CERTIFICATION OF APPROVAL

Thermal Stress Distribution in the Drum Brake of a Small Vehicle

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9445

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Approved by,

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

ANUAR BIN AHMAD

ABSTRACT

In this project, the approach of finite element analysis is used to evaluate the thermal stress distribution in the brake drum of a small car. During braking, the kinetic energies of a moving vehicle are converted into thermal energy through frictions in the brakes. Excessive thermal stress may cause undesirable effect on the material of the brake drum that eventually leads to initiation of crack. For the optimized design of a brake drum, it does appear to be very important to examine the thermal stress distribution in the brake drum at different thickness of drum's wall. In this study, the stress distribution is being investigated using Three-Dimensional axisymmetric Finite Element Analysis method. The temperature distribution is distributed differently by different thickness of the drum's wall. Higher thickness of the wall will result better distribution, thus lower temperature at interested point. The study for the thermal stress also shows similar result, where the stress for the higher thickness is lower than the stress with lower thickness.

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First and foremost, thank to Allah S.W.T for the strength and opportunity given to complete all the tasks allocated for Final Year Project 1 and Final Year Project 2 throughout the year of 2010.

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NOMENCLATURE

σ	Thermal stress (Pa)
E	Modulus of elasticity (Pa)
a_l	Linear coefficient of thermal expansion (m/m°C)
ΔT	Variation of temperature (°C)
a	Displacement of length (m)
u	Initial vehicle velocity (m/s)
v	Final vehicle velocity (m/s)
a	Vehicle acceleration (m/s^2)
t	Braking time (s)
v_t	Drum tangential velocity (rad/s)
a_t	Drum tangential acceleration (rad/s^2)
ω	Drum angular velocity (rad/s)
α_d	Drum angular acceleration (rad/s^2)
θ	Drum angular displacement (rad)
Δt	Time interval
D	Tyre outer diameter
d	Drum inner diameter (m)
F	Total force to stop the vehicle
F_{fr}	Frictionforce between brake shoe and rubbing surface (N)
ΔU	Work of force to stop the vehicle (J)
T	Kinetic energy of moving vehicle (J)
m	Vehicle with passengers mass (kg)
g	Gravitational acceleration (9.81 m/s^2)
ΔQ	Heat absorbed in time interval (I)
A	Shoe-drum contact area (m^2)
Q	Frictional heat flux (W/m^2)
k	Thermal conductivity (W/m.K)
C	Specific heat (J/kg.K)

α	Thermal diffusivity (m^2/s)
ρ	Density
h	Coefficient convection heat transfer ($W/m^2.K$)
T	Temperature (°C)
E	Energy generation (J)
dx	x-axis direction
dy	y-axis direction
dz	z-axis direction
dr	Radial direction.
$d\phi$	Angular direction
p	Time denotation

CHAPTER 1
INTRODUCTION

1.1. Background

Safety in automotive, especially passenger cars have been discussed and improved since first car was running on the road in early 19th century. There are a lot of safety features on today's car such as seat belt, airbag, braking system and car's dynamic body design. Braking system is probably most applicable in automotive to stop the vehicle from moving and to do parking. Currently, there are two types of system; brake disc and drum brake. Both systems use friction as their working principle. Braking system require continuous adjusting mechanisms based on vehicle speed and road condition. The steering may control the direction of the vehicle but the tire with built-in brake stop the vehicle at desired position. They must perform efficiently for greater control under various operating conditions.

The contact between lining and drum will produce friction force which is converted to heat energy and dissipated to the atmosphere. The worst case is the short braking period from top speed when maximum heat is generated and the least possibility of the heat absorbed to flow out of the system. Thermal stresses that occur in a small vehicle brake during braking may cause undesirable effect on the material of brake drum that eventually leads to heat crack of brake drum. On the other hand, the drum-lining interface temperature may be related strongly with the fade in a brake and the performance of braking. Therefore, the investigation of temperature and thermal stress distribution in the brake drum during braking is very important.

Most thermal analysis assumes that the heat generated during braking is uniformly distributed over the nominal area of contact between the lining and the drum. Further study showed that about 95% of a major share of heat energy is dissipated through the brake drum and the remainders go to the brake shoe. The small percentage of heat entering the friction material will decrease by time.

After some stages through the braking cycle, the heat convecting through the drum will be greater than the heat generated on the braking surface and the heat from the friction material starts to conduct into the drum.

1.2. Problem statement

The severe brake application will create a thermal environment on the friction surface with an excessively high surface temperature. In addition, the thermal distortions of drum brake suggest the loss of the contact area between the drum frictional surface and the brake shoe lining during braking which may comprise the safety of the vehicle.

Therefore, it appears to be very important to examine the temperature and thermal stress distribution in the drum brake in the course of their heating and cooling by using a three-dimensional axisymmetric Finite Element Method such as ANSYS.

1.3. Objective

The objectives of this project are;

- To analyze the dynamic motion of the brake drum system of a small vehicle
- To conduct frictional energy analysis during brake application
- To simulate the thermal stress and temperature distribution within the drum brake material using the finite element approach in ANSYS

1.4. Scope of study

In this study, the focus will be on the brake drum of a small vehicle. Analyzing thermal stress and temperature distribution of brake system require complex method such as finite element method, and ANSYS is chosen for this project.

In order to see the differences of the temperature and thermal stress distribution, the thickness of the drum wall is varied by incremental of 2.5 mm starting from 12.5 mm, 15.0 mm (default value for the thickness) and 17.5 mm.

CHAPTER 2
LITERATURE REVIEW

2.1. Drum Brake Components

In drum brakes, fluid is forced into the wheel cylinder, which pushes the brake shoes out so that the friction lining are pressed against the drum, attached to the wheel, causing the wheel to stop. Heat is what causes the friction surfaces (shoes lining) to eventually wear out and require replacement.

