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Static and Fatigue Analysis of Al – B_4C Metal Matrix Composite Leaf Spring

Harmeet Singh[1], Gurinder Singh Brar[2]
[1]*PhD Student, IKG Punjab Technical University, Kapurthala (Punjab) INDIA 144603*
[2]*Department of Mechanical Engineering, Guru Nanak Dev Engineering College, Ludhiana (Punjab) INDIA 141006*

Abstract: ***Use of composite materials is spreading massively in mechanical, automobile, aerospace, electronics and communication engineering fields. Automobile engineers have shown great interest to change traditional steel leaf spring with light weight composite leaf spring of similar strength. In the present work, an attempt has been made to replace a rear leaf spring of Tata Ace (mini truck) made of EN45 spring steel with a metal matrix composite (MMC) leaf spring made from Al 7075 T651 material with 20% B_4C as reinforcement. Results show that deflection of composite leaf spring is 13% less as compared to steel leaf spring.***

Keywords: Composite Leaf Spring; Metal matrix composite, Al-B_4C; Fatigue Test; Static Test

I. INTRODUCTION

A metal matrix composite (MMC) is a composite material which uses two or three materials to form new metallic bond material. Aluminum, magnesium, boron carbide, silicon carbide, titanium and alumina are mostly used to manufacture metal matrix composite components. When more than two materials are used to manufacture composite material, the resultant is known as hybrid composite material. In MMC's, the second material is reinforced in the first material to make new material, and to improve the mechanical and thermal properties of the existing (base) material. The most widely used methods for the manufacture of MMC's are stir casting, centrifugal casting, squeeze casting and powder metallurgy. Metal matrix composites are used in automobile industry to manufacture interior, exterior, chassis and power transmission components. Due to increase in demand for better fuel efficient vehicles, light weight components and parts consolidation are the major issues to increase the demand of metal matrix based components in the automobile industry. New innovation, experiment and numerical analysis may help to develop new automobile component based on metal matrix composite material. In automobiles leaf springs are one of the essential suspension components.

Many researchers have worked to reduce weight of steel leaf spring or to replace steel spring with lighter composite leaf springs. Krall and Zemann [1] carried out experimental modal analysis for investigation of the dynamic behavior of CFRP leaf springs by two different methods – impact test and shaker test. A standard steel spring was used as reference. Three different composite springs were investigated and compared.

Boron carbide reinforced 2024 Aluminium matrix composite (manufactured by mechanical hot extrusion process) are widely used in the field of automobile, aerospace, thermal and structure industries [2]. Miracle [3] showed that the morphology, microstructure, yield strength, young modulus and ultimate tensile strength of composite material can be enhanced significantly over the monolithic aluminum 2024 alloy. Rahman and Rashed [4] concluded that when SiC was reinforced in Al matrix, it improves the mechanical properties, microstructure and wear characteristics of the material.

Nano particles can effectively enhancing the mechanical properties in the metal matrix composite than micron level particles because of its bonding nature as shown in the study conducted by Divagar et al. [5]. Investigation of fatigue life of the produced MMNCs were investigated by advanced rotating beam fatigue testing machine to understand the impacts of reinforced nano particles.

Mouleeswaran and Vijayaragan [6] used life data analysis approach to carry out static and fatigue analysis of steel leaf spring and composite multi leaf spring made up of glass fiber reinforced polymer. It was reported that fatigue life of composite was more than that of conventional steel leaf spring.

The research in automobile industries shows that many researchers have used composite materials to manufacture automobile components like piston, brake drum, connecting rod and valve stem. The research has also been carried out to determine mechanical properties, carry out shape optimization and to conduct failure behavior by experimental and finite element approach on composite leaf springs made of E-Glass/Epoxy material.

