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Structural and Thermal Analysis of Brake disc with Grey Cast Iron and Cenosphere-Aluminium Composite

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Abstract – *The slowing or stopping of a wheel is the highlighting feature of a disc brake. The repetitive braking incurs a high amount of heat generation during the process. Braking indulges high heat generation by means of friction between the rotor disc of the brakes and the brake caliper. This heat generation comprises of several physical and chemical changes within the rotor disc and the changes solely depend on the properties of the materials used. The conventionally used material of the brake disc: grey cast iron with high strength and low heat transfer coefficient is compared with a newly formed composite of cenosphere-aluminium with high heat transfer coefficient when compared materials for similar use. Static structural and transient thermal analysis is performed using the ANSYS workbench 16.2 on the solid rotor disc of the disc brake which is initially developed using Solidworks 2016. A detailed comparison is procured with the analytical results obtained from FEM. And therefore, based on the performance and strength, the best alternative material for the rotor disc is suggested.*

Key Words: Cenosphere-aluminium composite, heat flux, total deformation, equivalent stress, heat transfer coefficient, cast iron, static structural, transient thermal.

1. INTRODUCTION

In today's budding automotive market the competition for better piece of motorized vehicle is growing extremely. The racing fans involved will certainly know the prominence of honest brakes not merely for safety but also for remaining competitive. The disc brake (a tool for slowing or stopping the rotation of a wheel) usually is made up of cast iron or ceramic composites including carbon, Kevlar and silica, which is connected to the wheel and eventually to the axle, to pause the wheel. During this action, the brakes gain K.E. of the moving member. The energy absorbed by brakes is dissipated to the surroundings in the form of heat. The chief types of braking's used in automotive comprises of drum brakes and disc brakes. Although both the types have the similar braking methodology, the former brakes are the current trend and extensively used in the contemporary world, this paper advances around the processes related with it [1-3]. A rotor (brake disc) is one which is inflexibly tailored to and rotates with the wheel. Two brake pads (linings) are placed inside a caliper equestrian on the knuckle. The knuckle is attached on the chassis. When the driving force smashes the brakes, the hydraulic brake cylinder pressure upsurges and consequently the piston pushes the pads into interaction with the rotor. The friction forces amid the restraint apply braking torque on the rotor, which is linked to the wheel, and therefore the following friction between the tire and the road makes the car stop.

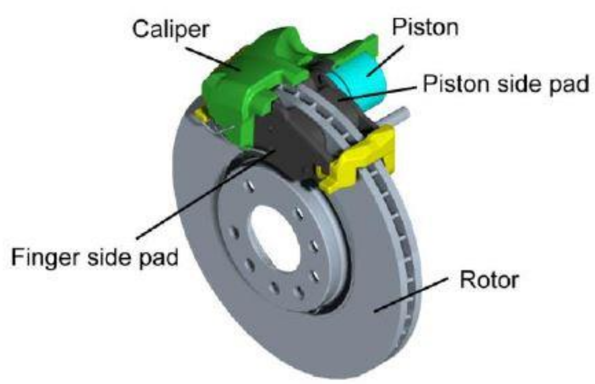

Fig 1: Disk Brake

1.1 Working principle of disc brake

When a brake device or pedal is pushed, the push rod which is associated to lever or pedal and master cylinder piston thrusts the master cylinder piston. The movement associated with it allows the master cylinder piston to glide and push the return spring within the bore of principal cylinder, which creates pressure within the reservoir tank. At this instant a primary seal permits the brake fluid of reservoir tank to run over it hooked on the brake hosepipes. A subordinate seal ensures that the brake fluid does not go opposite side. Then the fluid arrives in to cylinder bore of calliper assembly thru brake hosepipes and impulses the calliper piston. At this instant the piston ring changes in rolling shape with piston [4]. At that time the calliper piston pushes brake pad. This drive causes brake pads to stick with brake disc and create friction to stops the rotor to rotate. By this means, disk brake system stops or slows down the automobile. When the brake lever or pedal is free, the piston ring pushes the calliper piston back to cylinder bore of calliper till both the calliper piston and piston ring derive into their original figure. At this moment retraction spring pushes the brake pads to their old position. The return spring in master cylinder assembly shoves the master cylinder piston back into its original position and lets the fluid to drift back to tank via hosepipe and master cylinder bore.