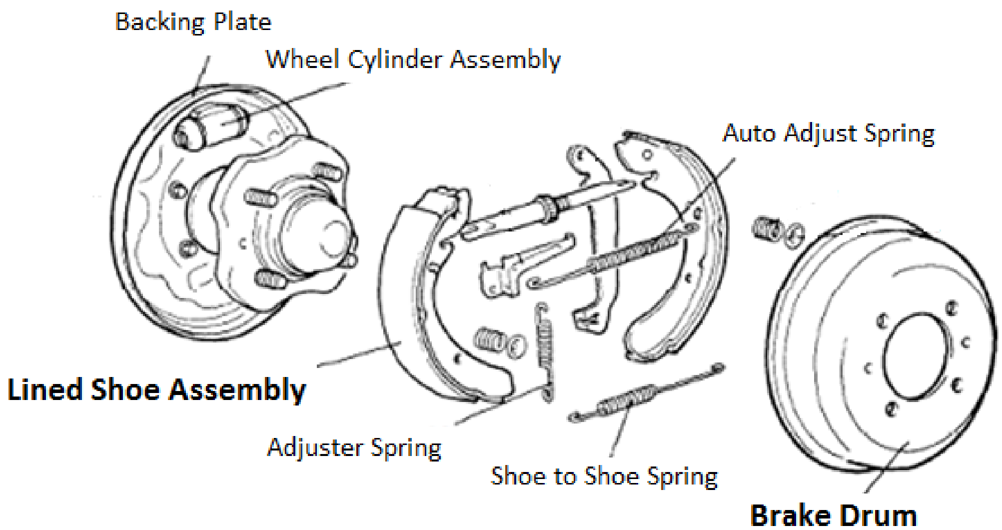


Figure 2.1: The Drum Brake Components

Drum brakes consist of backing plate, lined shoe assembly, brake drum, wheel cylinder assembly, adjuster springs and automatic adjusting system as shown in **Figure 2.1** [1]. When the driver apply the brake pedal, the brake fluid is forced under pressure into the wheel cylinder, which is turn pushes the brake shoes into contact with machined surface on the inside of the drum. When the pressure is released, return spring pull the shoes back to initial position. As the brake lining wear, the shoes must travel a greater distance to make a contact.

When the distance reaches certain point, the automatic adjusting system will react by adjusting the rest point of the shoes so that they are closer to the drum.

2.2. Heat Transfer Principle

2.2.1. Thermal Stress

Solid matter will change in dimension if exposed to temperature differences [2]. The expansion or contraction is insignificant for fluid because of material bonding. But for solid like steel, any changes in temperature will affect the dimension and material properties. If the temperature increases, the material will expand, while contract if the temperature decreases. The change in dimension is linearly related to temperature changes. An understanding of origins and nature of thermal stresses is important during the braking process because inaccurate calculation can lead to fatal effect such as fracture or undesirable plastic deformation. The sources of thermal stresses are;

- Restrained thermal expansion or contraction
- Temperature gradients

The heat transfer of conduction is given by

$$q = hA(\Delta T)$$

where
q = quantity of heat transfer
h = material thermal conductivity
A = exposed surface area
ΔT = temperature gradients

Based on the equation above, the heat transfer depends on type of material, size or shape and significance of temperature difference.

Thermal stress may be established as a result of temperature difference across bodies, which are frequently caused by rapid heating and cooling, in that the outside changes temperature more rapidly that the interior; differential dimensional changes serve to restrain the free expansion or contraction of adjacent volume elements within the piece.

2.2.2. Thermal Strain

The strain is defined by

$\varepsilon = \alpha \Delta T$

where

$\varepsilon =$ strain

$\alpha =$ coefficient of thermal expansion

$\Delta T =$ temperature gradients

The strains are related to the stress by Hooke's Law of linear isothermal elasticity

$\varepsilon = E * \sigma$

where

E = modulus of elasticity

σ = stress

The total strains are the sum of the components and are therefore related as follows to the stresses and the temperature in any coordinate system

$$\frac{1}{e}\left[\sigma_{xx} - v\left(\sigma_{yy} + \sigma_{zz}\right)\right] + \alpha T = \varepsilon_{xx}$$

$$\frac{1}{e}\left[\sigma_{yy} - v(\sigma_{xx} + \sigma_{zz})\right] + \alpha T = \varepsilon_{yy}$$

$$\frac{1}{e}\left[\sigma_{zz} - v\left(\sigma_{yy} + \sigma_{xx}\right)\right] + \alpha T = \varepsilon_{zz}$$

where

α = coefficient of thermal expansion

T = temperature

2.2.3. Thermal Expansion

Thermal expansion is defined by the increase in volume of a material as its temperature is increased, usually expressed as a fractional change in dimensions per unit temperature change. When the material is a solid, thermal expansion is usually described in terms of change in length, height, or thickness. If a crystalline solid has the same structural configuration throughout, the expansion will be uniform throughout the dimensions. Otherwise, there may be different expansion coefficients and the solid will change shape as the temperature increases. If the material is a fluid, it is more useful to describe the expansion in terms of a change in volume. Because the bonding forces among atoms and molecules vary from material to material, expansion coefficients are characteristic of elements and compounds.

The coefficient of thermal expansion, α describes by how much a material will expand for each degree of temperature increase, as given by the formula below

$$\alpha = \frac{1}{L}\frac{\partial L}{\partial T}$$

where

∂L = the value of length changing of the material in the direction being measured

∂T = the value of temperature changing over which *dl* being measured

L = the original length of the material in the direction being measured

Although $\boldsymbol{\alpha}$ **ratio** is dimensionless, expansion has the unit k−1, and is normally quoted in parts per million per °C rise in temperature.

