Journal of Engineering Science and Technology
9th EURECA 2017 Special Issue September (2018) 74 - 82

ANALYSIS OF CARBON REINFORCED METAL MATRIX COMPOSITE FOR IC ENGINE VALVES

P. SIVASHANKARI*, A. KRISHNAMOORTHY,
S. PRAKASH, S. RAJA, S. VENKATESH

School of Mechanical Engineering, Sathyabama Institute
of Science and Technology, Rajiv Gandhi Salai, OMR, Chennai, TamilNadu, India
*Corresponding Author: jsrshank1981@gmail.com.

Abstract

To fabricate valves in IC Engines for commercial cars using composite materials. The main objective to have a composite material is to increase the tensile strength, to reduce the wear and tear, thereby enhancing the mechanical and thermal properties and the performance of valve in commercial vehicles. This project was done combining a metal matrix composite with a polymer. The need to have materials such as this is to increase the durability of the material and it is evident from research is that metal matrix composite shows a better result than the existing material. By using ANSYS software, the Finite Element Analysis (FEA) for the engine valve guide was done. It was found that use of these materials showed a higher percentage increase in mechanical and thermal properties.

Keywords: Carbon fiber, Mechanical properties, Metal matrix composites, Reinforcement, Thermal properties.

1. Introduction

To fulfill the requirement of the today's trend such as lightweight, corrosion resistance, wear resistance, thermal resistance, durability of the component and mainly of lightweight, which plays a main role in the fuel consumption, hence the new technological period has come forth with the change of material and introducing new materials with the combination of composites. The researchers have involved in finding new materials for different applications in the entire field. One of the most challenging creation is the metal matrix, which is the combination of one are more different materials which are more peculiar in their characteristics for fabricating the component for the different applications. By adding the composite material to the metal matrix, it improves the strengthens of components and improves the concept of lightweight. This concept and need for lightweight structural materials for the application of components in the different field of industries such as automobile, aerospace, aircraft.

The materials such as aluminium and titanium could not satisfy the recent challenge due to the significant getting worse at the relatively low temperature and the expenditure of the availability of the material respectively. The hardness, tensile strength, compressive strength and other thermal and mechanical properties can be improved by combining or reinforcing the composite materials such as ceramic and carbon fiber to the metal matrix. Application of aluminium metal matrix composites include automotive industries, aerospace and aircraft industries and hold the greatest future growth.

The principle stress and strain distribution and temperature for the whole surface of the engine valve were obtained and the required output result for the Finite Element Analysis (FEA) was obtained by using ANSYS software. This project is to analyze the mechanical Properties with Aluminium reinforced composite material (MMC) with the polymer Carbon Fiber (*CF*) for the application of valves. The current materials used for manufacturing the IC engine valves are the alloys of titanium, carbon steel, high strength nickel-chromium-iron and stainless steel.

The main importance to choose this material is because of cost reduction and its availability. Composite materials are finding its way into the industry as it adds more weight age and performance to the materials property.

2. Material Selection

Since the work concentrates on the automobile industry, it is essential to consider the properties of the materials used in such applications through which the failure can be analyzed. Apart from this, properties such as high strength, corrosion performance, high impact strength and high modulus, ductility and distortion after machining also play an important part in material selection. However, the exact set of properties and their importance is heavily dependent on the specific component or part and properties of tensile and compressive strength, Young's modulus, corrosion.

3. Related Work

The composite matrix with inorganic polymer strengthens with relation to interference condition [1] states that polymer matrix resulted in improvements in both mechanical and thermal properties when compared to existing material. The input parameters were standard and the results obtained showed good improvements than the existing material. The MMC reinforced with *CF* [2] states that it expresses a great result to substitute in the current materials such as alloys and unreinforced metals in the industry of automobile and it is essential to consider the properties of the materials used in such applications through which the failure can be analyzed [3, 4]. Due to the reduction of the coefficient of friction and increase in wear resistance, they are promising materials for a variety of engineering applications.

By using FEA, the Comparative Study of different materials with Al-Sic [5] stated that for high temperature and pressures such as racing cars, turbo-charged engines, loco aircraft engines aluminium SiC composites are suitable, where cost is not a major factor. The tribological and mechanical behavior of particulate Aluminium matrix composites [6] states that mechanical and tribological properties were better for single reinforcement than pure aluminium and furthermore it was observed that hybrid matrix composites possess a better mechanical and Tribological properties compared to single reinforcement composites.

