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Design and Thermal Behaviour of Brake Discs with Various Ceramics for Effective Heat Transfer

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Abstract: Since decades, the only source of the material is reinforced alloys of such as iron, steel or aluminium are used in the automobile industry but due to high demand for performance. Researchers found introducing ceramic components can withstand elevated temperatures which are produced during working. Nowadays ceramics are used in Pistons, piston-skirts, cylinder heads, intake manifolds, etc. The work here is been carried out by scrutinizing different compositions of ceramics on a 3D model brake disc in replace of a traditional cast-iron disc. Apart from withstanding high temperature, foremost is heat dissipation to the airstream. Performing transient thermal analysis shows the characteristics of thermal stability, heat dissipation and other mechanical behaviour w.r.t various conditions. Giving the results of better thermo-mechanical stability over present materials such as thermal behaviour, strength to weight ratio, wear and tear resistance, withstanding chemical erosion subjected to acidic and caustic environments that occurs in other materials.
Keywords: Thermal, Ceramics, disc, Heat, Dissipation, Stability

I. INTRODUCTION

Present day industries of aerospace and automobile are been upgrading to advance manufacturing techniques about brake discs using ceramic composites replacing present alloys to compete over different mechanical properties of elasticity, hardness, tensile strength at soaring temperatures keeping their wear and tear resistance to minimum using different materials to have the optimum strength to weight ratio. As ceramics deliver high performance in both dry and wet conditions of comfort, durability, resistance, corrosion and high-tech appeal.

A ceramic is an inorganic non-metallic solid made up of either metal or non-metal compounds that have been shaped and then hardened by heating to high temperatures. In general, they are hard, corrosion-resistant and brittle. Traditional ceramics are clay-based, but high-performance or advanced ceramics are being developed from a far wider range of inorganic non-metal materials. Advanced ceramics have the properties of high strength, high hardness, high durability and high toughness.

These advanced ceramics are generally oxides of elements or non-oxides (like borides, nitrides and silicide's) Production processes firstly involve thoroughly blending the very fine constituent material powders. After shaping them into a green body, this is high-temperature fired (1,600–1,800°c). This step is often carried out in an oxygen-free atmosphere.

The high temperature allows the tiny grains of the individual ceramic components to fuse together, forming a hard, tough, durable and corrosion-resistant product. This process is called Sintering.

II. MATERIALS INVOLVED

Types of Ceramics used

1) *Aluminium oxide (Al2O3):* Aluminium oxide (Al2O3) is commonly called as alumina which is a naturally occurring compound in the form of crystalline polymorphic having alpha- Al2O3 as the mineral corundum. Alumina is naturally a passive compound towards oxidation with high electrical resistivity and relatively high thermal conductivity in ceramic materials. Also, it is relatively hard and tough. Therefore, it is employed in making of abrasives for abrasive water jet machining.
2) *Silicon Carbide (SiC):* Silicon Carbide (SiC) is the only compound formed between silicon and carbon, by a high-temperature chemical reaction of sand and carbon at a temperature range of 1600-2500°c. It is one of the ceramics which poses high strength, hardness, elastic modulus and excellent thermal shock resistance. Having these factors making it involved in the manufacture of heat exchangers, fixed and moving turbine components.
3) *Silicon Nitride (Si3N4):* Silicon Nitride (Si3N4) is formed by heating crystals of silicon in a temperature range of 1300-1400°c surrounded by an atmosphere containing nitrogen in it. Further, it is carried by a spark plasma sintering process, where the powder is rapidly heated by continuously sending pulses of electric current through it. Therefore, the characteristics of very hard and high thermal stability making it to find its application in manufacturing of bearings, cutting tools and aerospace components.

4) *Reinforced Carbon-Carbon (RCC):* Reinforced Carbon-Carbon (RCC) is material which consists of carbon fibre that is reinforced in the matrix of graphite. This compound is further developed as Carbon fibre-reinforced Silicon Carbide(C/Sic) which is more durable than RCC but quite heavier than RCC. Because of the low coefficient of thermal expansion, it is well suited in the structural applications of higher temperatures.
5) *Zirconia:* Zirconia is a ceramic formed by the reaction of zircon with oxygen and has different crystal structures at elevated temperatures like monoclinic below 1170 °c, tetragonal between 1170 °c and 2370 °c, and cubic above 2370 °c. Zirconia has monoclinic structure at room temperature and transition occur at elevated temperatures to tetragonal and cubic. This transition induces cracks when the temperature cools down. In order to avoid this, it is blended with some other compounds to stabilize it. The mechanical and thermal properties of zirconia make it the most opted ceramic out of all.