Volume coefficient of thermal expansion $$\frac{\Delta V}{V_0} = \alpha_v \Delta T$$

Area coefficient of thermal expansion $$\frac{\Delta A}{A_0} = \alpha_A \Delta T$$

2.2.4. Temperature Distribution

If the temperature conductivity is constant, the heat equation is shown below

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} + \frac{q}{k} = \frac{1}{\alpha} \cdot \frac{\partial T}{\partial t}$$

where $\boldsymbol{\alpha}$ **ratio** defined as in equation below

$$\alpha \quad = \frac{k}{\rho c_p}$$

where
k = thermal conductivity
ρ = material density
c_p = specific heat capacity

Under steady state condition, there can be no change in the amount of energy storage, thus the heat equation become

$$\frac{\partial}{\partial x}\left(k.\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k.\frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(k.\frac{\partial T}{\partial z}\right) + q = 0$$

2.3. Kinematics Principle

2.3.1. Rigid Body in Rectilinear Motion

Consider a vehicle moving at initial speed of u when the driver applies the brake to stop the car. The car decelerates with constant magnitude of a until it stops after a period of time, t. The appropriate equation of motion is shown below

$$v = u + at$$

where
a = the deceleration of the vehicle
v = the final velocity of the vehicle
u = the initial velocity of the vehicle

The distance of the vehicle travelled, s before it stops is shown below

$$v^2 = u^2 + 2as$$

2.3.2. Rigid Body in Fixed Axis Motion

The brake drum rotates about a fixed axis which is located at the center of the drum diameter. The shoe moves from one edge to the other, point 1 to point 2, refer to **Figure 2.2**, and it is continuous until the car fully stops.

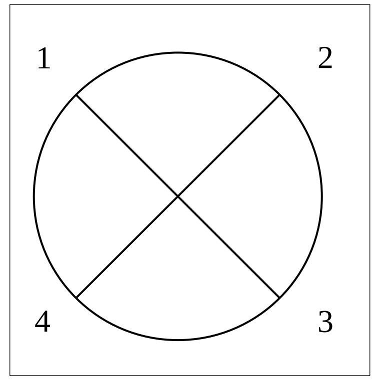


Figure 2.2: The Step of Complete Drum Brake

The vehicle moves at an initial velocity, *u* and deceleration of *a*, thus the brake drum motion can be expressed as

$$u = v_t = \frac{1}{2} D\omega$$

$$a = a_t = \frac{1}{2} D\alpha$$

where

v_t = tangent velocity at outer point of the vehicle's tire

a_t = tangent deceleration of outer point

ω = initial angular velocity

α = constant angular deceleration

During braking, the angular velocity will be decreased at constant angular deceleration as the shoe move from a point to the next point. The angular velocity of the drum at the next point and the time interval of each shoe motion are defined by:

$$\omega_1^2 = \omega_0^2 + 2\alpha\theta$$

$$\omega_2 = \omega_1 + \alpha\Delta t$$

where

θ = angular displacement

Δt = time interval

2.3.3. Work-Energy Principle

Energy is the ability to do work. Any object in motion is said to have kinetic energy (KE). The net work done defines a change in translational kinetic energy:

$$w_{net} = KE_{final} - KE_{initial}$$

where

$$KE = \frac{1}{2}mv^2$$

Thus,

$$w_{net} = \frac{1}{2}mv_{final}^2 - \frac{1}{2}mv_{initial}^2$$

The potential energy required to stop the vehicle is defined by

$$\Delta PE = Fs$$

Thus,

$$\Delta PE = w_{net}$$

$$KE_{final} = Fs + KE_{initial}$$

Since no final velocity, $v_2 = 0$, there is no kinetic energy, thus

$$-Fs = \frac{1}{2}mv_{initial}^2$$

CHAPTER 3

METHODOLOGY

3.1. Research Methodology

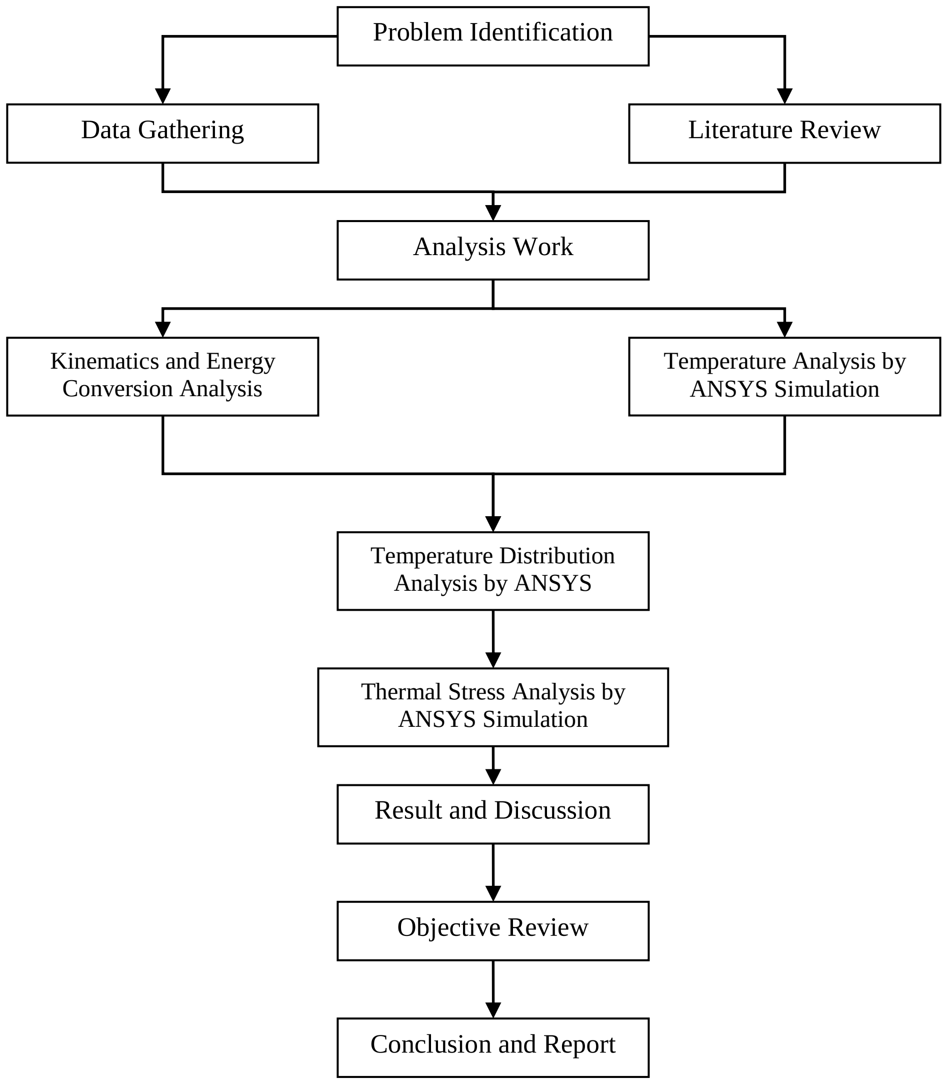


Figure 3.1: Flow Chart of Main Activities

Refer to Appendix E for detail of FYP 1 and FYP 2 project milestone.

