

Performance of hybrid nano-micro reinforced mg metal matrix composites brake calliper: simulation approach

N Fatchurrohman* and S T Chia

Faculty of Manufacturing Engineering, Universiti Malaysia Pahang,
Kuala Pahang, 26600 Pekan, Pahang, Malaysia

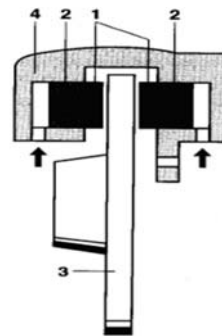
Corresponding author email: fatchurrohman@ump.edu.my

Abstract. Most commercial vehicles use brake calliper made of grey cast iron (GCI) which possesses heavy weight. This contributes to the total weight of the vehicle which can lead to higher fuel consumption. Another major problem is GCI calliper tends to deflect during clamping action, known as “bending of bridge”. This will result in extended pedal travel. Magnesium metal matrix composites (Mg-MMC) has a potential application in the automotive industry since it having a lower density, higher strength and very good modulus of elasticity as compared to GCI. This paper proposed initial development of hybrid Mg-MMC brake calliper. This was achieved by analyzing the performance of hybrid nano-micro reinforced Mg-MMC and comparing with the conventional GCI brake calliper. It was performed using simulation in ANSYS, a finite element analysis (FEA) software. The results show that hybrid Mg-MMC has better performance in terms of reduction the weight of the brake calliper, reduction in total deformation/deflection and better ability to withstand equivalent elastic strain.

1. Introduction

Brake calliper, acts as a U-shaped housing that wraps around the brake rotor and is mostly made of grey cast iron (GCI). The current problem of existing GCI brake calliper is it possesses heavy weight which contributes to higher fuel consumption as has been highlighted by [1]. Brake calliper (floating) has one or more pistons and only located on the inboard side of the calliper. Calliper body is mounted on a pin to give cylindrical support and allow moving linearly. During braking, hydraulic pressure forces the piston inwards, pushing the pads against the revolving brake disc. The calliper creates a reaction force cause the calliper slide over the pin leading to clamp action on rotor. Figure 1 presents an illustration of a floating brake calliper.





1 Brake pads, 2 Piston, 3 Brake disc, 4 Floating calliper, 5 Support

Figure 1. An illustration of a floating brake calliper [2].

The clamping force results in frictional force and generates heat may be transferred to the calliper body through the brake pads. Single piston is preferable due to light weight, less leakage points and also performs least uneven pad wear as compared to more pistons [3]. High structural stiffness could prevent uneven wear of brake pads and large deformations of brake calliper results in short pedal travel, improving comfort, driving feelings and safety [4]. Another problem of GCI brake calliper is deflection due to the hydraulic pressure acting on the piston and calliper housing, which is also known as “bending of bridge”. This problem will result in extended pedal travel since additional fluid volume is required to compensate for deflections. Therefore, minimizing the mass and maximizing the stiffness should be primary design considerations.

Kumar et al. [5] have highlighted that the usage of magnesium (Mg) alloys has considerably increased in automotive sector. They have mentioned that the potential of Mg alloy as substitution to aluminium alloys and iron alloys. Mg-Al-Zn alloys are widely used in many applications due to its both high strength and ductility. The addition of nano particles reinforced metal matrix composites are being studied in recent years, due to their promising properties are suitable for the used in functional and structural applications [6]. According to Macke et al. [7], advanced nano and micro reinforced metal matrix composites can effectively reduce mass, improve reliability and efficiency.