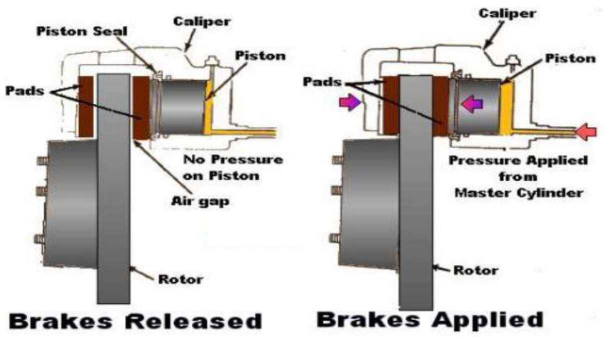

Fig 2: Working of disc brake

1.2 Conventional material and its properties

Usually, rotors used in passenger cars, are prepared of grey cast iron. The brake pads can be made of many different material combinations, but are essentially constructed of four components: a binder, reinforcing fibres, fillers, and frictional additives. The analysis performed here has 2 materials of which the conventional grey cast iron is primarily analysed with the following properties:

Table -1: Mechanical properties of grey cast iron

Mechanical properties of Grey Cast Iron	
Density	7200 Kg/m^3
Coefficient of thermal expansion	1.1 e^{-5} C^{-1}
Young's modulus	1.1 e^{11} Pa
Poisson's ratio	0.28
Shear modulus	4.2969 e^{10} Pa
Ultimate tensile strength	2.4 e^{8} Pa
Ultimate compressive strength	8.2 e^{8} Pa
Isotropic thermal conductivity	52 W/m/C
Specific heat	447 J/Kg/C

1.3 Cenosphere-Aluminium Composite

The commonly used aluminium composite for these applications is the aluminium alloy-based metal matrix with ceramic particle reinforcement, which is considerably more expensive than the ceramic particles derived from fly-ash. Material costs exclusive of mixing and processing costs for cenosphere composites are very positive compared to orthodox Al–SiC ingredients. Because of low cost of cenosphere particles, the whole cost drops sharply with accumulative reinforcement content [5]. Their comparative lower density to conventional grey cast irons results in reduction of weight up to 20% in their applications. The study here revolves around reinforced aluminium alloy 6063. Its small thermal development and high durability to hot and cold conditions makes it appropriate for disc brakes. Various volume percentages of cenosphere were reinforced out of which 10% cenosphere addition resulted in good mechanical and tribological properties.

Table -2: Mechanical properties of composite

Mechanical properties of 10vol% Cenosphere-AA6063 composite	
Density	2140 Kg/m^3
Coefficient of thermal expansion	2.046 e^{-5} C^{-1}
Young's modulus	8.37 e^{7} Pa
Poisson's ratio	0.33
Shear modulus	3.1466 e^{7} Pa
Ultimate tensile strength	9.5 e7
Ultimate yield strength	1.427 e^{7}
Isotropic thermal conductivity	250 W/m/C
Specific heat	921.1 J/Kg/C

2. FINITE ELEMENT ANALYSIS

The finite element method has become a influential tool for the numerical resolutions of a wide range of engineering complications. It has been developed concurrently with the cumulative use of the high- speed electronic digital computers and with the growing emphasis on numerical methods for engineering study. In this step it defines the analysis type and options, apply loads and initiate the finite element solution [6-7]. This involves three stages:

- Pre-processor phase
- Solution phase
- Post-processor phase

The ANSYS Workbench delivers a unified working environment for developing and managing a variety of CAE information and makes it easier for set up and works with data at a great level. Workbench provides improved interoperability and mechanism over the flow of data between these task modules. Numerous tools and techniques are unified to efficiently manage big models. Data can be transported from a 2D coarse model [Full Model] to a 3D sub model. Sub modelling is presented for structural and thermal investigation types with solid geometry.

