

Development and Analysis of Finned Brake Drum Model for Effective Heat Transfer

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Abstract

Brake drum is one of the important components of braking system in automotive applications. Brakes of an automobile generally fail when the working stress exceeds the maximum permissible stress and excessive heating of brake drum. Heat remained in drum without being released is key parameter for failure of brake drum. Weight of brake drum is another key parameter which is to be considered. In this paper, these two parameters are satisfied by modifying the brake drum into rectangular and triangular finned brake drum by converting the one fourth height into the annular rectangular and triangular fins. The rate of heat transfer and fin effectiveness are calculated theoretically. The model is then designed in CATIA V5R17 software and the heat flow and temperature gradient along the surface are analyzed using two different materials for brake drum i.e. grey cast iron and aluminum 6061, temper t6 by using ANSYS R16.0 software and the results are compared.

Keywords: Brake drum, Fin, Annular Fins, Effective Heat Transfer, CATIA, ANSYS.

I. INTRODUCTION

The brakes are energy conversion system which converts the kinetic energy of a moving vehicle into thermal energy. The systems are designed to decelerate the vehicle wheels movement through friction, thereby absorbing the kinetic energy at the wheels. The drum brakes are mainly used at the rear wheels while the disc brakes are extremely used for the front bakes because of their greater directional stability. In brake drum, friction is caused by a set of shoes that presses against the inner surface of a rotating brake drum. Within the drum are shoes lined with friction material. The brake shoes moves against the inner surface of the brake drum by the action of the piston inside the wheel cylinder. The hydraulic fluid under pressure in the wheel cylinder moves the pistons which forces the brake shoes against the brake drum. The wheel cylinder and the shoes are mounted on the back plate. The brake drum is the large critical part of the braking system that rotates round the brake shoes. When the drum is heated by hard braking, the diameter of the drum increases and the brake pedal must be further depressed to obtain an effective braking action. This is known as brake fade. By introducing the fins on the outer surface the rate of heat transfer can be increased.

1.1 Formulation of the problem for the development and analysis of Brake Drum

Brake drum fails under the excessive temperature makes the drum to wear and tear, brake fade, etc. One of the failure is brake fade which is caused by the excessive heat of the inner surface by the pressing of the brake shoe against the drum. This failure can be minimized by increasing the dissipation of the heat to air, this can be achieved by the fins which increases the surface area of the brake drum. For this problem, fins are added to the outer surface of the brake drum. It increases the weight so it is converting one-fourth (1/4) of the overall height thickness of the original model into extended surface (fins) and then analyzed in this paper.

1.2 Design Methodology

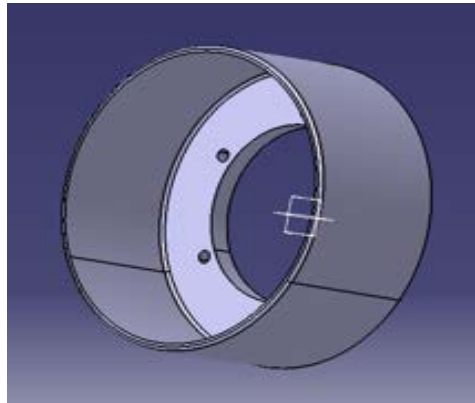
1. The models of original brake drum, rectangular finned brake drum and triangular finned brake drum have been designed in CATIA V5R17 software.
2. Structural analysis of the original and modified brake drum is done using ANSYS R16.0 software.
3. Thermal analysis of the original and modified brake drum is done using ANSYS R16.0 software.

1.3 Design Variables of Original and Modified Brake Drum

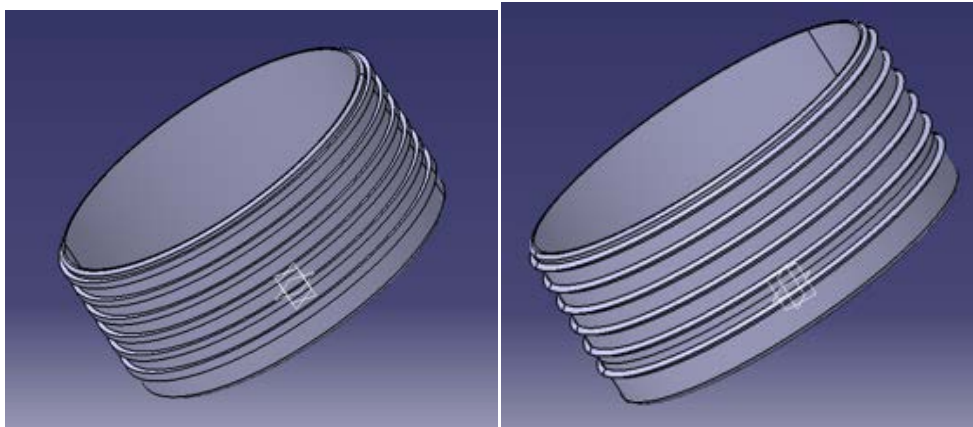
Following are the design variables for the original and modified brake drum

Table 1. Models Specification

Sl.No	Parameter	Value
1	Dust Shield Recess diameter	480 mm
2	Brake Face Diameter	460 mm
3	Brake Face Width	180 mm
4	Overall Height	210 mm
5	Squealer Band Thickness	10 mm
6	Width of fin	10 mm
7	Bolt Hole Diameter	20 mm
8	Number of Bolt Hole	6
9	Hub Pilot	280 mm
10	Bolt Circle Diameter	20 mm
11	Number of fin	6



(a)



(b)

(c)

Fig 1. (a) Original model, (b) Rectangular finned model, (c) Triangular finned model

II. STRUCTURAL ANALYSIS

The amount of friction developed between the two surfaces in contact is independent of the area of the surface in contact. However the magnitude of the force of friction or retarding force created between the brake lining and the brake drum depends upon the pressure or force exerted on the shoes by the retarding mechanism and the coefficient for the two materials. For the purpose of this paper, a retarding force of 150N was considered to be acting between the brake lining and the brake drum.