4. Methodology

The following process was done to samples under utmost safety precaution and care. The apparatus used for the testing purpose that is both mechanical and metallurgy were under ASTM standards. Furthermore, microscopic structure analysis was conducted. The sample compositions were 83% of aluminium and 7% of Silicon carbide and 10% carbon fibers and for the second sample 82% of aluminium 6% of Silicon carbide and 12% of carbon fibers. The Solid model was done using modeling software and later the material was analyzed using ANSYS [7] software under standard input properties of the materials.

The fabrication process followed here was stir casting [8] Aluminium powder was poured into the cast at a temperature above 600 ˚C and allowed to melt completely, simultaneously Silicon Carbide and Carbon fibers powder were taken in correct proportions and stirred well. The stirred mixture was preheated up to a certain temperature in order to bond with the Aluminium metal. Stir casting method [9-12] was followed as it is cost effective and quite simple in terms of getting the weight of the final product and the most important advantage in this is that, the time processing which is far less compared to other processes.

The solid cylinder obtained was machined to the desired shape for further testing [13]. The solid cylinder was machined into four different moulds for tensile test, compression test, impact test and thermal conductivity test. Further, a 5 mm piece from the solid mould was observed for metallurgical testing. Testing was performed with the help of experts and the machines used were under ASTM standards. Figures 1(a) to (e) show the fabrication process of the material. Fig. 1(a) shows the CF and Sic poured into aluminium cast, Fig. 1(b) shows the electric stirrer used to stir with slack observed at far end, Fig. 1(c), cast being poured onto the mould, Fig. 1(d) the sample milled for the tensile test, Fig. 1(e) the sample milled for the compression test.

(a) CF and SiC poured aluminium cast

(b) Electric stirrer used to stir with slack observed at far end

(c) Cast being poured onto the mould

(d) The sample milled for tensile test

(d) The sample milled for compression test

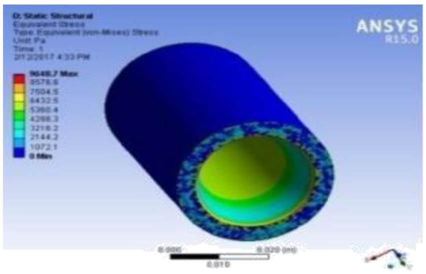
Fig. 1. Fabrication process of the material.

5. Experimental Results

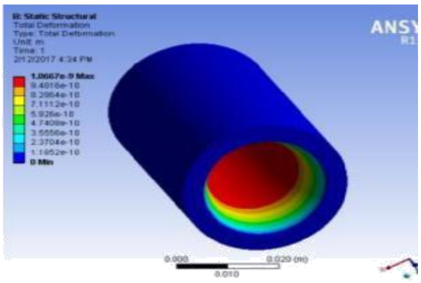
The results are obtained by both the analysis method and experimental method. The results are compared with the software and the mechanical type.

5.1. ANSYS Report for the samples

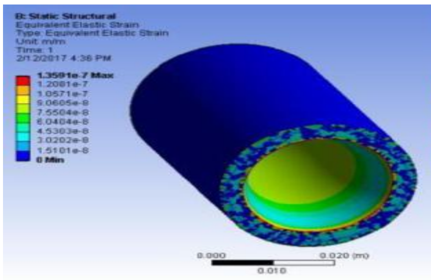
The experimental results obtained were positive. FEA was conducted using the analytical software ANSYS, the software gives the predicted value of the minimum and the maximum values of the samples to the given dimensions. The results obtained were positive, the FEA analysis results were positive and the minimum and maximum Von-Misses stress values were found in the engine valve guide as 0 Pa and 9648.7 Pa respectively. The minimum and maximum total deformation values were found in the engine valve guide as 0 m and 1.0667e^{-09} m respectively. The minimum and maximum equivalent elastic strain values were found in the engine valve guide as 0 mm and 1.3591e^{-07} mm respectively. It was observed that steady state mechanical properties matched the existing material. The directional heat flux from cylinder side to the outer side were found to be reduced. The directional heat flux values are -2.4564e^{-05} W/m^2 and 2.3746e^{-05} W/m^2. The temperature distribution was observed and found to be safe. The Total heat flux decreases from cylinder side to the outer side. The respective Total heat flux values are -8.4914e^{-06} W/m^2 and 3.2703e^{-05} W/m^2 and the results obtained for static structural such as Von-Misses stress on the surface, total deformation on the Surface, Equivalent elastic strain on the surface and for steady state thermal analysis such as directional heat flux on the surface, temperature on the surface, total heat flux on the surface are mentioned below in Fig. 2(a), which shows the Von misses stress on the material surface Fig. 2(b) equivalent elastic strain on the material surface Fig. 2(c) total heat flux on the material surface, Fig. 2(d) total deformation on the material surface, Fig. 2(e) directional heat flux on the material surface, Fig. 2(f) temperature distribution on the material surface.