2.1 Three dimensional model of solid rotor disc

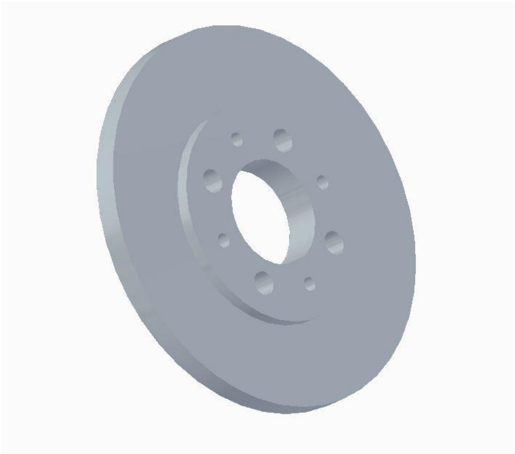

Fig 3: 3-D image of the solid rotor disc

The 3-D modelling of the solid rotor disc was carried out using the Solidworks software version 2016. The dimensions for the rotor disc were taken as the standard dimensions and the further development of the project revolves around this model of the rotor disc. The thickness of the outer flange of the rotor disc was set at 15mm.

2.2 Meshing

The aim of meshing in Workbench is to deliver robust, easy to use meshing tools that will shorten the mesh generation procedure. The model used must be segmented into a number of small pieces recognized as finite elements. Meanwhile the model is divided into a number of discrete parts, in simple terms, a mathematical net or "mesh" is required to carry out a finite element analysis. A finite element mesh model created is presented in fig.4. The mesh results are as shown in table No 3. The type of mesh used in the analysis is of three dimensional triangular elements. The meshing relevance centre was kept fine and the smoothing process was maintained at a minimum pace. The span angle centre was kept fine with minimum edge length of 2.0mm.

Table -3: Meshing details

Meshing details	
Number of nodes	25365
Number of elements	13465

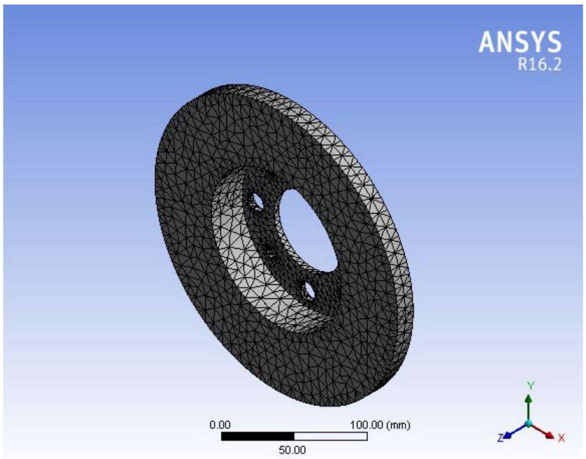

Fig 4: FEA mesh model for solid rotor disc

2.3 Thermal and structural boundary conditions

The boundary conditions are presented into module ANSYS Workbench, by selecting the mode of simulation and by defining the physical attributes of materials and the initial conditions of simulation. In this work, a transient thermal analysis will be carried out to investigate the heat flux variations by applying temperature constraints for the braking procedure as shown in fig 5. Additionally, structural investigation is carried out by coupling thermal analysis. In addition convection heat transfer coefficient is applied at the surface of the ventilated disc for the analysis as shown in fig 6.