2.1 Theoretical Calculations on Brake Drum

From the concept of thin and thick cylinders [6], the brake drum can be assumed to be a thin cylinder as thickness to inner radius ratio is not greater than 1/10. It involves two kinds of stress i.e., hoop stress and longitudinal stress. The hoop stress can be taken as equivalent stress as its magnitude is high compared to longitudinal stress.

According to the boundary conditions, the force of 150 N acts on the internal wall of brake drum. The hoop stress is the force exerted circumferentially (perpendicular both to the

axis and to the radius of the object) in both directions on every particle in the cylinder wall. It can be described as: $\sigma = (Pd)/2t$

where P is intensity of internal pressure

d is Internal diameter of cylindrical shell

t is thickness of cylindrical shell.

$$\begin{aligned} \text{Equivalent stress } \sigma &= (150 \cdot 0.460) / (2 \cdot \pi \cdot 0.230 \cdot 0.180 \cdot 2 \cdot 0.010) \\ &= 13262.112 \text{ Pa} \end{aligned}$$

The circumferential strain (ϵ_c) in the brake drum during braking is given by

$$(\epsilon_c) = (\sigma_c - \mu \sigma_l) / E$$

Where σ_c is hoop stress in Pascal

σ_l is longitudinal stress in Pascal

μ is poisons ratio

E is the young's modulus of the material used for brake drum.

$$\begin{aligned} \text{Equivalent strain } (\epsilon_c) &= (\sigma_c - \mu \sigma_l) / E \\ &= (Pd/2tE) (1 - 0.5\mu) \\ &= (13262.1192 \cdot 0.86) / 110 \cdot 10^9 \\ &= 1.03 \cdot 10^{-7} \end{aligned}$$

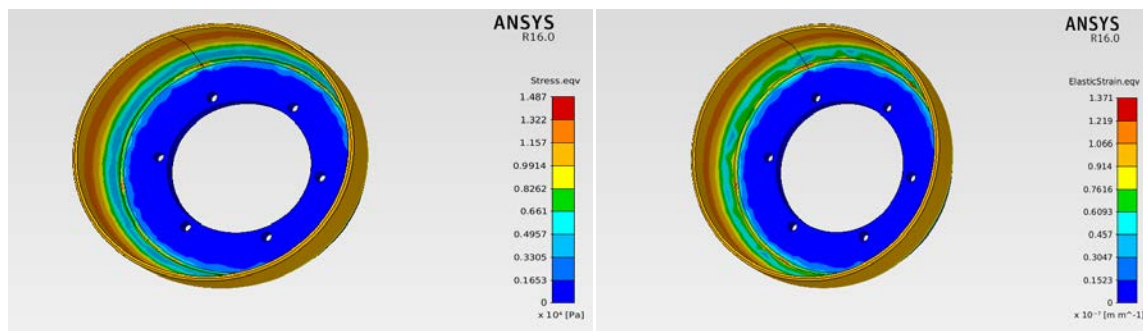
Similarly, for the rectangular finned brake drum and triangular finned brake drum using grey cast iron and aluminium 6061, temper t6 are calculated and tabulated.

2.2 Static Structural Analysis by using ANSYS R16

Static structural analysis is a technique used to obtain the equivalent stresses and the equivalent strains in the brake drum models