3.2. Data Gathering

In order to see the actual thermal stress distribution, the dimension of the drum brake in this study should be the same as the dimension of real life drum brake. The actual vehicle specifications and drum brake parameters are used in this investigation. The specifications of the vehicle are shown in **Table 3.1.**

Table 3.1: The Specifications of the Vehicle Model

No	Parameter	Value
1	Engine capacity	1300 cc
2	Weight of car, w	1725 kg
3	Maximum speed, $v_{initial}$	160 km/h
4	Deceleration, $-a$	0.7 G

The parameters of the drum brake that are required to perform the calculation are shown in **Table 3.2.**

Table 3.2: The Parameters of the Drum Brake

No	Parameter	Value
1	Diameter of tire, D	569.7 mm
2	Drum inner diameter, d	250 mm
3	Shoe angle contact, Ø	100^o
4	Shoe width, W	185 mm

The material of the drum brake is Ductile Cast Iron ASTM A536. The thermal properties for that material are shown in **Table 3.3.**[3]

Table 3.3: The Thermal Properties of Brake Drum Material

No	Parameter	Value
1	Thermal conductivity, k	60.5W/mK
2	Specific heat capacity , C_p	434 J/kg.K
3	Density, ρ	7850 kg/m^3
4	Thermal diffusivity, α	1.776E-06 m^2/s
5	Coefficient of thermal expansion, α_1	1.2E-05 ^{o}C^{-1}
6	Melting point, T_{melt}	1175 ^{o}C

The kinematics movement of the drum must be analyzed in order to simulate the thermal stress inside the drum. Calculations involved are

- The system's total energy (comprising e.g. kinetic, gravitational and elastic potential) initially, i.e. before braking
- The system's final total energy i.e. after braking
- The initial and final velocities of the brake drum
- The desired braking period Δt, or alternatively the corresponding rotation of the drum $\Delta\theta$

3.3. Assumption Made To Perform Calculation and Simulation

3.3.1 Heat Transfer

- All the kinetics energy is converted to heat energy (frictional effect)
- 95% of heat energy is absorbed by drum and 5% dissipated to brake shoes lining

3.3.2. Kinematics Equation

- The vehicle is not moving, velocity of zero after brake has been applied
- The weight of car distribution is 50/50, where 50% weight is support by the front tire and the remainder by the rear tire
- The load distribution ratio not changing during braking or movement process
- The potential energy is zero, based on insignificant change of brake drum height.

3.4. Drum Modeling

The three dimensional drum is modeled using CATIA, refer to Appendix A for drawing detail and the simulation of the model is by ANSYS Workbench Interface. In order to see the differences in thermal stress distribution, three thickness of drum brake will be used and each one using same material, refer to **Figure 3.2**.

In order to ease the simulation, the two-dimensional brake cross-sectional profile is drawn and area is created within the combination of lines.

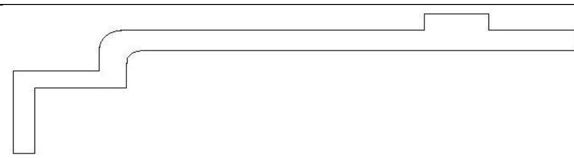
Model	Cross Section	Thickness
A		12.5 mm
B		15 mm (datum)
C		17.5 mm

Figure 3.2: The different thickness for Model A, B and C

The brake volume is divided into 18 sections, which created 20^{o} surface angle for each section. Each shoe will be made at 100^{o} angle and the rest surface of two 80^{o}. For each time step, this contact section will move at a distance of single section until 18th section is completed. Heat flux will be applied on contact section surfaces and convection load is applied to the entire part of the model.

3.5. Simulation

After modeling process had been carried out, the simulation starts with material definition. Full transient analysis is selected. In applying the thermal load, several assumptions had been made;

- Coefficient of friction remains constant during braking
- Thermal properties are invariant with temperature
- Heat flux is constant along with contact surface
- Film coefficient of convection is to remain constant at all time

SOLID90 is chosen as the element type for simulation and the temperature is the only degree of freedom. The model will undergo the meshing process using hexahedral method. The drum brake after meshing process is as shown in **Figure 3.3**.