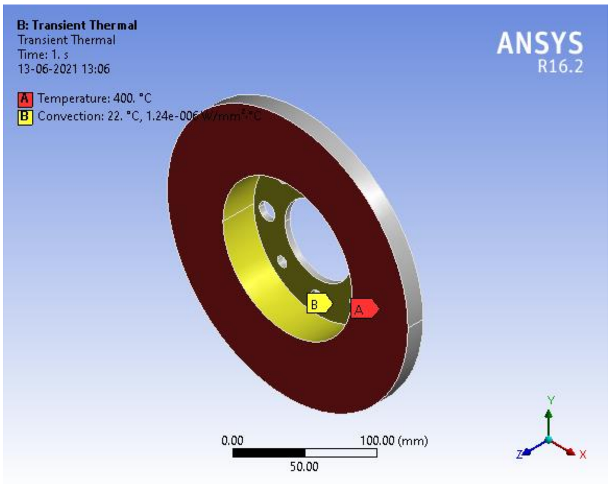

Fig 5: Thermal boundary conditions for rotor disc

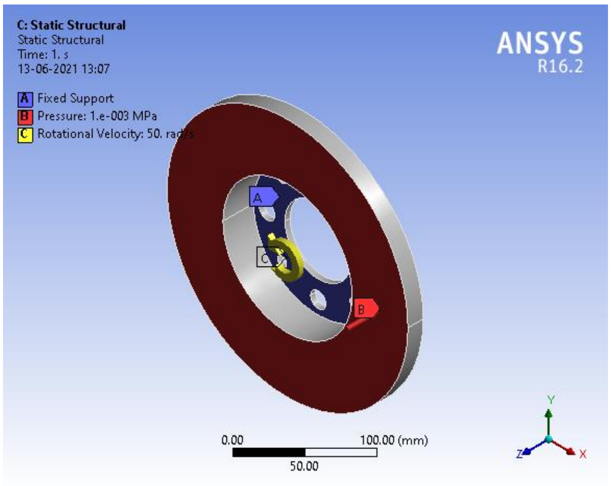

Fig 6: Structural boundary conditions of rotor disc

3. RESULTS

To authenticate the present model, a transient thermal analysis behavior of the disc brake was performed for the operating condition of the constant hydraulic pressure of 1MPa and an angular velocity of 50 rad/s during the brake application. The neutral temperature of the system was assumed to be 22°C and the maximum temperature that could occur on the outer flange of the rotor disc was assumed to be at an average of 400°C (a temperature between the ranges of 200-600°C). The ANSYS simulation is obtained for the single brake application. The braking time of the system is taken to be 1s at constant speed driving. The single step used for time computation includes a total number of 6 sub steps. The results obtained from the analytical and FEM solutions are compared for both transient and structural behavior of the model. Finally the model with the desirable property values is suggested. The comparison for different parameters of the analysis is provided to validate the results.