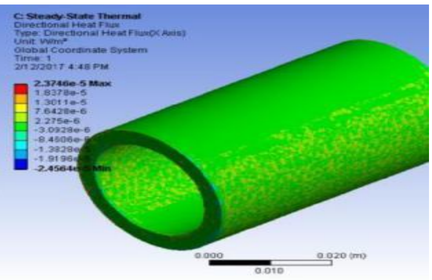
(a) Von-Misses stress on the material surface.



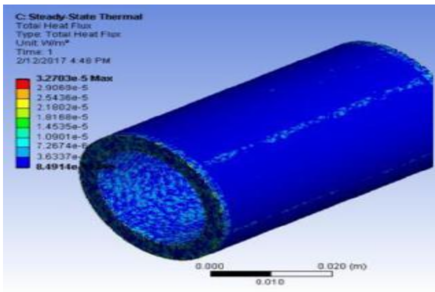
(d) Total Deformation on the material surface.



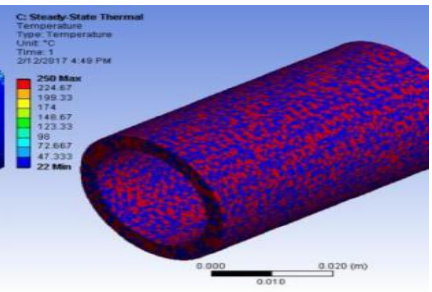
(b) Equivalent Elastic on the material surface



(e) Directional Heat Strain Flux on the material surface



(c) Total Heat Flux on the material surface



(f) Temperature Distribution on the material surface

Fig. 2. FEA evaluation.

5.2. Mechanical characteristics of the samples

The mechanical properties when compared with ASTM standards for carbon fiber are tensile strength and compressive strength are 110 N/mm^2, the result of the sample proved to have more for 10% carbon fiber along with MMC the tensile strength is 340.203 N/mm^2 and for the compressive strength is 336.464 N/mm^2 and that of 12% carbon fiber along with MMC the tensile strength is 304.218 N/mm^2 and the compressive strength is 298.568 N/mm^2. The thermal conductivity for carbon fiber is 21- 180 W/m K, the result of the samples also proved to lie within the limits of the standards for 10% of carbon fiber along with MMC is obtained as121.63 W/m K and that of 12 % of carbon fiber along with MMC is 124.31W/m K. Further mechanical properties and thermal properties obtained for the material was obtained and the results were found to be matching the existing material as shown in Table 1.

Table 1. Mechanical and thermal properties of test materials.

Properties	MMC with CF 10%	MMC with CF 12%
Rockwell Hardness Test	54.66	62.06
Impact Test(J)	7	9
Ult. Tensile Strength(N/mm^2)	340.203	304.218
Ult. Compressive strength(N/mm^2)	336.464	298.568
Thermal Conductivity (W/m K)	121.63	124.31

Figure 3 illustrates about the stress- strain curve for the compressive strength of the sample carbon fiber of 10 % with the metal matrix composite. The compressive strength obtained is 336.464 N/mm^2 and the tensile strength obtained is 340.203 N/mm^2.

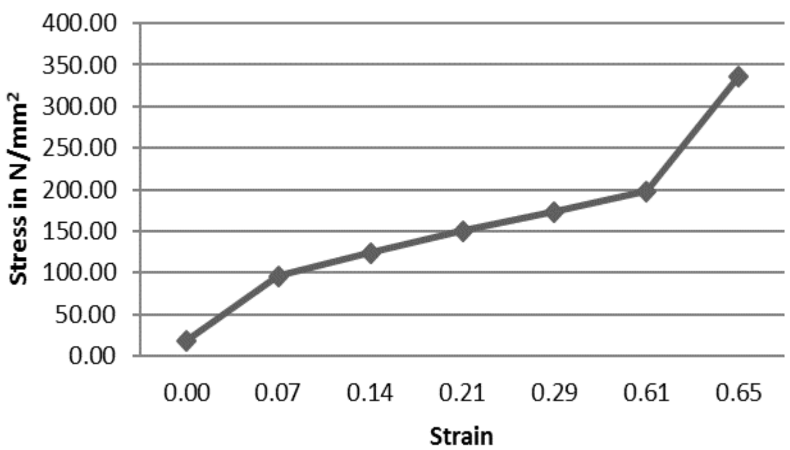


Fig. 3. Stress-strain curve for compressive strength - CF 10 %.