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The present study attempts to investigate possibility to manufacture metal matrix composite leaf spring by stir casting method and to perform static and fatigue analysis. For the present work, the rear leaf spring of Tata Ace (mini truck) made of EN45 spring steel has been considered. The Aluminum and boron carbide reinforced composite manufactured by stir casting technique was tested under static and fatigue loading as per the standards - IS 1135: 1995, leaf springs assembly for automobiles [7] and SAE HS - J788 - Manual on Design and Application of Laminated Springs [8].

II. EXPERIMENTAL PROCEDURES

Stir casting process was used to manufacture composite leaf spring. Aluminum of grade 7075- T651 was used as base material and 20% by weight of boron carbide was used as reinforcement. The ultimate tensile strength of Aluminium 7075 T651 is 570 MPa while that of Boron carbide is 450-750 MPa.

Electric muffle furnace was used to heat the aluminum up to 850ºC. The mould of leaf spring was prepared by steel leaf spring. Alongside, boron carbide was also pre-heated to about 500ºC temperature in order to remove the dissolved gases which would have otherwise resulted in the formation of blow-holes, during the casting process. When aluminum temperature reached to 850ºC than boron carbide was added in very control manner to the crucible. The mixture of aluminum and boron carbide was stirred with the help of the stir casting machine at 400 rpm for about 10 minutes in order to ensure homogeneous mixture of the materials. When the materials got properly mixed, the mixture was poured to the prepared mould of the leaf spring as shown in Fig. 1. After solidification composite leaf spring was removed from the mould.

Fig. 1 Casting of MMC – Molten MMC being poured into mould

III.RESULTS AND DISCUSSION

Existing EN45 spring steel leaf spring and composite leaf spring prepared of Al – B_4C by stir casting method were subjected to static and fatigue tests as per IS 1135: 1995 and SAE HS - J788 standards.

A. Static Test

The total kerb weight of Tata Ace (mini truck) is 885 kg and gross vehicle weight is 1550 kg. The present steel leaf spring of EN45 material is 915 mm in length, 57 mm in width and 7 mm thick. EN45 material possesses following mechanical properties i.e. modulus of elasticity – 204 GPa, poisons ratio – 0.3, tensile strength – 621 MPa and density – 7850 kg/m^3. To find the deflection, load applied on the spring was from initial load of 1000 N to final load of 5400 N.

An electro-hydraulic leaf spring test rig was used to perform static test on steel spring and composite leaf spring. In this test ring, the plunger was moved up to desired height so that fixture can be fixed and leaf spring was mounted with help of a special fixture. The load was then applied at the centre of spring and deflection of the spring at centre was recorded at different loads. Load deflection curves under different loads are shown in Fig. 2. Final deflection values of composite spring was 13% less than steel spring deflection value which means more stiffness in the spring.

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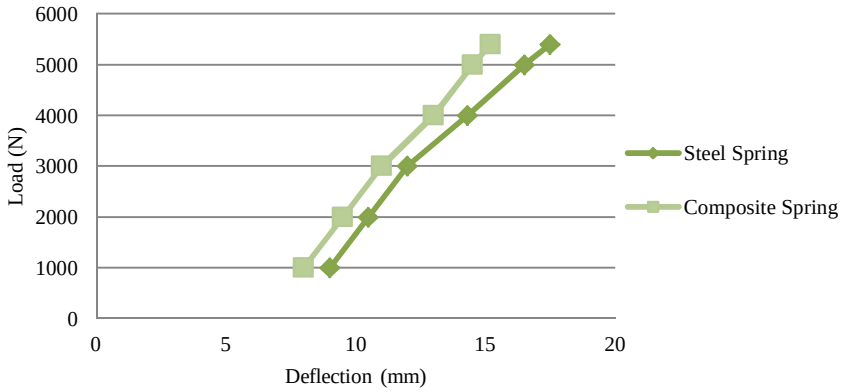

Fig. 2 Load deflection curve for steel and composite leaf springs

B. Fatigue Strength

Fatigue test is important to find the maximum load that a sample can endure for a specified number of cycles. The main reasons for fatigue failure are number of cycles, range of stress and local stresses. To find out the fatigue strength, fatigue test was performed on steel and composite leaf spring separately. A considerable time is required to find the fatigue strength of leaf spring. So, SAE procedure has been used to find the fatigue strength of leaf spring, especially for steel spring. The SAE spring design procedure is helpful to estimate actual fatigue strength of leaf spring under normal working condition [8].