(a) Original Brake Drum

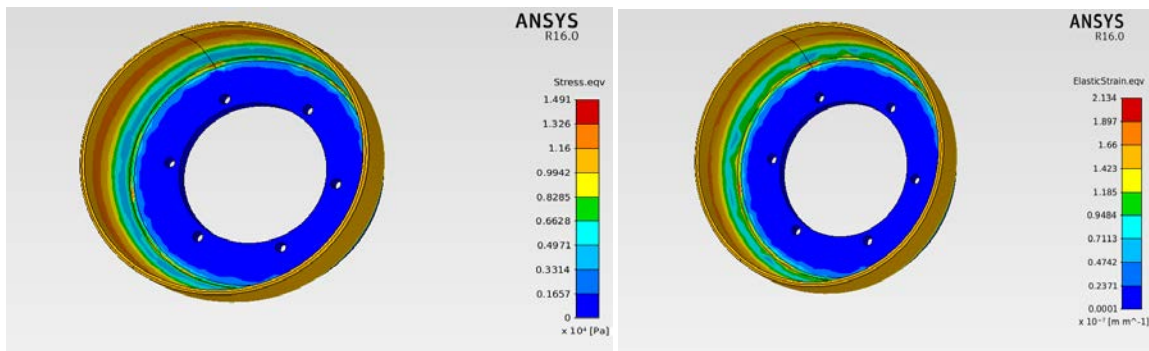
(i) Grey Cast Iron



(a) Equivalent Stress

(b) Equivalent strain

(ii) Aluminium 6061, temper t6 alloy

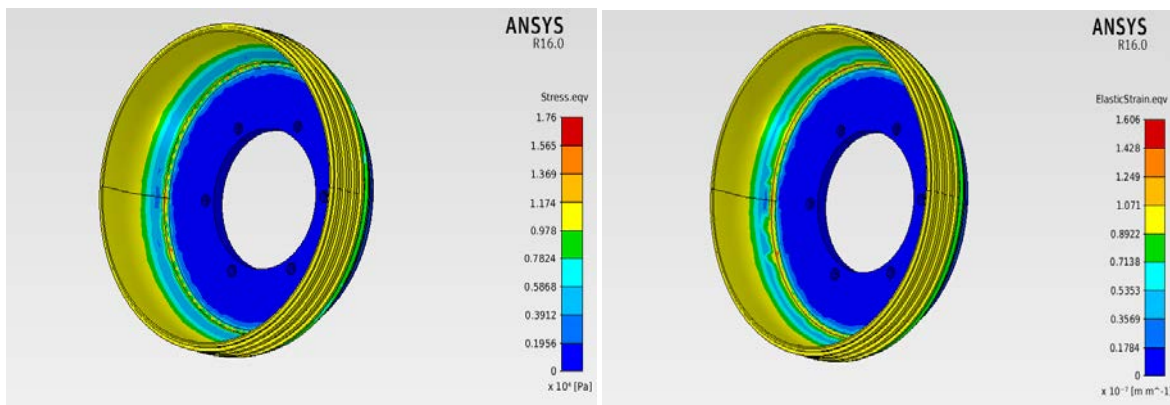


(a) Equivalent Stress

(b) Equivalent strain

(b) Rectangular Cross-Sectioned Annular Finned Brake Drum

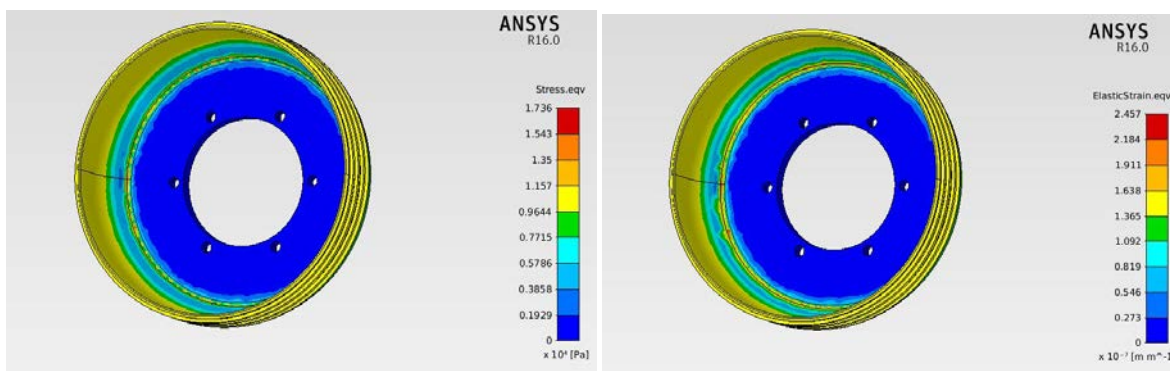
(i) Grey Cast Iron



(a) Equivalent Stress

(b) Equivalent strain

(ii) Aluminium 6061, temper t6 alloy

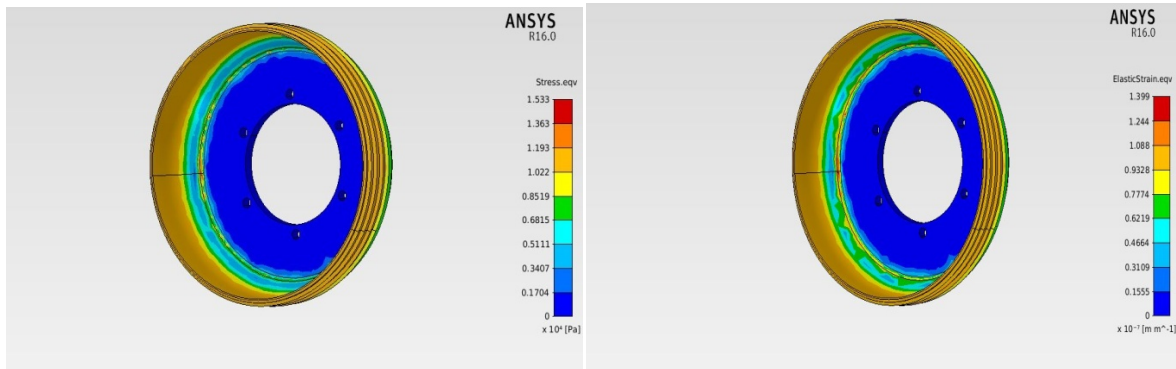


(a) Equivalent Stress

(b) Equivalent strain

(b) Triangular Cross-Sectioned Annular Finned Brake Drum

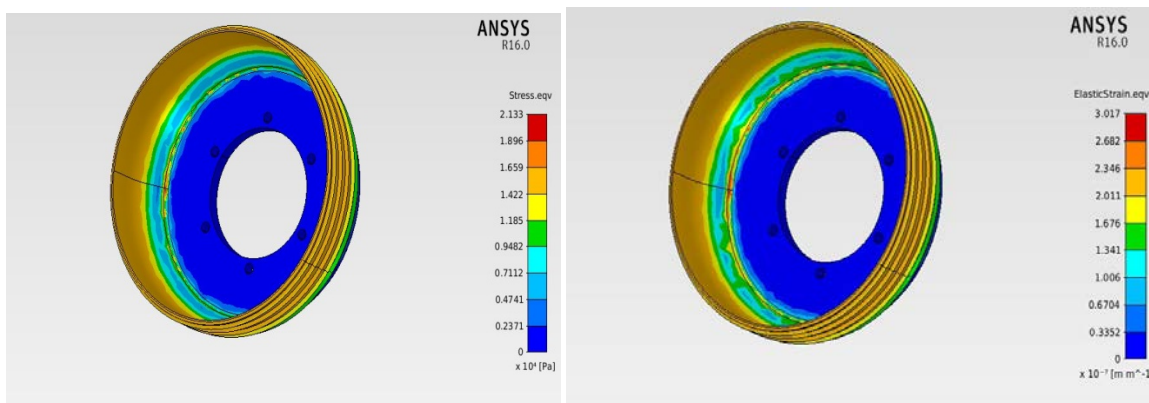
(i) Grey Cast Iron



(a) Equivalent Stress

(b) Equivalent strain

(ii) Aluminium 6061, temper t6 alloy



(a) Equivalent Stress

(b) Equivalent strain

The equivalent stresses and strains are compared with the theoretical calculations and are tabulated in the results.