III. ADVANTAGES OF CERAMIC BRAKE DISC OVER METALLIC ALLOYS

In a high-end Performance car, the high power on the wheels needs a lightweight wheel assembly system where Ceramics brake discs are very light in weight over cast iron. Due to intense heat generations, cast iron wears out quickly but ceramics are heat resistant up to 1000°c with corrosion and wear resistance. The extreme hardness and relatively lightweight material add a good strength to weight ratio over cast iron

Using ceramics, these materials possess more resistance compared to other metals, including tribological properties, thermal insulation and superior electrical capacity. Having fewer physical limitations, the life of the ceramic brake disc lasts 60 times longer than a standard cast iron disc, prolonging the life of the disc.

IV. DESIGN CONSIDERATIONS

A. According to a General High-end Performance Car.

1) Brake disc Diameter **-** 400mm.
2) Brake disc Thickness – 38mm.
3) Mass of the vehicle ~ 1900 kg.
4) Velocity of the Vehicle ~ 100 Kmph.
5) Heat generated – 0.95% of Kinetic energy.

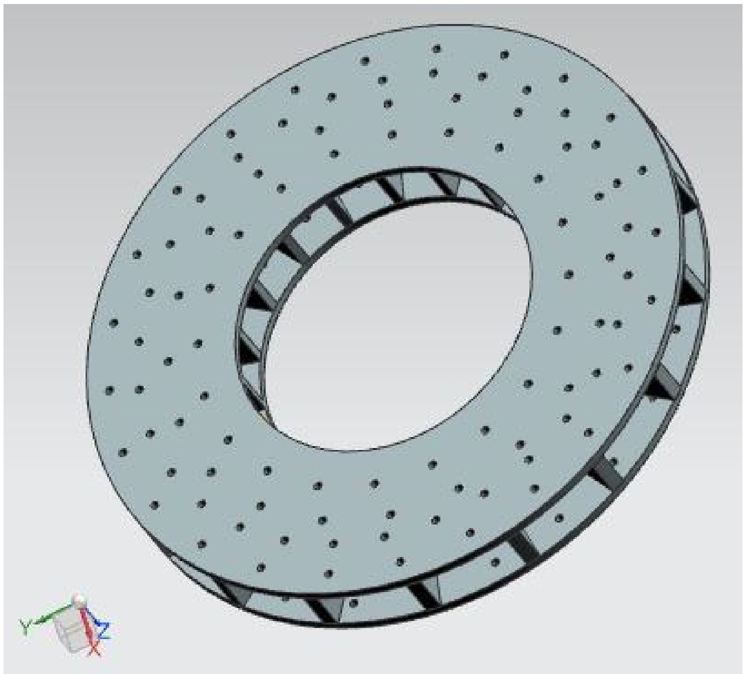

Fig. 1 3D CAD model of the brake disc.

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TABLE I
Mechanical and thermal properties of various ceramics

Material / Parameter	Aluminium oxide (Al_2O_3)	Silicon Carbide (SiC)	Silicon Nitride (Si_3N_4)	Reinforced Carbon-Carbon (RCC)	Zirconia (ZrO_2)
Density(kg/m^3)	3980	4840	3250	1700	6150
Poisson's ratio	0.33	0.37	0.28	0.32	0.32
Modulus of elasticity (GPa)	413	137	297	228	250
Yield strength (MPa)	665	1245	525	700	711
Thermal conductivity(W/m-K)	38.5	20.7	43	40	2.7
Specific heat(J/Kg-K)	955	650	1100	760	540

B. Analysis of the Ceramic Brake Disc

The following figures shows the analysis results of heat flux and temperature generated in two parts of a and b which are performed in the solid works software with respect to the abovementioned ceramic materials by considering the design factors given in **3.1** and Table 1: mechanical and thermal properties of various ceramics. The methodology adopted for analysis is by calculating the heat power generated which is 0.95 times of kinetic energy acting upon it for 3 seconds giving a value of 232.161KW. The same force is applied on various ceramic compositions and the results generated are shown below.