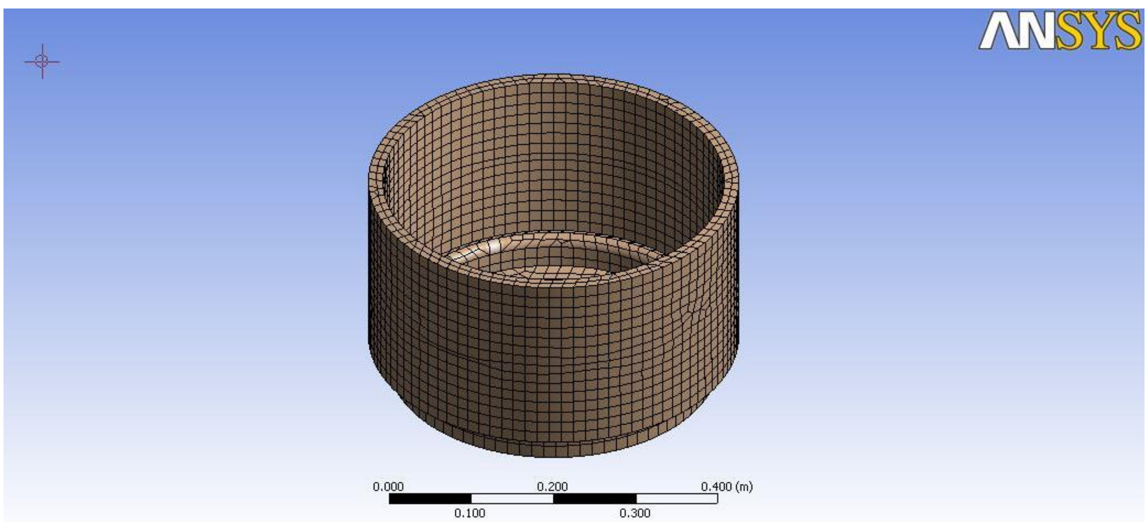


Figure 3.3: The Drum Brake after Meshing Process

The properties of finite element model can be referred to **Table 3.4.**

Table 3.4: The Properties of Finite Element Model

Properties	Model A	Model B	Model C
Element type	Hexahedral element		
Number of nodes	16209	16209	18834
Element size	5.0 mm		
Number of elements	3437	3437	3944

CHAPTER 4
RESULTS AND DISCUSSION

4.1. Energy Conversion Analysis

Figure 4.1 shows the decrease of the velocity of the vehicle with time. The initial velocity is at the vehicle's top speed, which is 160 km/h, equal to 44.44 m/s and the vehicle constantly decelerates at 0.7G until it reach its final velocity, which is 0.0 m/s. The time taken to reach its final velocity is 6.3022 s. Refer to Appendix B and Appendix C for complete calculation steps.

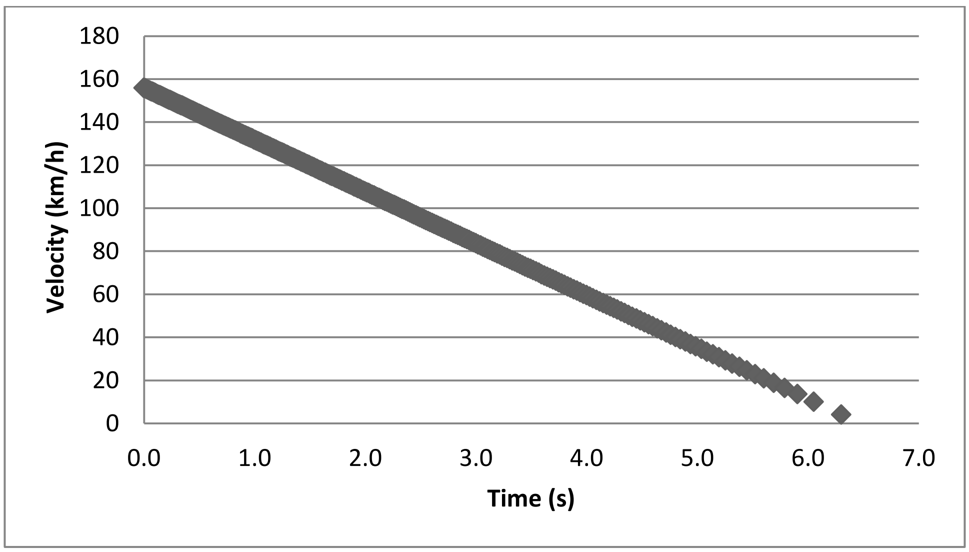


Figure 4.1: Velocity vs Time

The moving vehicle stored the kinetics energy. During braking process, this kinetic energy is converted into heat energy due to frictional force between brake shoes and drum brake contacts. Heat energy absorbed increases in quadratic rate and reach the maximum value of 161.740 kJ at 6.302 s as shown in **Figure 4.2.**

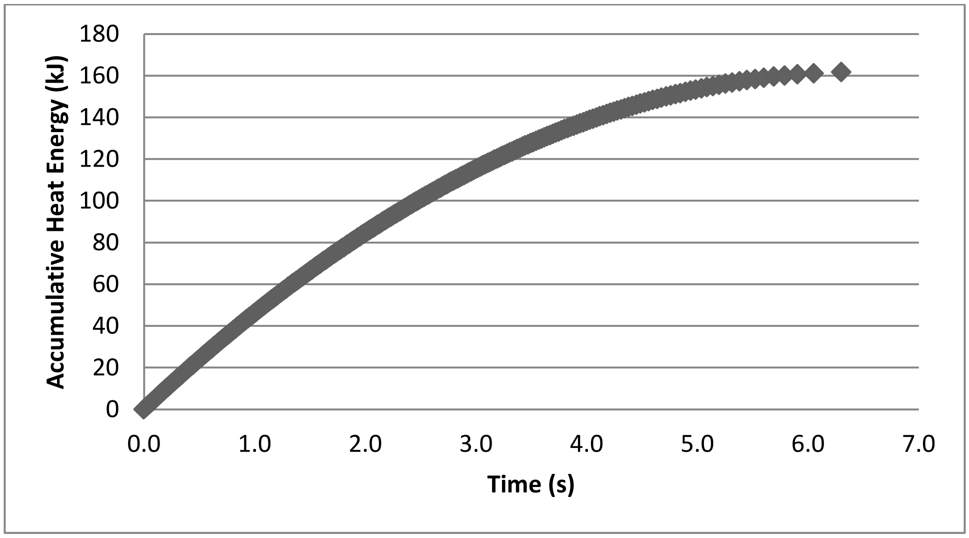


Figure 4.2: Accumulative Heat Energy vs Time

4.2. Heat Flux Generation

The heat energy absorbed by the drum brake is considered as heat flux. Heat flux is calculation of the amount of heat per area of material. **Figure 4.3** shows the decrease of heat flux with time, indicating that heat is dissipated to drum brake surface until no heat energy is left.