3.1 Equivalent stress diagram

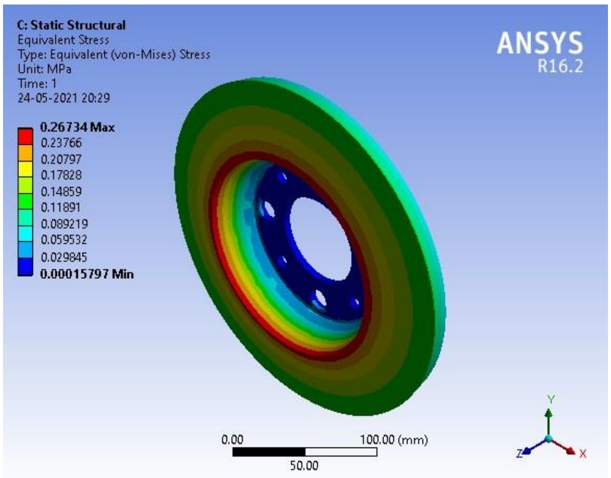

Fig 7: Equivalent stress diagram for grey cast iron

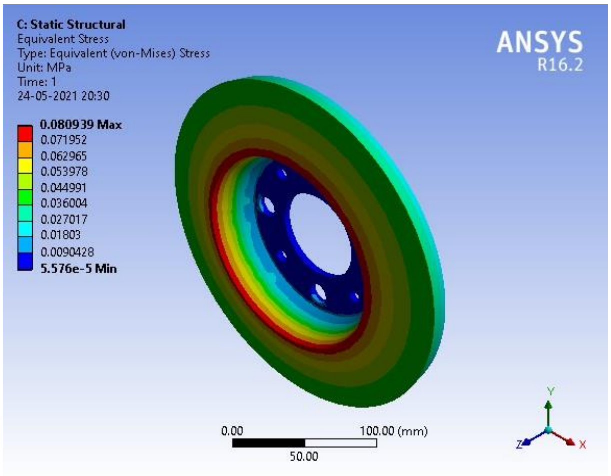

Fig 8: Equivalent stress diagram for cenosphere-aluminium composite

3.2 Total deformation diagram

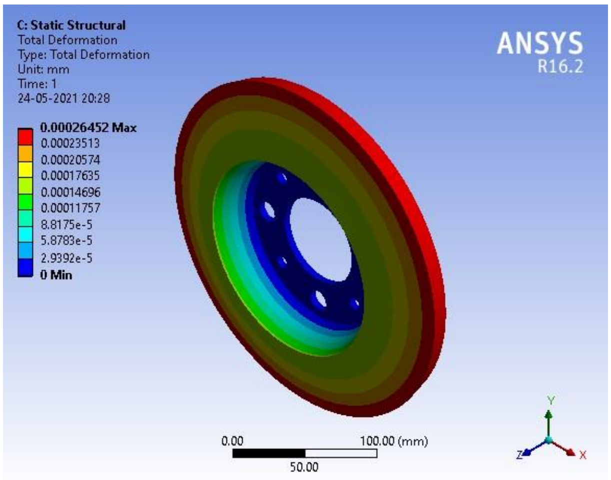

Fig 9: Total deformation diagram for grey cast iron

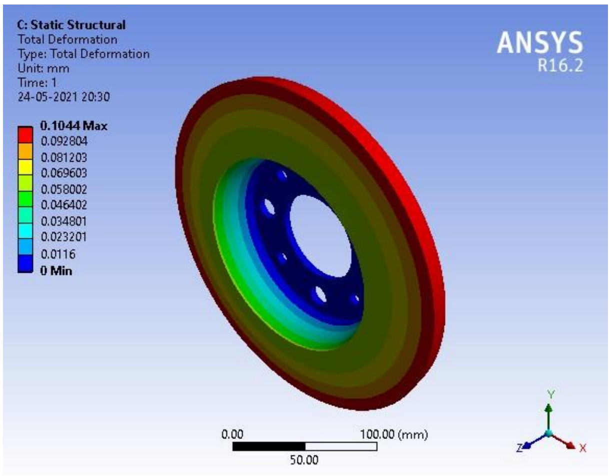

Fig 10: Total deformation diagram for cenosphere-aluminium composite

3.3 Total heat flux diagram

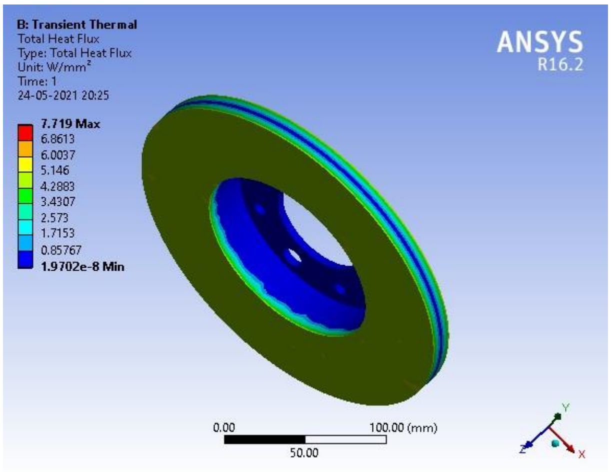

Fig 11: Total heat flux diagram for grey cast iron

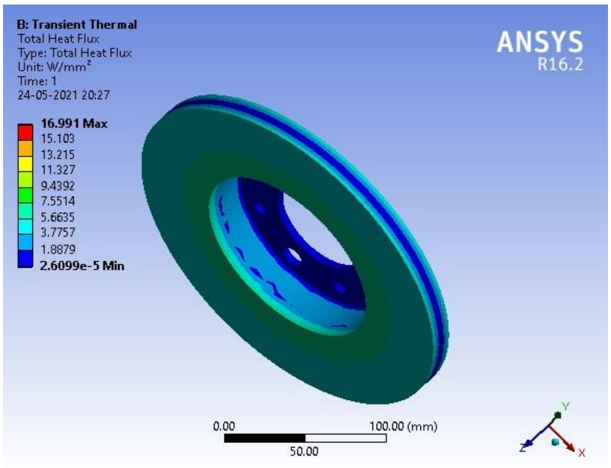

Fig 12: Total heat flux diagram for cenosphere-aluminium composite

4. COMPARISON AND DISCUSSION

The values obtained after the analysis are carefully observed and are plotted against the load applied using the subsequent sub steps involved. The plot of equivalent stress against the applied load is observed in fig 13. Similarly the plot of total deformation with load applied and the plot of total heat flux with the applied load are portrayed in fig 14 and fig 15 respectively. It is to be duly noted that the blue line in the graph represents the composite material of cenosphere-aluminium (represented as CA in the fig) and the red line shows the variation of values of the grey cast iron (represented as CI in the fig). The graphs provide a better picture for the comparison of the obtained results in addition to the table provided with exact obtained values of the analysis (table 4). The three parameters used here can drive us to the conclusion that we ought to seek after the completion of the comparison.

