TiC composite, unreinforced alloy and spheroidal graphite (SG) iron were considered for the study of performance through comparison. The details of experimentation and testing are discussed in this section.

2.1. Material and sample preparation

The aluminum silicon alloy (LM6) was used as matrix material due to its good casting properties [21,22]. TiC particulates of 325 mesh size were used as reinforced material. The TiC particulates were chosen because of good mechanical properties [Table 1] and wetting properties [23–26]. Such wetting properties lead to greater affinity for molten aluminum and reduced tendency for particle agglomeration [19]. The chemical compositions of matrix and reinforcement are shown in Table 2. Stir casting process was chosen for the preparation, considering its effectiveness among the processes [27]. The addition of TiC increases the temperature of the melt to 800 °C due to its reaction. Small amount of Mg was also added to the melt before mixing to avoid oxidation and improve the wetting of TiC particulates. Mixing was done with a stirrer at a speed of 900 rpm and 800 °C for about 10 min [28].

Test samples and steering knuckles with three different weight percentages 10, 12 and 15 were prepared by the stir casting technique for fatigue and impact studies. Steering knuckles made of unreinforced alloy and SG iron were also fabricated for comparison. The mechanical properties of SG iron steering knuckle used in this work are shown in Table 3 [29]. The dimensional details of steering knuckle were taken from a hatchback car fitted with MC Pherson suspension system. The fabricated steering knuckle for the experimental study is shown in Fig. 2(a) and (b).

2.2. Mechanical testing

Metal matrix composites with three different weights 10, 15 and 20 were fabricated for this study. The tensile test bars [Fig. 3(a)] were prepared according to ASTM E-08 standard [30] from the cast specimens. Tensile tests were conducted on the test bars using a 250 kN servo hydraulic Instron UTM. The fatigue test bars [see Fig. 3(b)] were prepared from the cast specimens as per ASTM E466-82 [31]. Constant amplitude axial fatigue tests were conducted in tension–compression mode at a stress ratio of $R=0.1$ and a frequency of 15 Hz in an Instron fatigue testing machine. The tests were conducted at various stress levels until fracture or 1E+07 cycles [13]. The Charpy impact tests were carried out as per ASTM E-23 standard [refer Fig. 3(c)] at room temperature, in a standard instrumented impact testing unit [32].

2.3. Steering knuckle: fatigue and impact load testing

The wheel movement of the car was controlled through the steering knuckle as shown in Fig. 1. A fatigue fixture set up as shown in Fig. 4 was fabricated to achieve the load transfer happening in the real suspension system. The fixture accommodates the knuckle in such a way that the tie rod portion of the knuckle experiences the load during testing. Fatigue test was conducted on knuckles by tension–compression mode with a starting load of ±0.5 kN. Then the load was gradually increased up to ±5 kN with a load increment of ±0.5 kN between every two lakh cycles. The stress ratio of $R=-1$ and frequency 15 Hz were constant for all load conditions. The drop tower impact test was conducted on the composite steering knuckle at an impact velocity of 4 m/s. An Instron testing system was used to determine