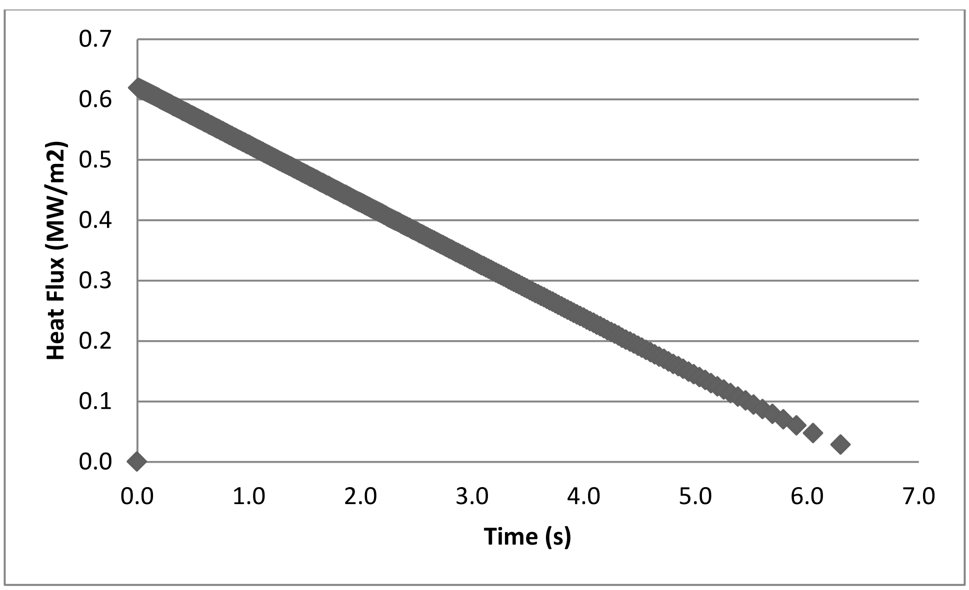


Figure 4.3: Heat Flux vs Time

4.3. Temperature Distribution

The heat generated is distributed throughout the drum brake. The drum material is assumed homogeneous; therefore the heat is distributed equally throughout the body. The heat flux was exerted along the line of inner surface of drum, therefore the heat transfer to outer surface. **Figure 4.4 to 4.6** shows the different path of thermal distribution. Different node marked as point of interest where temperature is measured. Note that node A to J is along the rubbing surface.

- Path 1, which is along the contact surface, is represented by node A,F,L,K and J
- Path 2, which is along at the outer surface of contact area, is represented by node B,C,E,G,H and I
- Path 3, which is along the drum cross section, is represented by node F,E and D

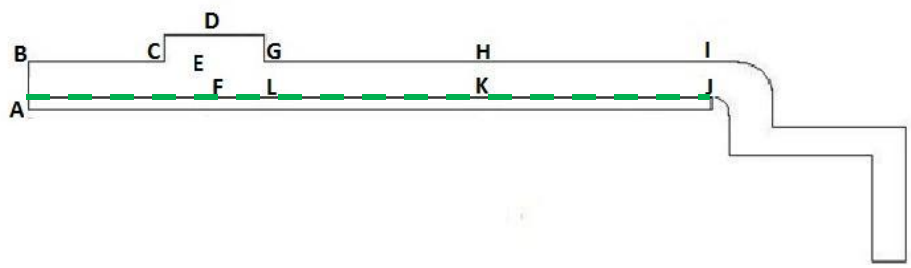


Figure 4.4: Path 1 along the contact surface

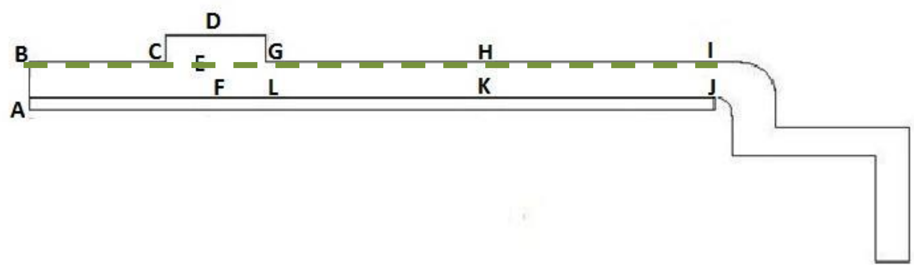


Figure 4.5: Path 2 along the outer surface of drum

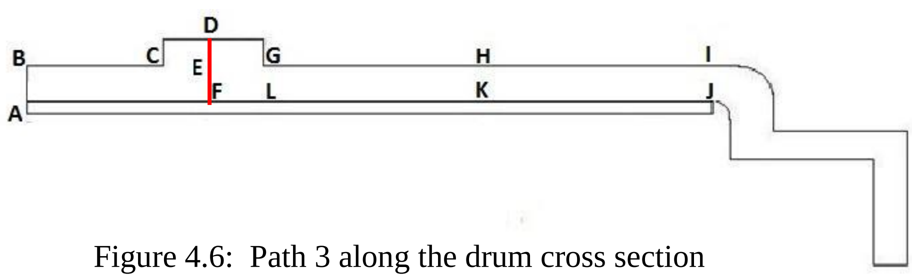


Figure 4.6: Path 3 along the drum cross section

4.3.1. The temperature distribution for Path 1

The temperature at the interval of 1.0 s, with additional 0.5 s for initial reading and 6.3 s for last reading is recorded along the path in order to investigate the temperature distribution in the horizontal direction of the rubbing surface. **Figure 4.7** shows the dimension of the cross section of the drum with the location of the points of temperature measurement.