Figure 4 represents the stress- strain curve for the compressive strength of the sample carbon fiber 12 % combined with the metal matrix. The compressive strength obtained is 298.568 N/mm^2 and the tensile strength obtained is 304.218 N/mm^2.

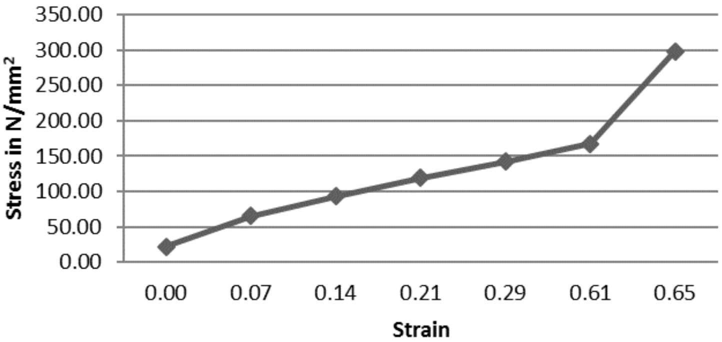
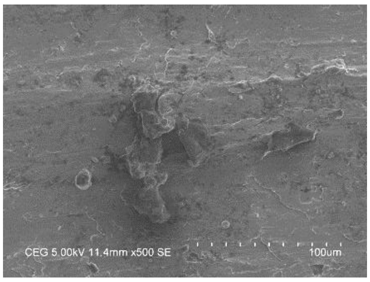
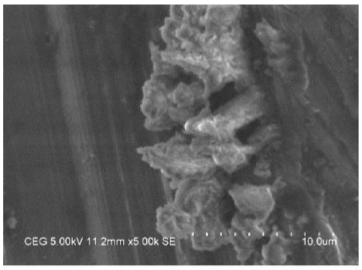


Fig. 4. Stress-strain curve for compressive strength - CF 12%.

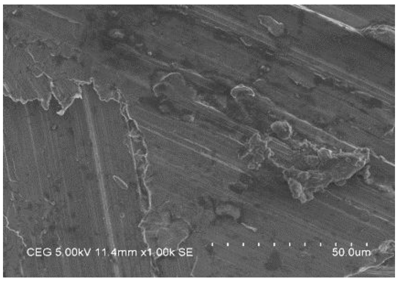
Figures 5 show the metallurgical testing results (SEM analysis) of the material which was conducted at various scales to determine the fiber structure on the surface of the material (a) SEM of MMC with 10%CF (b) SEM of MMC with 10% CF (c) SEM of MMC with 12% CF (d) SEM of MMC with 12% CF.



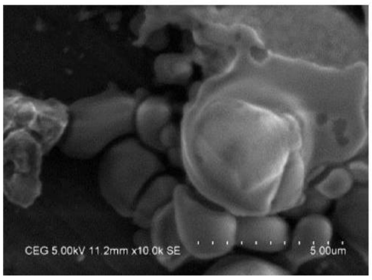
(a) SEM of MMC with 10%CF



(c) SEM of MMC with 12%CF



(b) SEM of MMC with 10%CF



(d) SEM of MMC with 12%CF

Fig. 5. Metallurgical testing results.

6. Conclusion

It can be concluded that the results obtained were positive,

- The FEA analysis results were positive and the minimum and maximum Von-Misses stress values were found in the engine valve guide as 0 Pa and 9648.7 Pa respectively.