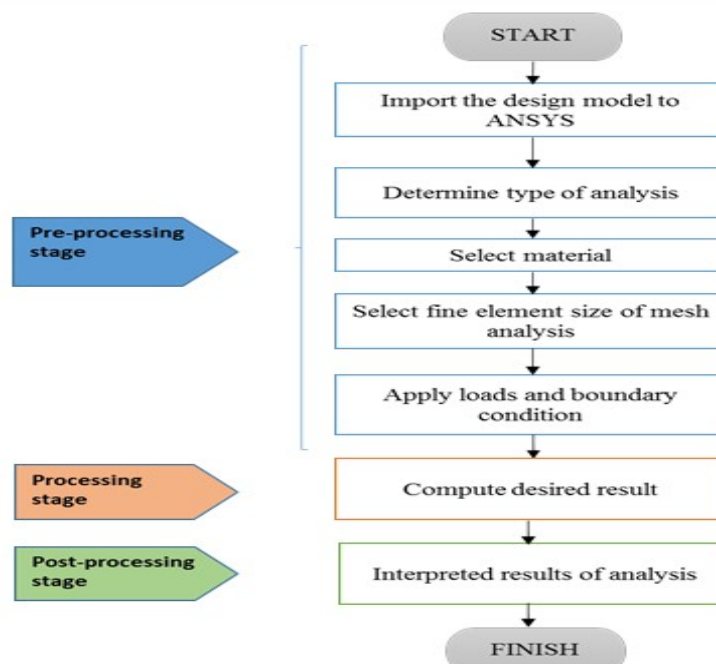
Hybrid nano-micro reinforced Mg-MMC has a potential application in the automotive industry due to their significant improved properties including high specific strength and stiffness, temperature resistance, low thermal expansion coefficient and light weight. This appear to offer more advantages over GCI in brake calliper application. Nguyen et al. [8] have studied the microstructure and mechanical behaviour of Mg alloy AZ31 hybridized with nano sized alumina to improve the ductility and micro-sized copper particulates to enhance the microstructural characteristics, hardness and strength of AZ31 alloy which synthesized through the technique of disintegrated melt deposition. The primary goal of this paper is to perform simulation and to compare hybrid nano-micro reinforced Mg-MMC material with conventional GCI for brake calliper application.

2. Methodology

To perform the analysis finite element analysis (FEA) is applied using ANSYS simulation software. Three stages are involved (Figure 2); pre-processing stage include which type of analysis, material properties, select fine element size of mesh analysis, loads and boundary condition are defined. The processing stage where the desired result is computed and solved; and the results are interpreted during post-processing stage. The material properties used is presented in table 1, both for GCI and hybrid nano-micro Mg-MMC (AZ31-14.0vol% SiCmicro-1.0vol% SiCnano) respectively.

Table 1. Material properties of GCI and hybrid nano-micro Mg-MMC.

Properties	GCI	Hybrid nano-micro Mg-MMC
Density (kg/m^3)	7200	1995
Young's modulus, (GPa)	100	103
Poisson's ratio	0.28	0.27
Tensile yield strength, (MPa)	276	300
Tensile ultimate strength, (MPa)	250	380

**Figure 2.** Flowchart for FEA analysis.

To improve the mesh quality, additional control be added to the default mesh before solving. Mesh parameters such as element quality, skewness and orthogonal quality were considered. An average element mesh quality of 0.8 and above is considered acceptable. In order to achieve high mesh quality, different meshing techniques were used. There are three advanced size functions can be employed: proximity, curvature and fixed. Both proximity and curvature were turned on for this model in order to have a much better mesh along the curve regions and varying cross sections. "Patch conforming" mesher under "tetrahedrons" were the most suitable as they capture the curvatures more accurately as compared to other method such as multizone, hexagonal dominant and sweep. Standard skewness and orthogonal quality mesh metrics spectrums were shown in Figure 3.

The brake calliper model was meshed consisting of 457326 nodes and 302619 elements as shown in Figure 4. Through the suitable meshing method, mesh parameter like average element quality achieved 0.82, average skewness quality has reached 0.26, and average orthogonal quality have achieved 0.85 shown in Figure 5-7. These elements confirm the high meshing quality used in this work.

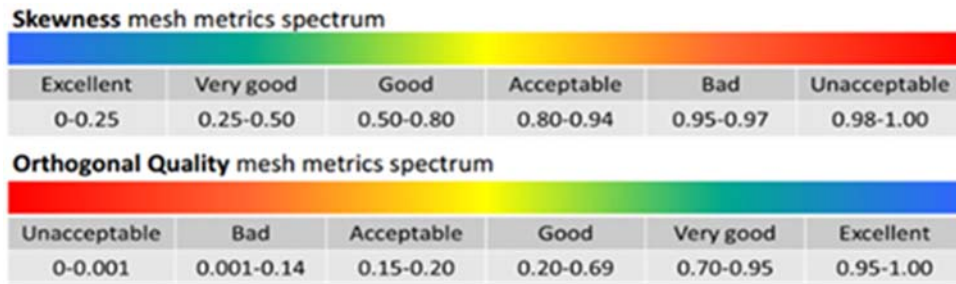


Figure 3. Skewness and orthogonal quality mesh metrics spectrums.