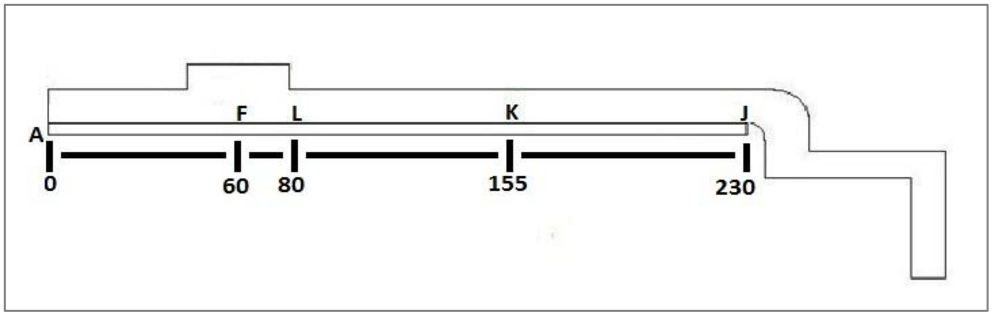


Figure 4.7: The dimension of the cross section of the drum with the location of the points of temperature measurement

The temperature distribution for different thickness of wall is shown in **Figure 4.8** to **Figure 4.10**. Notice that the temperature distributions of these three cases are similar. This shows that different outer geometry of the drum has not affected the temperature distribution. This is because the same heat flux is applied to the wall and the material is the same. Based on **Figure 4.8**, the temperature drops slightly at the distance of 60 mm and rise again at the distance of 80 mm and drops dramatically after the distance of 155 mm. The first temperature drop occurs because of the presence of circumferential fin that is purposely designed to enhance the temperature distribution. The second drop happens because of the thermal energy dissipation to other drum parts that are not exposed to the heat flux.