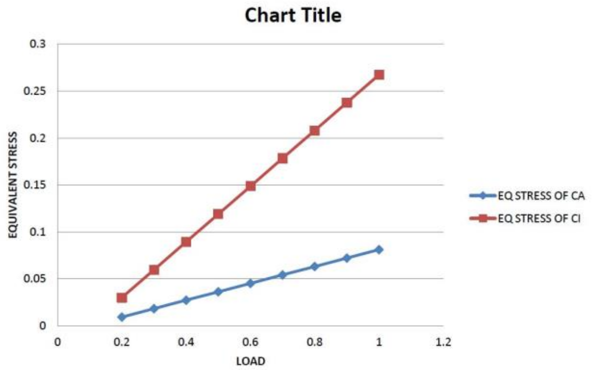

Fig 13: Load Vs Equivalent stress

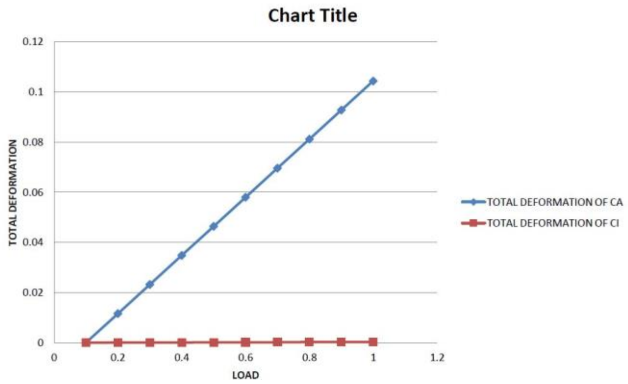

Fig 14: Load Vs Total deformation

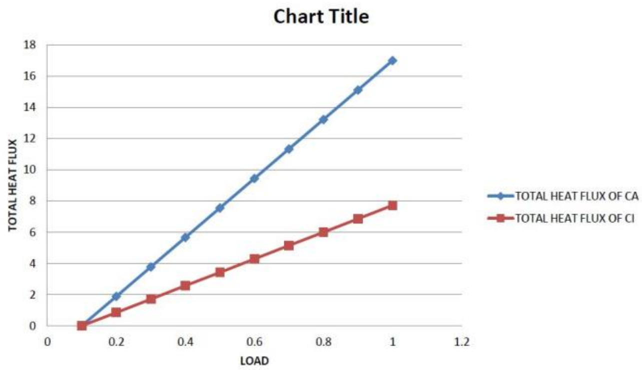

Fig 15: Load Vs Total heat flux

Table 4: Comparison of parameter values

Comparison of maximum and minimum values for different parameters		
Properties	Grey Cast Iron	Cenosphere-aluminium composite
Max Total Deformation (mm)	0.00026452	0.1044
Min Total Deformation (mm)	0	0

Max Total Heat flux (W/mm^2)	7.791	16.991
Min Total Heat flux (W/mm^2)	0.0000000197	0.000026099
Max Equivalent stress (MPa)	0.26734	0.080939
Min Equivalent Stress (MPa)	0.00015797	0.00005576

5. CONCLUSION

After comparing different results of change in heat flux, deformation and the stress fields obtained from the analysis, we concluded that the cenosphere-aluminium composite can be an alternative to the grey cast iron to be used for braking applications. The reason behind conclusion was the fact that the total heat flux value obtained for the grey cast iron was nearly half the value of the same for cenosphere composite indicating that it was able to withstand high temperature change that generally occurs during the braking process up on the disc of brakes. Adding to feature, the composite also had the lesser amount of the stress developed within it, which was way far below its actual yield stress limit, making it a perfect choice for the application sought after. The third and the last parameter used for the comparison was the total deformation which was higher for the composite as compared to the value of the cast iron for the same. Even though the deformation turned out to be villain in the analysis, researches have shown that the value of deformation can be a maximum of 0.15mm, whilst the value obtained for the same in the analysis was 0.1044mm, allowing it to be used for the braking application [10]. The major advantage of the alternative used for the braking is the weight reduction of the system. There was almost a 20% weight reduction of the disc which makes the vehicle lighter. This weight reduction, as an effect, will lead to the fuel efficiency of the vehicle. This material is a perfect match for the applications involving a repeated braking which eventually will involve higher temperature dissipations.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial benefits or personal relationships that could have seemed to affect the work stated in this paper.

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