III. THERMAL ANALYSIS

In acceleration, heat energy of the fuel is converted by the engine into kinetic energy to move the vehicle. In braking, the kinetic energy is converted into heat by means of friction produced between the two mating surface of the brake drum. The amount of friction developed between the two surfaces in contact is independent of the area of the surface in contact. However the magnitude of the force of friction or retarding force created between the brake lining and the brake drum depends upon the pressure or force exerted on the shoes by the retarding mechanism and the coefficient for the two materials. For the purpose of this paper, a retarding force of 150N was considered [1] to be acting between the brake lining and the brake drum.

Since the brake shoes lining are poor conductor of heat, most of the heat remains inside the brake drum during braking. Under severe condition, brake drum may reach 590K temperature. This is also because lining covers a large portion of the inner surface of the brake drum, so that a little cooling space is available. This shows that the inner surfaces of

the brake drums are exposed to intense heating. This heat needs to be dissipated rapidly to prevent brake failure. During the simulation [3], the exterior and the interior temperature of the brake drums were assigned to be 20°C and 120°C respectively. In simulating the models, the following specifications and properties of the brake drum material grey cast iron and aluminium 6061, temper t6 [2] are shown in table 2 and table 3 were taken into account.

Table 2 Material specifications and properties for grey cast iron and aluminium alloy

S.No	Property	Grey cast iron	Aluminium alloy
1	Young’s modulus (E) GPa	110	71
2	Poisson’s ratio	0.28	0.33
3	Bulk modulus, K MPa	83	69.6
4	Shear modulus, G MPa	42.9	26.6
5	Density kg/m ³	7200	277
6	Thermal Expansion / °C	11*10 ⁻⁶	23*10 ⁻⁶
7	Specific heat J kg ⁻¹ C ⁻¹	420	896

3.1 Theoretical Calculations on Finned Brake Drum

Before calculations, Richardson number was calculated for the brake drum, obtained less than unity, forced convection predominates over natural convection. So heat transfer coefficient can be estimated by using constant wall temperature condition. The Nusselt number, Reynolds number and Prandtl number are calculated by using following formulae

$$Nu = 0.332 (Re)^{0.5} (Pr)^{0.33}$$

$$Nu = f(Re, Pr)$$

$$Pr = (\mu C_p) / k$$

The properties are referred to table 2.

Therefore Prandtl number, $Pr = (18.14 \times 10^{-6} \times 1005) / 0.02593$

$$= 0.7$$

Therefore Nusselt number = $0.332 \times (6700.701)^{0.5} \times (0.703)^{0.33}$

$$= 24.51$$

Nusselt number $Nu = (hL)/k$

Where h = heat transfer coefficient (W/m²K)

L= characteristic linear dimension(m)

k= thermal conductivity (W/m-K)

$$hL/k = 24.51$$

$$h = (24.511 * K) / L$$

$$= (24.511 * 0.02593) / 0.007$$

$$= 91.415 \text{ W/m}^2\text{K}$$

3.1.1 Calculation of Heat Transfer for Original Brake Drum Made of Grey Cast Iron

For calculating of the original brake drum, by comparing with electric circuit analogy we obtain

$$\text{Heat transfer rate } Q = \Delta T / R_{th}$$

i) Conductive resistance

From Fourier's law of heat conduction for cylindrical bodies

$$Q = (2\pi k L \Delta T) / \ln(r_2 / r_1)$$

ii) Thermal resistance = $R_{th} = \Delta T / Q$

$$= \ln(r_2 / r_1) / (2\pi k L)$$

For given brake drum without fins thermal resistance is

$$R_{th} = \ln(240/230) / (2 * \pi * 45 * 0.180)$$

$$= 0.0008362 \text{ K/W}$$

iii) Convective resistance

A thermal resistance may also be associated with heat transfer by convection at a surface. From Newton's law of cooling,