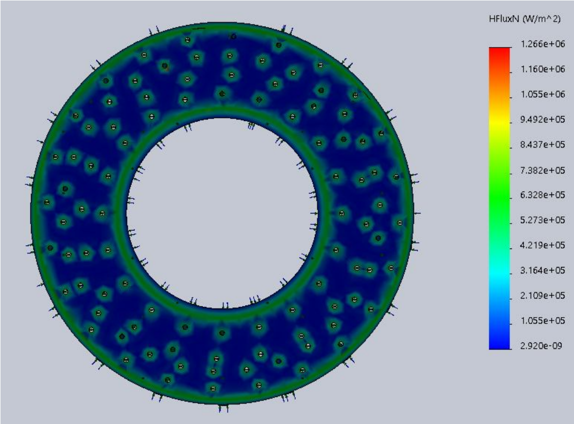

Fig.2 (a) Heat flux of Al2o3 brake disc

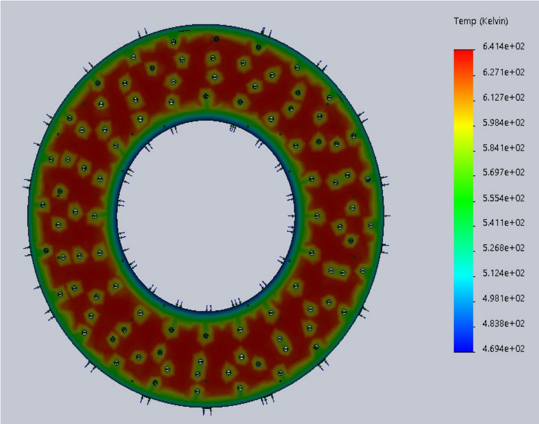

Fig.2 (b) Temperature generated of Al2o3 brake disc

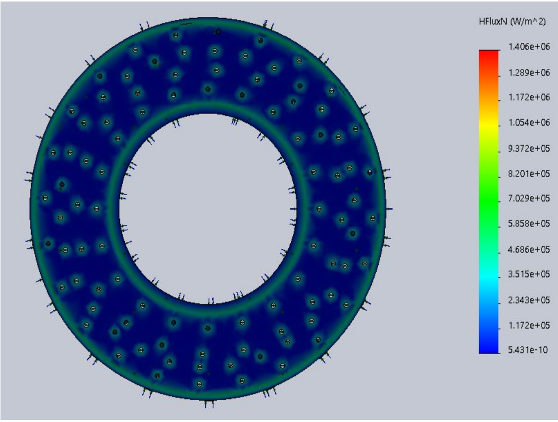

Fig 3(a) Heat flux of SiC brake disc

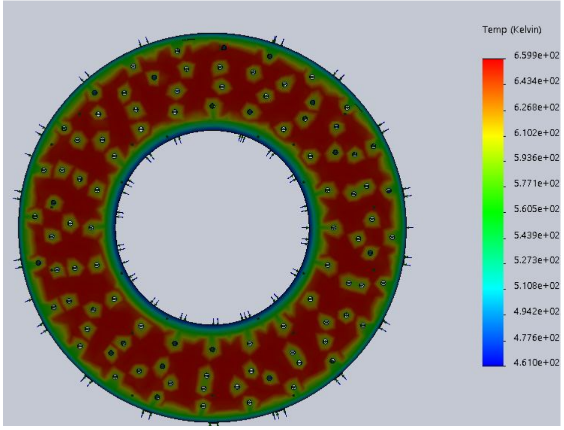

Fig 3(b) temperature generated of SiC brake disc

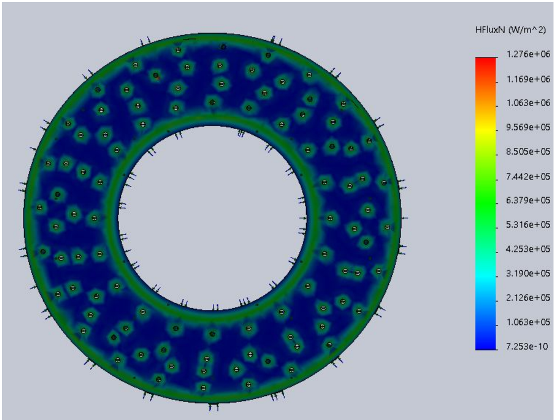

Fig 4(a) Heat flux of Si_3N_4 brake disc

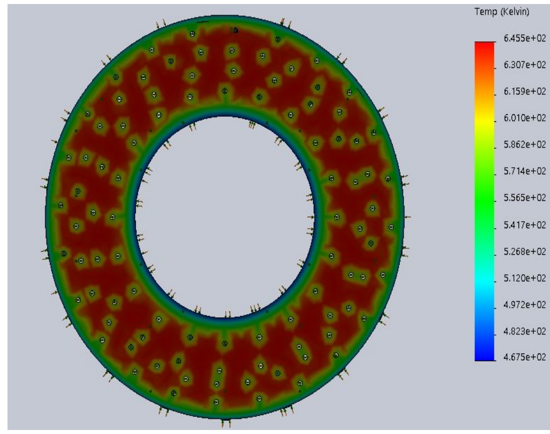

Fig 4(b) temperature generated of Si_3N_4 brake disc

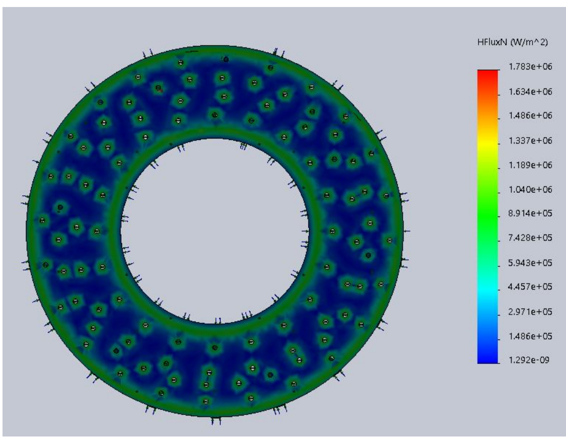

Fig 5(a) heat flux of RCC brake disc.

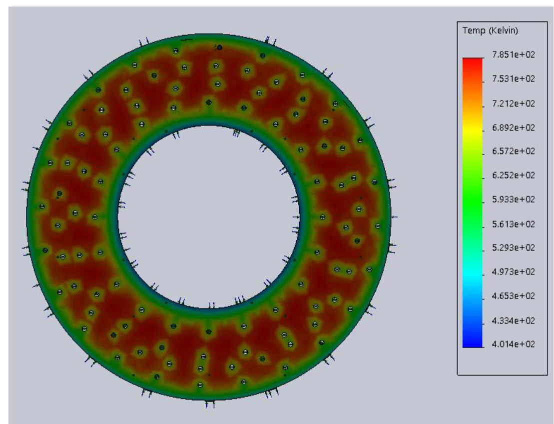