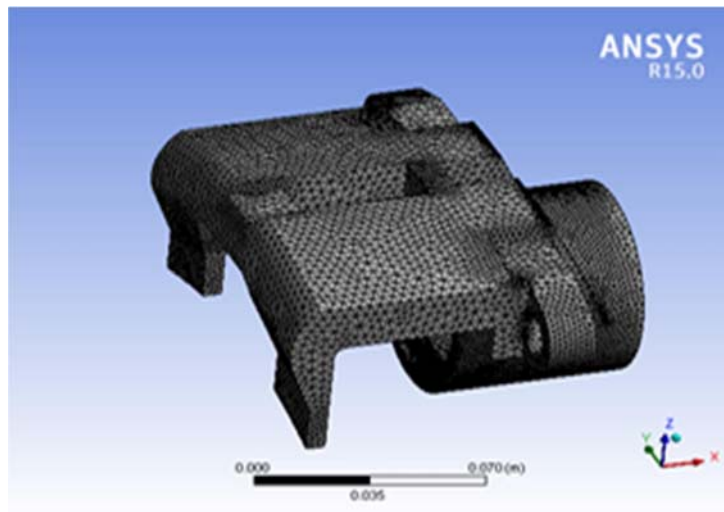


Figure 4. Refined mesh original brake calliper model.

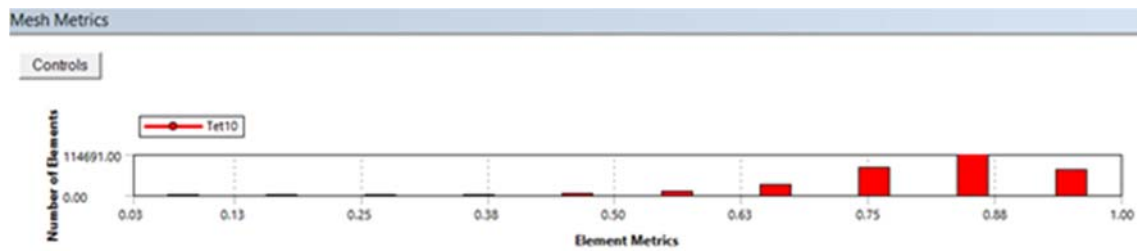


Figure 5. Mesh average element quality.

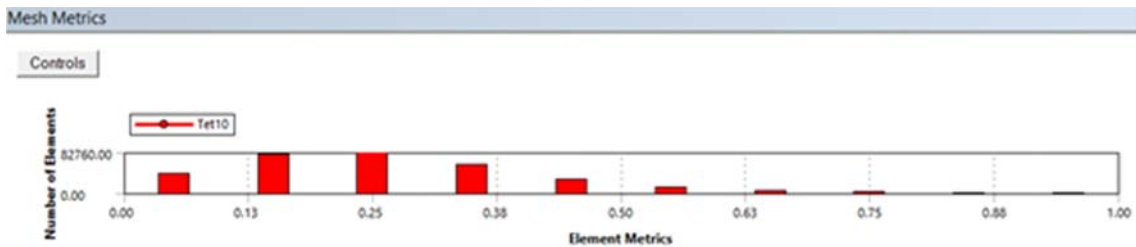


Figure 6. Mesh average skewness quality.

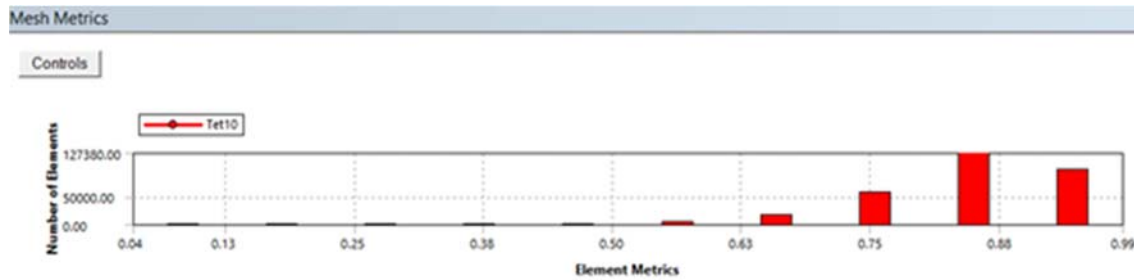


Figure 7. Mesh average orthogonal quality.

Loads and boundary condition were set according to the brake pipeline pressure (fluid pressure). The load was set at the extreme condition, which is the panic braking situation. In this condition the brake fluid pressure was set at 7 MPa [9]. This pressure was transferred onto the calliper housing. Then it was converted to force at the inner face of the cylinder and reaction force on finger area [4]. Both loads have the same values because they are equal and opposite force caused due to fluid pressure.