1) *Fatigue test of steel leaf spring*: Hydraulic load test machine was used to determine fatigue strength which include stroke of 0 – 150 mm as shown in Fig. 3. According to IS 1135: 1995 standards, fatigue strength of leaf spring must be stand above the 100000 cycle [7]. After initial start of machine, loading and unloading cycle was repeated until the end of the test was reached. The hydraulic test rig initial deflection was 9 mm and the initial stress is 203 MPa. Final stress of the spring was 17.5 mm and the stress is 304 MPa. It was found that fatigue life of the steel spring was above 100000 cycles.

Fig. 3 Fatigue testing of steel spring

2) *Fatigue analysis of composite leaf spring:* To find the fatigue strength of composite leaf spring similar hydraulic test rig machine as used for steel spring was used. Loads was applied from initial load of 1000 N to 5400 N. Hydraulic test machine was set to operate for a deflection of 70 mm and 25 strokes/min. The maximum and minimum stress values obtain during initial cycle of the leaf spring were 77 MPa and 105 MPa. During first 20000 cycles no crack formation was seen in the composite leaf spring. The maximum load applied on the composite leaf spring was 5400 N for 16 hours. Further, analytical model proposed by Hwang and Han [9] was used to know the number of fatigue cycles to failure for the composite leaf spring. The relation is given as:

$$N = \{B(1-r)\}^{1/c}$$

where, B and c are the constants with values 10.33 and 0.14012 respectively, N is number of cycles to failure and r is the stress level value which is the ratio of the maximum stress to the ultimate tensile strength. Fatigue life of composite leaf spring was calculated at

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different stress levels and is shown in Fig. 4 in the form of SN curve. It was found that metal matrix composite based leaf spring can withstand more than 100000 cycles under the stress level of 0.5. Also, no crack formation occurred upto 100000 cycles.

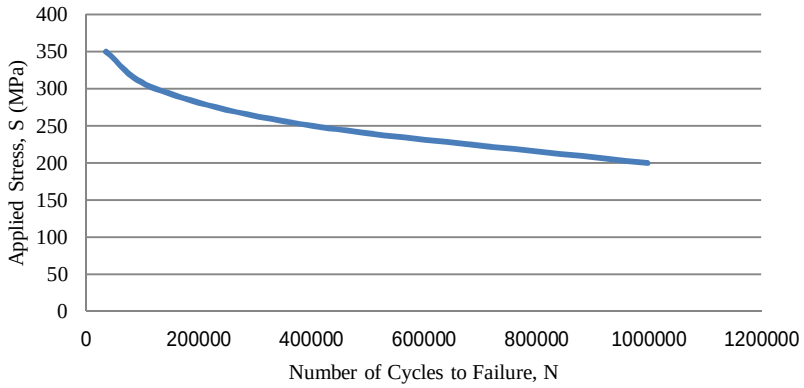

Fig. 4 SN curve for composite leaf spring

IV. CONCLUSIONS

Metal matrix composite based leaf spring of material 7075 Al reinforced with 20% B_4C was successfully manufactured by stir casting method. The composite leaf spring is lighter in weight as compared to conventional steel leaf spring. Metal matrix composite leaf spring is found to deflect 13% less as compared to existing steel spring which means increase in stiffness. Fatigue life cycle of both steel and composite leaf spring comes out to be more than the design value of 100000 cycles. It can be concluded that metal matrix composite leaf spring is an effective replacement for the existing steel spring used in automobile vehicles.