$$Q = hA(T_s - T_\infty)$$

The thermal resistance is then

$$R_{th} = (T_s - T_\infty) / Q$$

$$= 1/hA$$

For given brake drum,

$$\text{Area being exposed to air} = 2 * \pi * r_2 * L$$

$$= 2 * \pi * 0.210 * 0.240$$

$$= 0.31667\text{m}^2$$

Convective resistance = $1/(hA)$

$$= 1/(91.415 * 0.31667)$$

$$= 0.034544 \text{ K/W}$$

Total thermal resistance = $(R_{\text{conduction}}) + (R_{\text{convection}})$

$$= 0.0008362 + 0.034544$$

$$= 0.03538 \text{ K/W}$$

Rate of Heat transfer = $\Delta T / R_{\text{total}}$

$$= (120 - 30) / 0.03538$$

$$= 2543.7925 \text{ W}$$

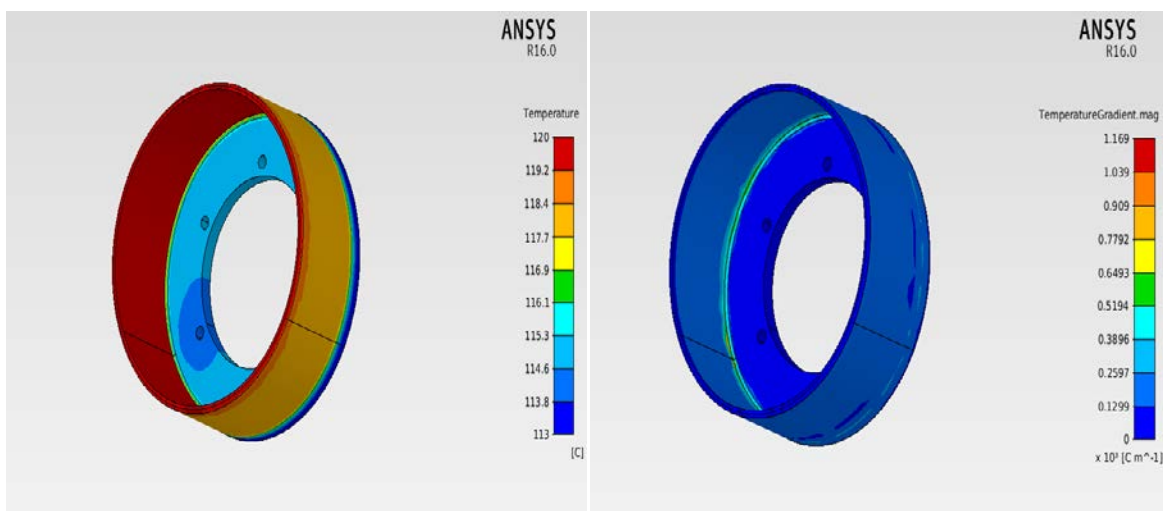
Similarly, for the rectangular finned brake drum and triangular finned brake drum using grey cast iron and aluminium 6061, temper t6 are calculated and tabulated.

3.2 Thermal Analysis by Using ANSYS R16.0

Thermal analysis is a technique used to obtain the temperature gradient, rate of heat flow and the temperature variation of the original and modified brake drum using grey cast iron and aluminium alloy.

a) Original Brake Drum

i) Grey Cast Iron



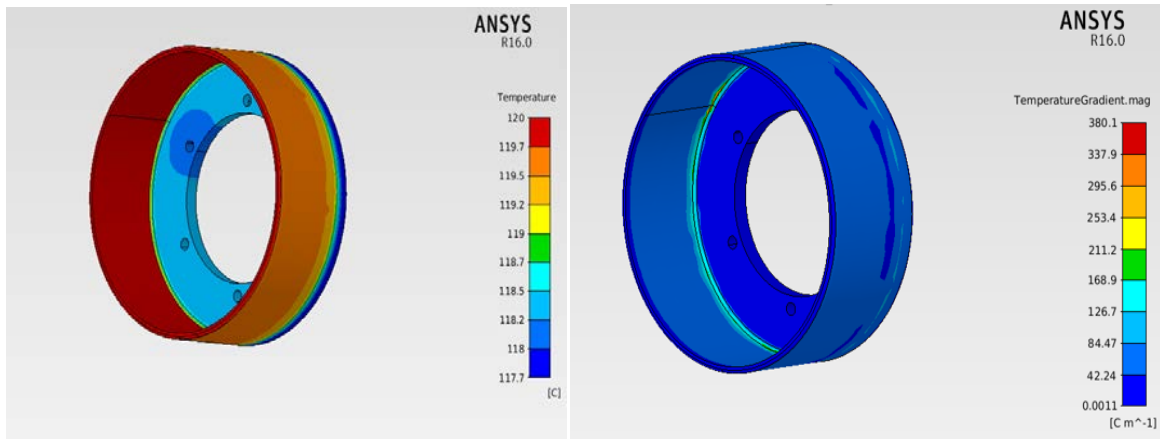
(a) Temperature Variation

(b) Temperature Gradient

Fig 2. Thermal Analysis on Original Brake Drum

The temperature variations and the temperature gradient are shown above using ANSYS R16 and the rate of heat flow in the original brake drum using grey cast iron is 2479.9 W.

ii) Aluminium 6061, Temper T6



(a) Temperature Variation

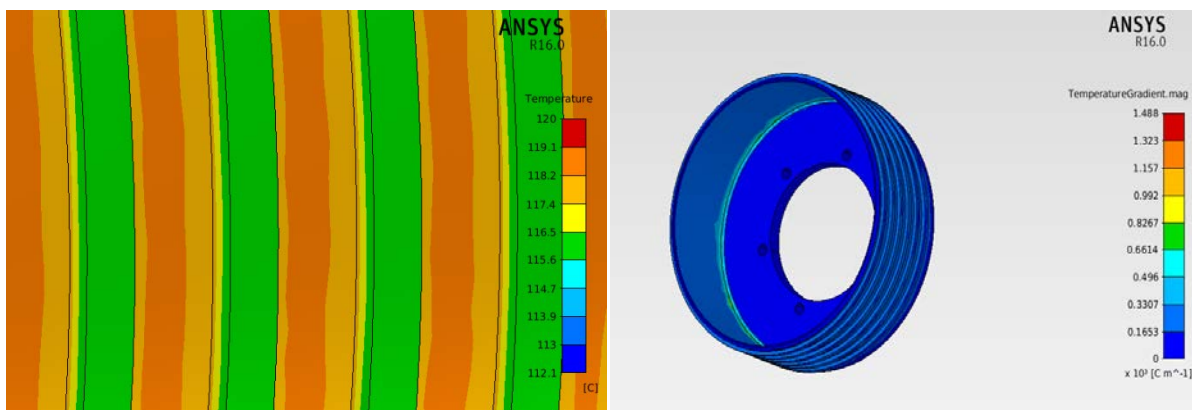
(b) Temperature Gradient

Fig 3. Thermal Analysis on Original Brake Drum

The temperature variations and the temperature gradient are shown above using ANSYS R16 and the rate of heat flow in the original brake drum using aluminium alloy is 2523.1 W.