3. Results and discussion

This section will discuss the results of the present FEA analysis. The results for GCI calliper are presented in Figure 8, while for hybrid Mg-MMC are shown in Figure 9. It is revealed that from the analysis brake calliper made of hybrid Mg-MMC have smaller total deformation distribution and maximum equivalent elastic strains compared to GCI. The values were reduced by 2.76% and 2.93% respectively. This can be achieved because hybrid Mg-MMC was stiffer than GCI since it possesses larger Young's modulus than GCI. Through the study of literature review, deflection of brake callipers, also known as “bending of bridge” was highlighted as the priority problem that affected the performance of brake calliper. This problem can be improved by bridge design features, as Sergeant et al. [4] stated that bridge design features are the most important in maintaining structural stiffness. The FEA analysis results are summarised in table 2. The table indicates that hybrid Mg-MMC has the desired results having low maximum equivalent von misses stress, small total deformation and low equivalent elastic strain. From the present model and materials properties comparisons, hybrid Mg-MMC brake calliper had reduced the weight almost 72.29% to the GCI calliper.

The comparison of maximum equivalent von misses stress on the stress distribution of hybrid Mg-MMC brake calliper exceed the GCI calliper by 0.89%. This is the area where improvement can be made. In fact, larger von misses stress implies that the material is close to the yield point. When the stress exceeded the yield point, the material can be suffered some level of permanent distortion which mean it does not return to its original shape. Von misses stress means the stresses which act to distort the shape of the part. Engineers will typically try to design such that the peak stresses as low as possible to reduce the distortion of material [10]. Related to this some works have been done by one of the author to modify the original hybrid Mg-MMC brake calliper with few alternative designs. This is targeted to improve the performance of hybrid Mg-MMC brake calliper.

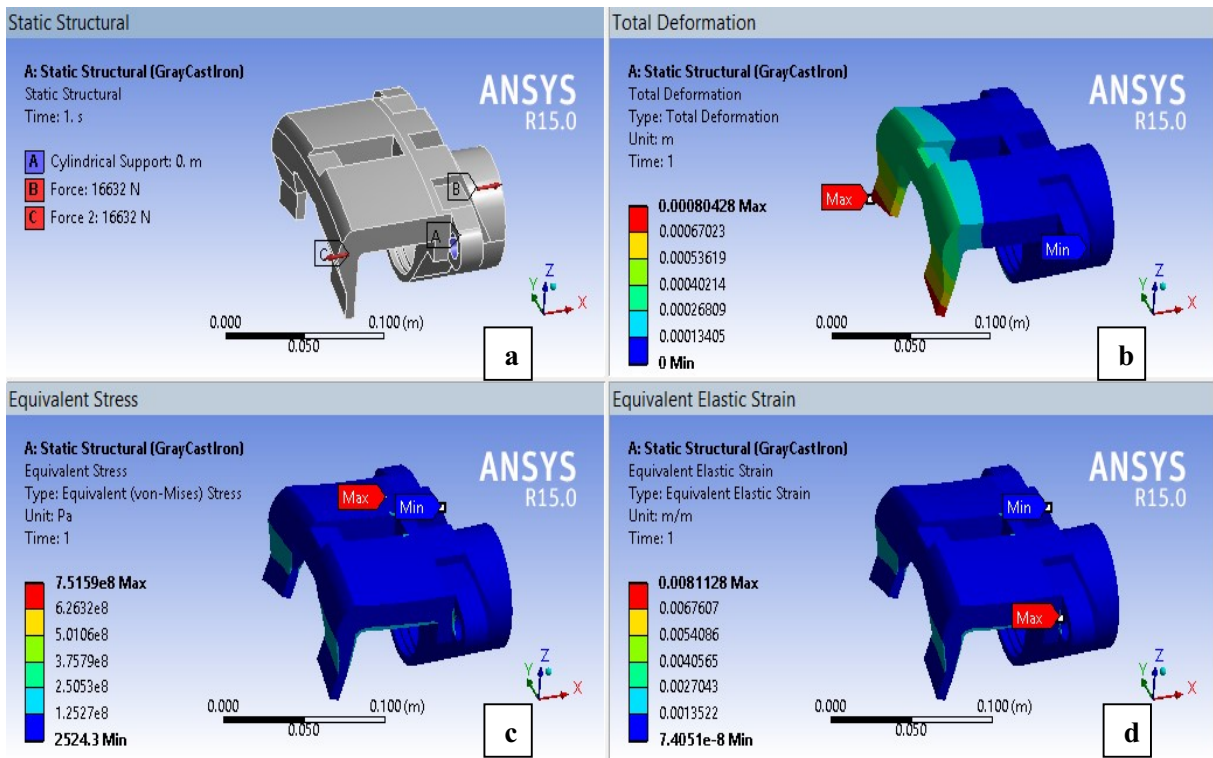


Figure 8. ANSYS analysis results GCI calliper (a) structural loadings (b) total deformation (c) equivalent stress (d) equivalent stress.