V. ACKNOWLEDGMENT

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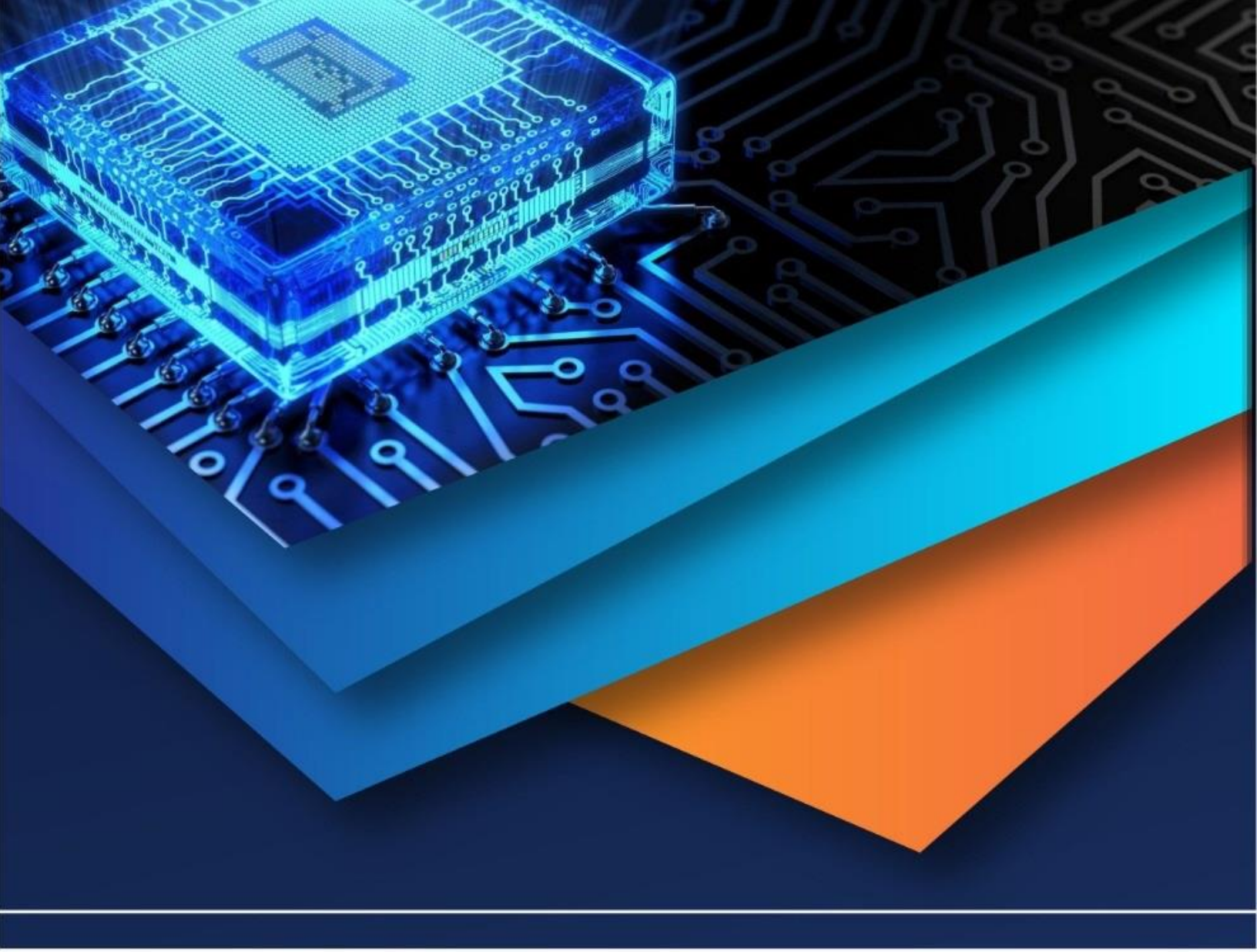

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