- The minimum and maximum total deformation values were found in the engine valve guide as 0 m and $1.0667e^{-09}$ m respectively.
- The minimum and maximum equivalent elastic strain values were found in the engine valve guide as 0 mm and $1.3591e^{-07}$ mm respectively.
- It was observed that steady-state mechanical properties matched the existing material.
- The directional heat flux from cylinder side to the outer side were found to be reduced. The directional heat flux values are $-2.4565e^{-05}$ W/m^2 and $2.3746e^{-05}$ W/m^2.
- The temperature distribution was observed and found to be safe. The Total heat flux decreases from cylinder side to the outer side.
- The respective total heat flux values are $-8.4914e^{-06}$ W/m^2 and $3.2703e^{-05}$ W/m^2 .
- It was observed that steady- state thermal properties of the material proved to be safe under normal working conditions.
- The Microstructure image clearly shows the fibers structure in spherodized form in both the samples.
- It was further observed that Sample 1 showed higher physical properties when compared to the existing material by 21% in tensile and 29% in compressive strength.
- The impact strength, when compared to existing material, showed an increase of 3J and the hardness of the material showed to be almost the same.
- The thermal properties of the sample showed an improvement by 26%.
- It was further observed that Sample 2 showed higher physical properties when compared to the existing material by 11% in tensile and 15% in compressive strength.
- The impact strength when compared to existing material showed an increase of 5J and the hardness of the material showed a 17%.
- The thermal properties of the sample showed an improvement by 29%. When compared to both the samples, Sample 1 showed a higher percentage is stressed by 22% and showed a reduction in thermal and impact properties by 7%. The hardness of sample 2 showed a 9% higher than sample 2.

Nomenclatures

CF	Carbon Fiber
SiC	Silicon Carbide

Abbreviations

ANSYS	Analysis System
ASTM	American Society for Testing and Materials
CF	Carbon Fiber
FEA	Finite Element Analysis
IC	Internal Combustion Engines
MMC	Metal Matrix Composite

References

1. Radford, D.W.; Grabher, A.; Bridge, J. (2009). Inorganic polymer matrix composite strength related to interface condition materials. *Materials*, 2(4), 2216-2227.
2. Shirvanimoghaddam, K.; Hamim, S.U.; Akbari, M.K.; Fakhrhoseini, S.M.; Khayyam, H.; Pakseresht, A.H.; Ghasali, E.; Zabet, M.; Munir, K.S.; Jia, S.; Davim, J.P.; and Naebe, M. (2017). Carbon fiber reinforced metal matrix composites: fabrication processes and properties. *Composites: Part A*: *Applied Science and Manufacturing*, 92, 70-96.
3. Kaufman, J.G. (2000). *Introduction to aluminum alloys and tempers* (6th ed.). ASM International, Library of Congress Cataloging.
4. Srivastva, H.K.; Chauhan, A.S.; Kushwaha, M.; Raza, A.; Bhardwaj, P.; and Raj, V. (2016). Comparative study of different materials with Al-Sic for engine valve guide by using FEM. *World Journal of Engineering and Technology*, 4(2), 238-251.
5. Sharma, P.; Khanduja, D.; and Sharma, S. (2014). Tribological and mechanical behaviour of particulate Aluminium matrix composites. *Journal of Reinforced Plastics and Composites*, 33(23), 2192-2202.
6. Bhandare, R.G.; and Sonawane, P.M. (2013). Preparation of aluminium matrix composite by using stir casting method & it's characterization. *International Journal of Current Engineering and Technology*, Special Issue-3, 148-155.
7. Bodunrin, M.B.; Alaneme, K.K.; and Chown, L.H. (2015). Aluminium matrix hybrid composites: a review of reinforcement philosophies: mechanical, corrosion and tribological characteristics. *Journal of Materials Research and Technology*, 4(4), 434-445.
8. Shirvanimoghaddam, K.; Khayyam, H.; Abdizadeh, H.; Akbari, M.K.; Pakseresht, A.H.; Ghasali, E.; and Naebe, M. (2016). Boron carbide reinforced aluminium matrix composite: Physical, mechanical characterization and mathematical modelling. *Materials Science and Engineering: A*, 658, 135-149.
9. Dave, M.M.; and Kothari, K.D. (2013). Composite material-aluminium silicon alloy: A review. *Indian Journal of Research*, 2(3), 148-150.
10. Ramesh, C.S.; Adarsha, H.; Pramod, S.; Khan Z. (2013). Tribological characteristics of innovative Al6061-carbon fiber rod metal matrix composites. *Materials & Design*, 50, 597-605.
11. Ramesh, C.S.; and Prasad, T.B. (2009). Friction and wear behavior of graphite-carbon short fiber reinforced Al-17% Si alloy hybrid composites. *Journal of Tribology*, 131(1), 014501-1-014501-5.
12. Wang, J.; Li, Z.; Fan, G.; Pan, H.; Chen, Z.; and Zhang, D. (2012). Reinforcement with graphene nanosheets in aluminum matrix composites. *Scripta Materialia*, 66(8), 594-597.
13. Nematzadeh, M.; Salari, A.; Ghadami, J.; and Naghipour, M. (2016). Stress-strain behavior of freshly compressed concrete under axial compression with a practical equation. *Construction and Building Materials*, 115(7), 402-423.