Fig 5(b) temperature generated of RCC brake disc

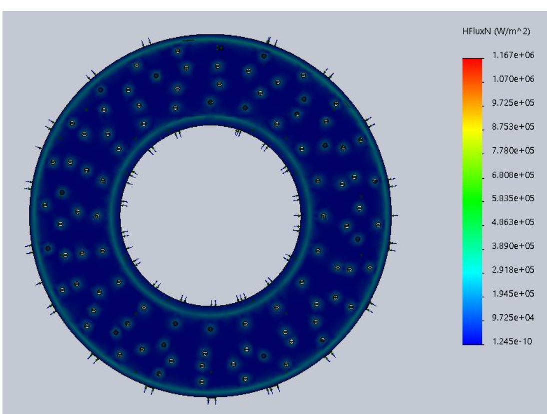

Fig 6(a) Heat flux of Zirconia brake disc

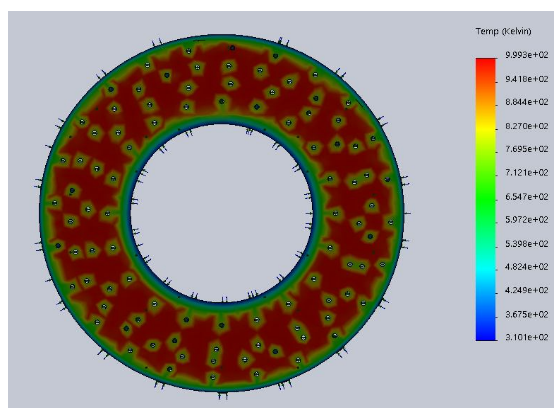

Fig 6(b) Temperature generated of Zirconia brake disc

V. RESULTS AND DISCUSSIONS

After performing transient-thermal analysis, the thermal behaviour of the various ceramics is tabulated below with maximum and minimum values of temperatures and heat flux observed. Recording Zirconia with maximum temperature of 999.3 K, minimum temperature and heat flux of 310.1K, 1.245e-10 W/m2 respectively. Maximum heat flux of 1.783e+06 is recorded in Reinforced carbon-carbon.