b) Rectangular Cross-Section Finned Brake Drum

i) Grey Cast Iron



(a) Temperature Variation

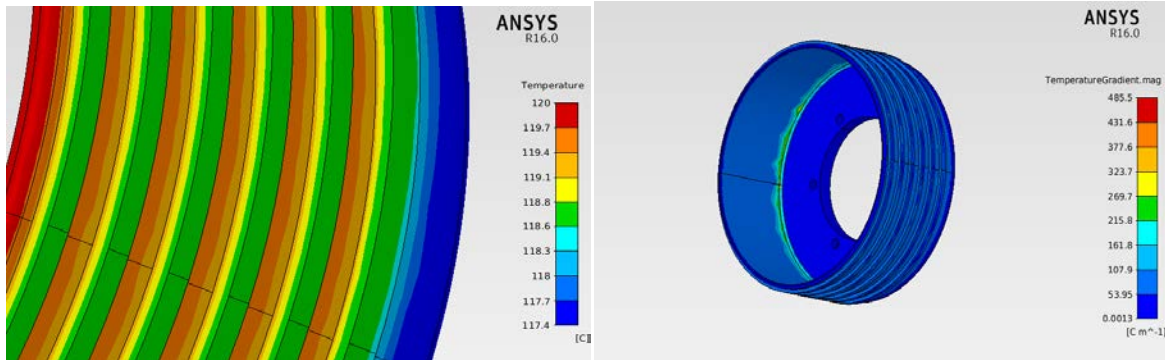
(b) Temperature Gradient

Fig 4. Thermal Analysis on Rectangular Cross-Section Finned Brake Drum

The temperature variations and the temperature gradient are shown above using ANSYS R16 and the rate of heat flow in the original brake drum using grey cast iron is 3405.4 W.

ii) Aluminium 6061, Temper T6

The temperature variations and the temperature gradient are shown above using ANSYS R16 and the rate of heat flow in the original brake drum using Aluminium alloy is 3491.6 W.



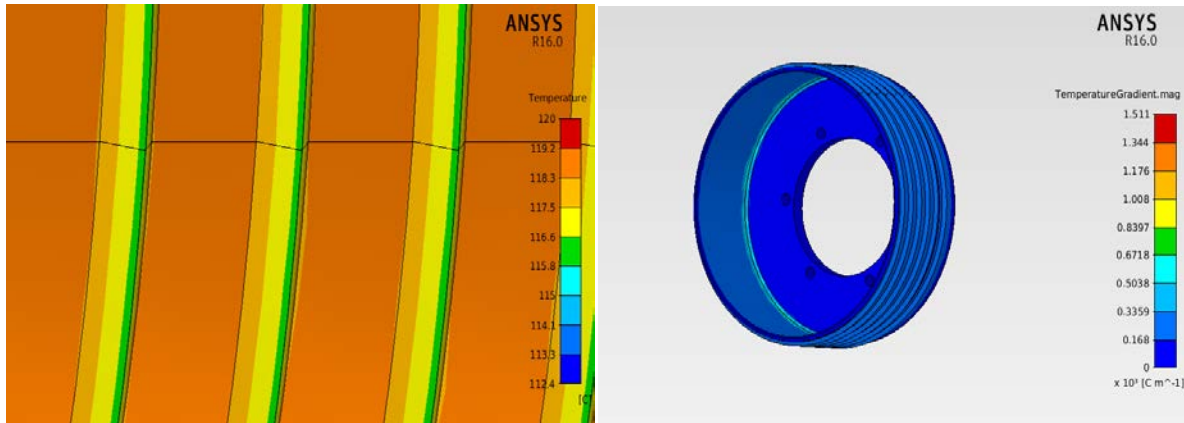
(a) Temperature Variation

(b) Temperature Gradient

Fig 5. Thermal Analysis on Rectangular Cross-Section Finned Brake Drum

c) Triangular Cross Section Finned Brake Drum

i) Grey Cast Iron



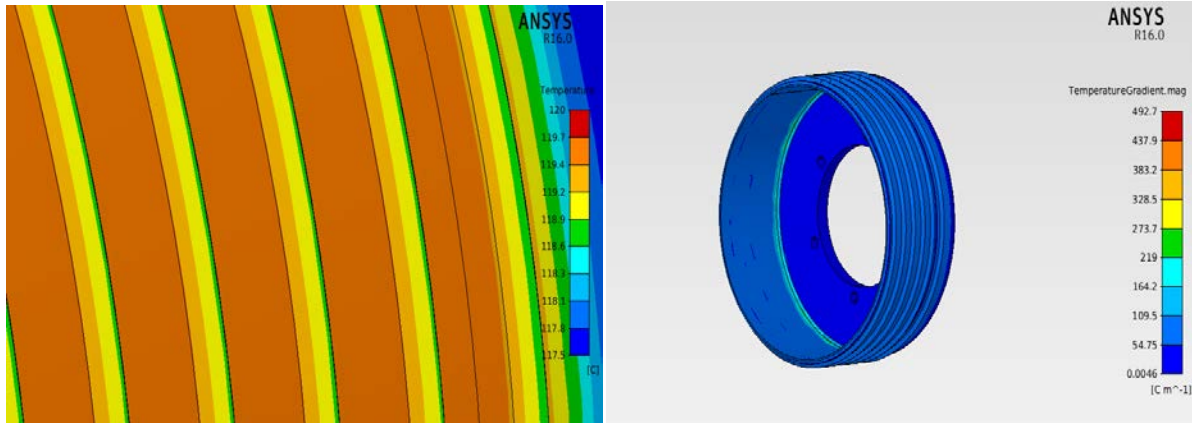
(a) Temperature Variation

(b) Temperature Gradient

Fig 6. Thermal Analysis on Triangular Cross Section Finned Brake Drum

The temperature variations and the temperature gradient are shown above using ANSYS R16 and the rate of heat flow in the original brake drum using grey cast iron is 3017.5 W.

ii) Aluminium 6061, Temper T6



(a) Temperature Variation

(b) Temperature Gradient

Fig 7. Thermal Analysis on Triangular Cross Section Finned Brake Drum

The temperature variations and the temperature gradient are shown above using ANSYS R16 and the rate of heat flow in the original brake drum using grey cast iron is 3078.4 W.