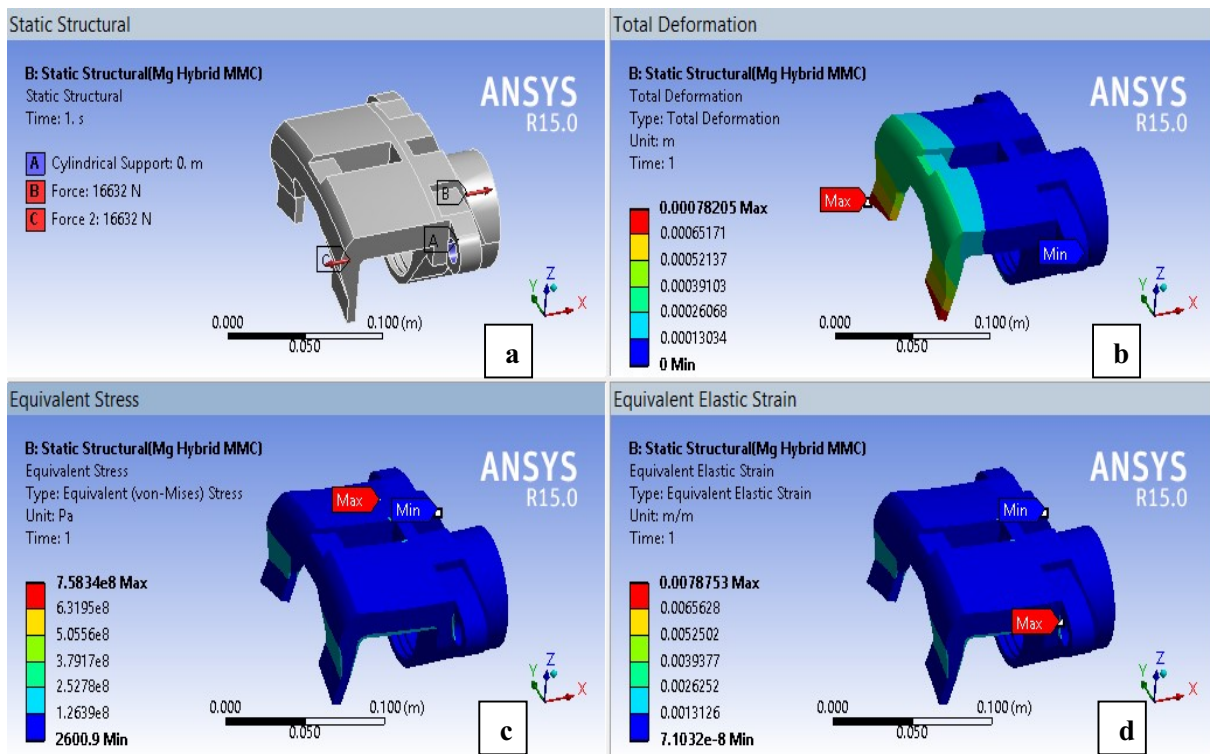


Figure 9. ANSYS analysis results Mg-MMC calliper (a) structural loadings (b) total deformation (c) equivalent stress (d) equivalent stress.

Table 2. Summarised FEA results of GCI and hybrid Mg-MMC brake callipers.

Properties	GCI	Hybrid nano-micro Mg-MMC	Percentage of improvement (%)
Total mass, kg	2.17250	0.60196	72.29
Max. Total Deformation, m	0.00080428	0.00078205	2.76
Max. Equivalent Stress, Pa	7.5159e8	7.5834e8	- 0.89
Max. Equivalent Elastic Strain, m/m	0.0081128	0.0078753	2.93

4. Conclusions

From this paper, it can be concluded that:

- The material of a brake calliper body must be rigid to allow less deflection and should be light to reduce the final weight.
- The proposed hybrid Mg-MMC, AZ31-14.0SiCmicro-1.0SiCnano can be a good alternative to replace GCI.
- The new material has potentially met the present demands for high performance brake calliper based on the extreme panic braking situation.
- From the results, the hybrid Mg-MMC calliper compared to the GCI has reduced the weight of the brake calliper, reduced in total deformation/deflection and better ability to withstand equivalent elastic strain.

Acknowledgements

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