TABLE II
Temperature and heat flux values of various ceramics

Property / Material	Maximum temperature(K)	Minimum Temperature (K)	Maximum Heat Flux(W/m2)	Minimum Heat Flux(W/m2)
Alumina (Al_2O_3)	641.4	469.4	1.266e+06	2.92e-09
Reinforced carbon-carbon (RCC)	785.1	401.4	1.783e+06	1.292e-09
Silicon Carbide (SiC)	659.9	461	1.406e+06	5.43e-10
Silicon Nitride (Si_3N_4)	645.5	467.5	1.276e+06	7.253e-10
Zirconia (ZrO_2)	999.3	310.1	1.167e+06	1.245e-10

VI. CONCLUSIONS

At the end of this study conducted it reflects that

A. As ceramic discs are generally light in weight, so these can be used as disc materials for high performance cars.
B. At higher speeds the heat generated by braking can reach up to 1000°C, so there is a high probability that the disc surface wears out, which would result in reducing thereby the co-efficient of friction between brake pad and disc.
C. The ability of cast iron to resist the heat flow through it is very poor as compared to ceramics from the above analysis performed. So, this rolls out to a conclusion of increasing the lifetime of braking components with uninterrupted braking performance for longer periods.

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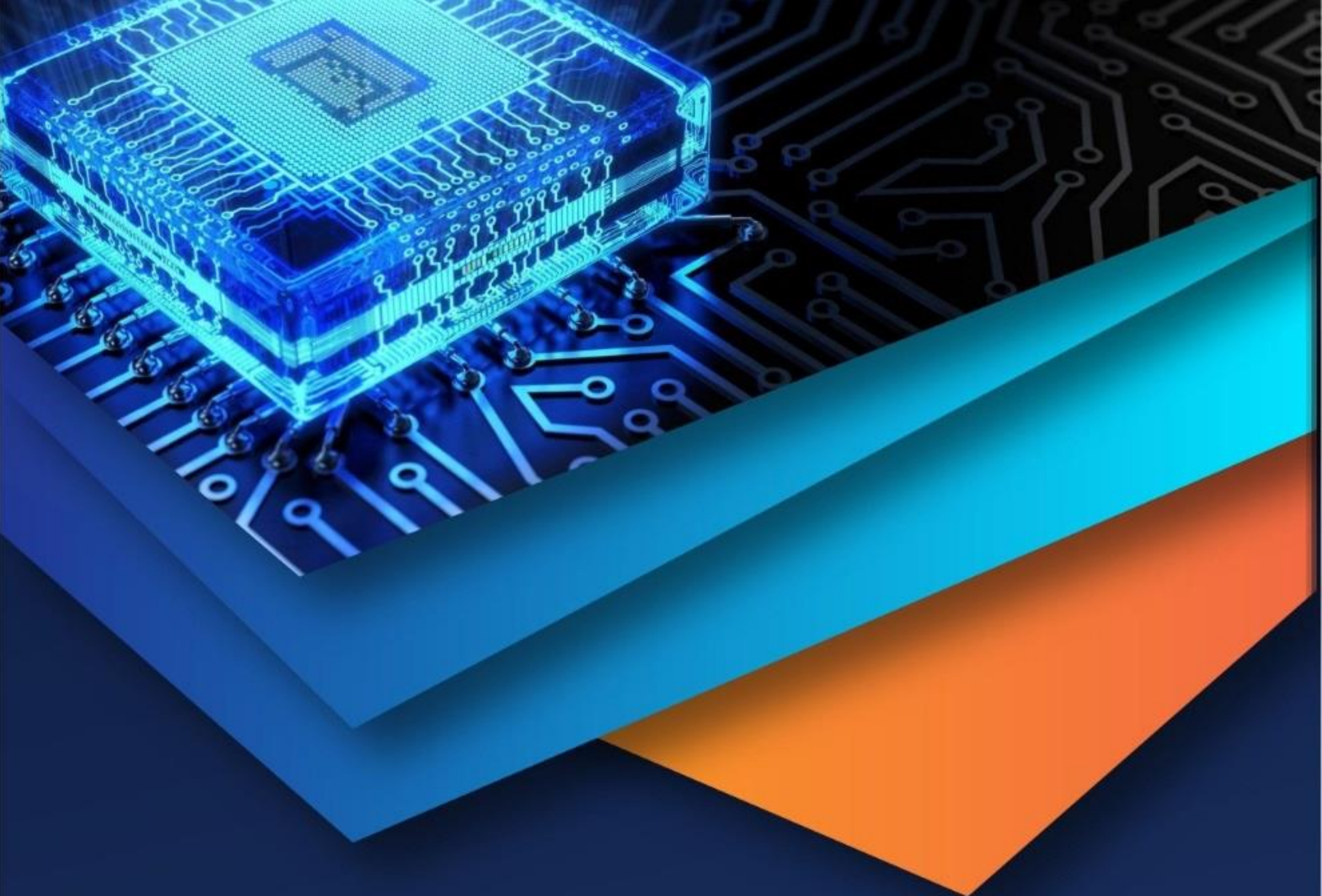

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