IV.RESULTS AND DISCUSSION

4.1 Structural Static Analysis Results

Static analysis is carried out using ANSYS R16.0 software for all the models of the brake drum using grey cast iron and aluminium. From the static analysis under static loading condition the stresses and strains are obtained.

(i) Grey Cast Iron

The static analysis is done on the rectangular finned brake drum, triangular finned brake drum and un-finned brake drum using grey cast iron. The obtained static analysis results are tabulated in tables 6.1 and 6.2.

Table 6.1 Equivalent Stress Results for Grey Cast Iron

Fin Configuration	Equivalent Stress (Pa)*10 ⁴		%Error
	Theoretical	ANSYS	
Brake drum without fin	1.326	1.487	1.211
Rectangular cross-section annular fins	1.473	1.76	1.943
Triangular cross-section annular fins	1.5297	1.533	0.215

From the table 6.1 it is observed that the values are obtained nearly and it is also observed that the values of the equivalent stress is maximum for the rectangular finned brake drum for the grey cast iron. The percentage error is about 1.943 for the rectangular finned

brake drum. Triangular finned brake drum have the equivalent stress value close to the rectangular finned brake drum and far more than the original brake drum.

From the table 6.2 it is observed that the values are obtained nearly and it is also observed that the values of the equivalent strain is maximum for the rectangular finned brake drum for the grey cast iron. The percentage error is about 5.94 for the rectangular finned brake drum. Triangular finned brake drum have the equivalent strain value close to the original brake drum and far less than the rectangular finned brake drum.

Table 6.2 Equivalent Strain Results for Grey Cast Iron

Fin Configuration	Equivalent Strain *10 ⁻⁷		%Error
	Theoretical	ANSYS	
Brake drum without fin	1.03	1.371	3.3106
Rectangular cross-section annular fins	1.152	1.606	5.94
Triangular cross-section annular fins	1.19	1.399	2.09

(ii) Aluminium 6061, Temper T6 Alloy

The static analysis is done on the rectangular finned brake drum, triangular finned brake drum and un-finned brake drum using aluminium 6061, temper t6. The obtained static analysis results from ANSYS R16.0 software are tabulated in tables 6.3 and 6.4.

Table 6.3 Equivalent Stress Results for Aluminium 6061, Temper T6

Fin Configuration	Equivalent Stress (Pa)*10 ⁴		%Error
	Theoretical	ANSYS	
Brake drum without fin	1.326	1.491	1.244
Rectangular cross-section annular fins	1.47	1.736	2.8
Triangular cross-section annular fins	1.529	1.659	1.68

From the table 6.3 it is observed that the values are obtained nearly and it is also observed that the values of the equivalent stress is maximum for the rectangular finned brake drum for the Aluminium alloy. The percentage error is about 2.8 for the rectangular finned

brake drum. Triangular finned brake drum have the equivalent stress value close to the rectangular finned brake drum and far more than the original brake drum.

From the table 6.4 it is observed that the values are obtained nearly and it is also observed that the values of the equivalent strain is maximum for the rectangular finned brake drum for the Aluminium alloy. The percentage error is about 2.3 for the rectangular finned brake drum. Triangular finned brake drum have the equivalent strain value close to the rectangular finned brake drum and far more than the original brake drum.

Table 6.4 Equivalent Strain Results for Aluminium 6061, Temper T6

Fin Configuration	Equivalent Strain *10 ⁻⁷		%Error
	Theoretical	ANSYS	
Brake drum without fin	1.559	1.734	1.72
Rectangular cross-section annular fins	1.733	1.957	2.3
Triangular cross-section annular fins	1.799	1.917	1.96

4.2 Thermal Analysis Results

Thermal analysis is carried out using ANSYS R16.0 software for all the models of the brake drum using grey cast iron and aluminium. From the thermal analysis under static loading condition the rate of heat flow reaction are obtained.

(i) Grey Cast Iron

The thermal analysis is done on the rectangular finned brake drum, triangular finned brake drum and un-finned brake drum using grey cast iron. The obtained thermal analysis results from ANSYS R16.0 software are compared with the theoretical calculations and are tabulated in table 6.5

Table 6.5 Heat Transfer Results for Grey Cast Iron

Fin Configuration	Heat Transfer in Watts (W)		%Error
	Theoretical	ANSYS	
Brake drum without fin	2543.795	2479.9	2.5117
Rectangular cross-section annular fins	3599.756	3405.4	5.399
Triangular cross-section annular fins	3077.522	3017.5	1.95

(ii)Aluminium 6061, Temper t6 Alloy

The thermal analysis is done on the rectangular finned brake drum, triangular finned brake drum and un-finned brake drum using aluminium alloy. The obtained thermal analysis results from ANSYS R16.0 software are compared with the theoretical calculations and are tabulated in table 6.6

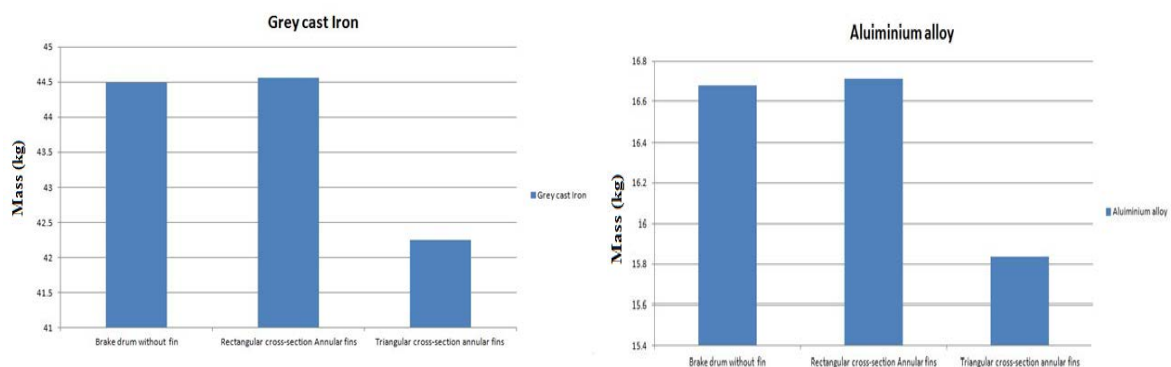
Table 6.6 Heat Transfer Results for Aluminium 6061, Temper T6

Fin Configuration	Heat Transfer in Watts (W)		%Error
	Theoretical	ANSYS	
Brake drum without fin	2588.4878	2523.1	2.526
Rectangular cross-section annular fins	3635.927	3491.6	3.969
Triangular cross-section annular fins	3103.1918	3078.4	0.798

The mass of brake drum manufactured by grey cast iron is very high compared to the aluminium 6061, temper t6 alloy. Brake drum made of grey cast iron is having very low heat flow when compared to rest of analysis. The value from ANSYS is 2479.9 W whereas when compared to theoretical calculation gives a reading of 2543.795 W, which gives an error percentage of 2.51.

The use of fins on brake drum enormously increased the heat flow with a minimal increment in mass of brake drum. The maximum heat flow obtained is from rectangular cross-sectioned annular finned brake drum and it is 3599.756 W theoretically when compared to 3405.4 W obtained in ANSYS.

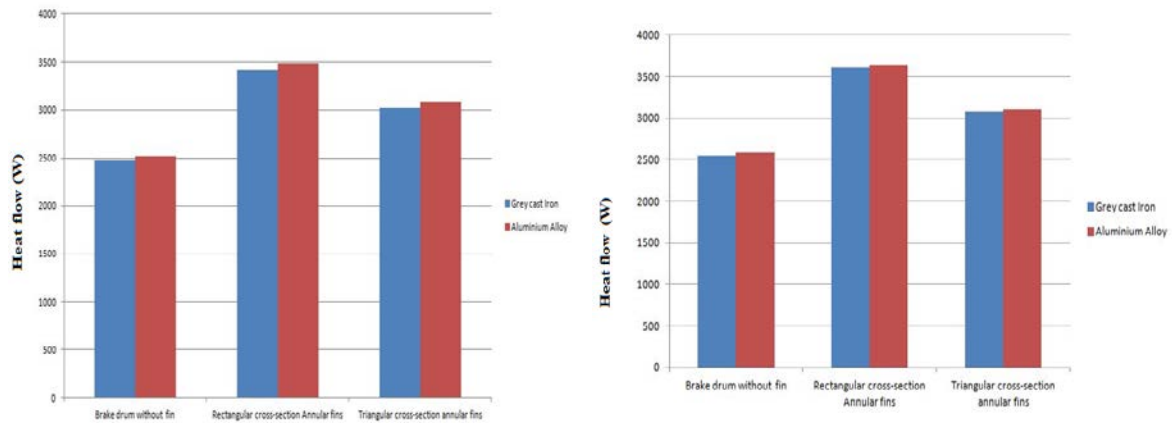
Grey cast iron has certain properties like wear resistance, machinability and is of low cost. Due to these reasons they are prominently used in brake drums. The values are compared to practical values and the two analyses validate each other.



(a) Mass Variation in Grey Cast Iron

(b) Mass Variation in Aluminium Alloy

Fig 8. Mass Variation of the Brake Drum



(a) Heat Flow using Theoretical calculations b) Heat Flow using ANSYS R16

Fig 9. Heat Flow in the Brake drum

The mass of brake drum obtained by using Aluminium alloy is very less when compared to Grey cast Iron. The heat flow is maximum in case of brake drum with rectangular cross-section annular fins. It gives a maximum heat flow of 3491.6 W with ANSYS while its counterpart is 3635.927 W by theoretical procedure for the same scenario.

As Aluminium is having very high conductivity and ductility, it is used as brake drum in front wheels of automobile.

V. CONCLUSION

The small stress and displacement shown by the modified model indicates that the modified model is stronger and rigid than original. The high temperature of the outer surface of the modified model shows that more heat is transferred and dissipated from the brake drum.

The use of two kinds of materials in brake drum manufacturing provides a range of heat flow values. This range of values is useful in the selection of material comparing with these two materials in different applications. From the above values the advanced materials like EN24 or EN8 material in vehicles which are not very much powerful.

By placing fins on the outer surface of the brake drum, the amount heat flow is increased. When the criteria is maximum heat flow then it is better to go for a brake drum with rectangular cross-section annular fins and is of high conductive material.

When heat flow along with weight of the brake drum are the main criteria then triangular fins on highly conductive brake drum is suitable because it increases heat flow along with reduction in weight of brake drum.

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