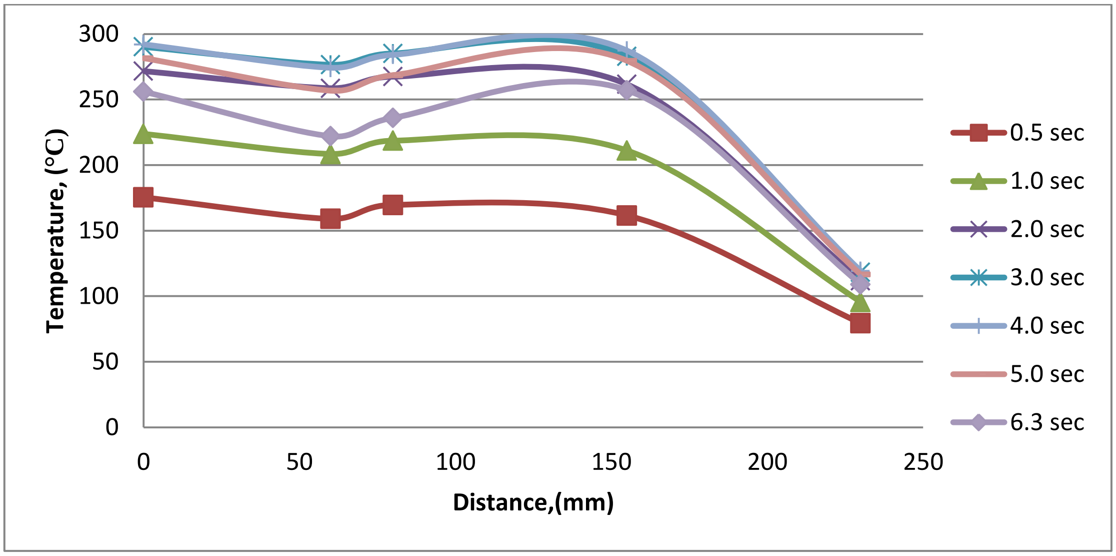


Figure 4.8: The temperature distribution of drum with wall thickness of 12.5 mm

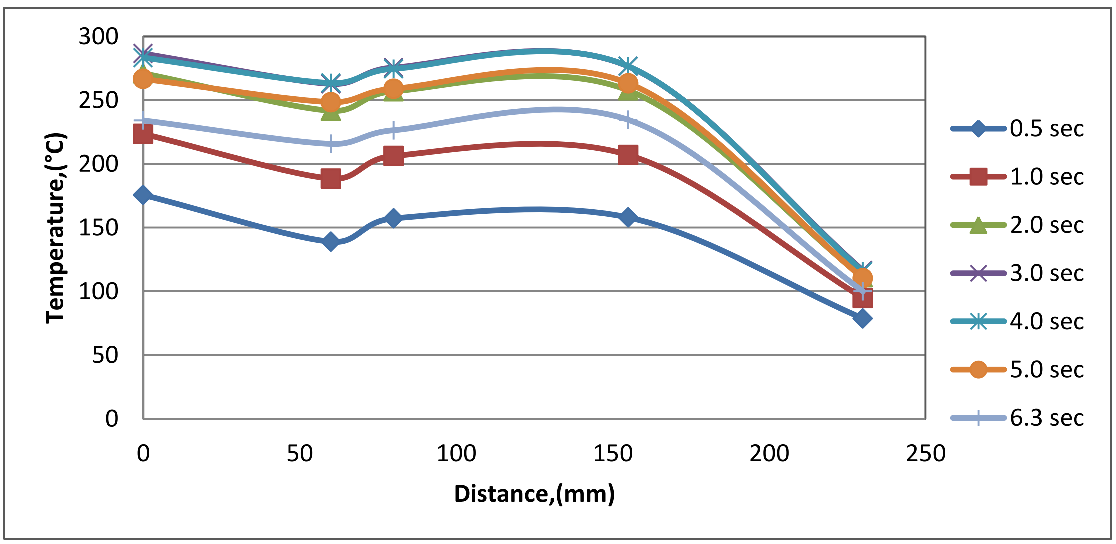


Figure 4.9: The temperature distribution of drum with wall thickness of 15.0 mm

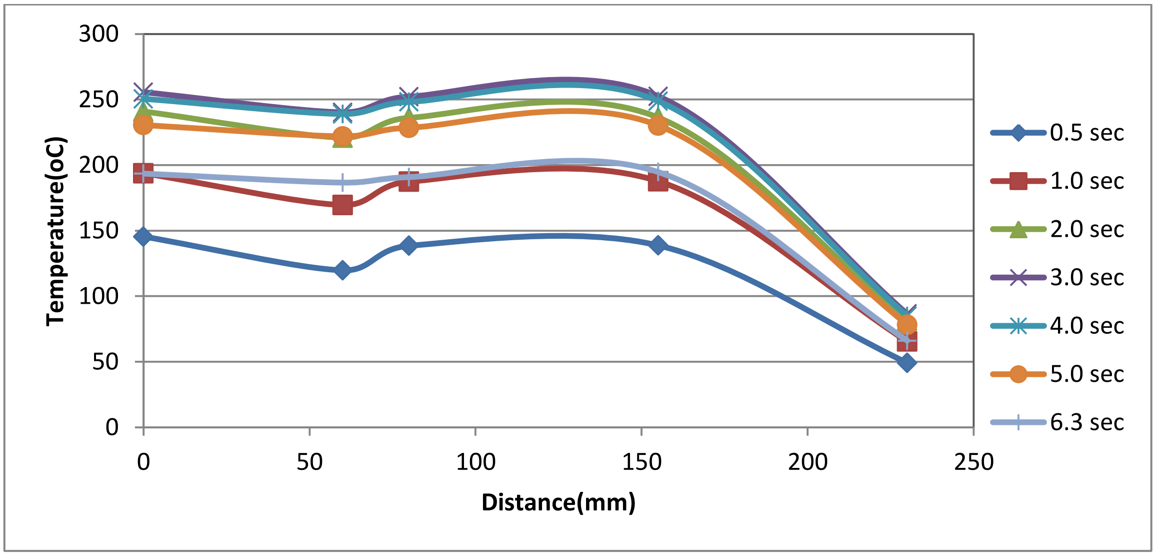


Figure 4.10: The temperature distribution of drum with wall thickness of 17.5 mm

4.3.2. The temperature distribution for Path 2

Similar to Path 1, the temperature at the interval of 1.0 s, with additional of 0.5 s and 6.3 s are recorded to investigate the temperature distribution in the horizontal direction of the outer geometry of the rubbing surface. **Figure 4.11** shows the dimension of the cross section of the drum with the location of the points of temperature measurement.

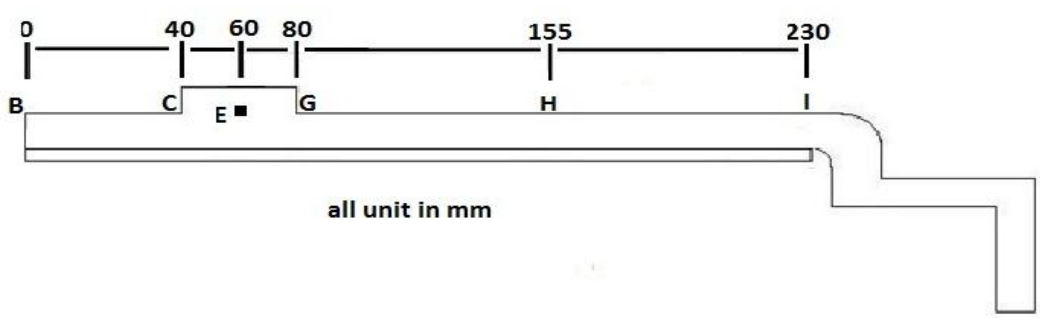


Figure 4.11: The dimension of the cross sectional of the drum with the location of the points of temperature measurement

Based on **Figure 4.12,** the temperature drops at first and reached its minimum at the distance of 60 mm. After that, the temperature rise until it reached its maximum at the distance of 155 mm and then drops again until 230 mm. The first drop is because of the presence of circumferential fin that is purposely design to enhance the temperature distribution. The temperature rise until 155mm because of no additional design and drops again because the temperature dissipates to drum part with no heat flux exposure. The thickness difference will result the temperature drop because the heat requires more time to dissipate to outer surface.

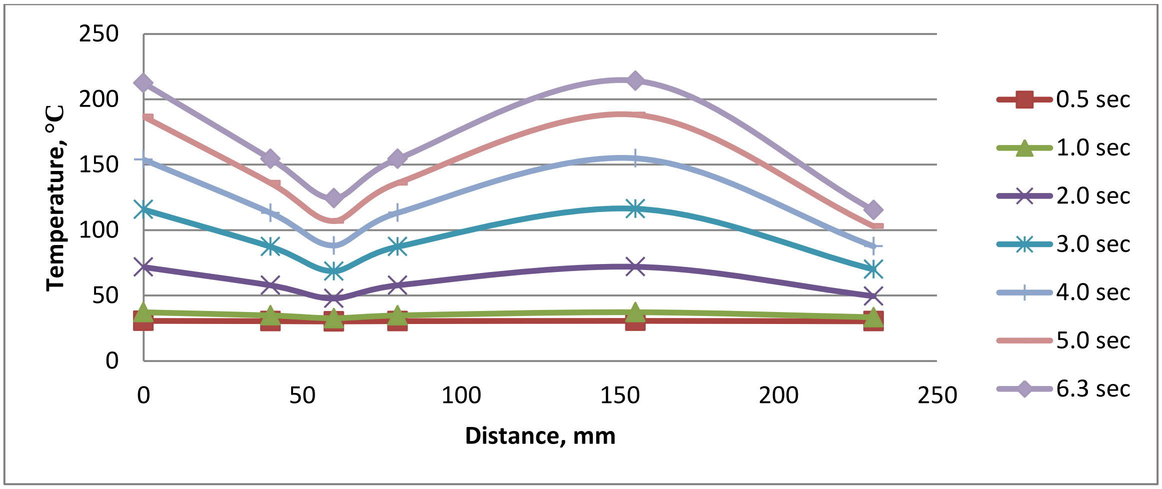


Figure 4.12: The temperature distribution of outer surface of the drum with wall thickness of 12.5 mm

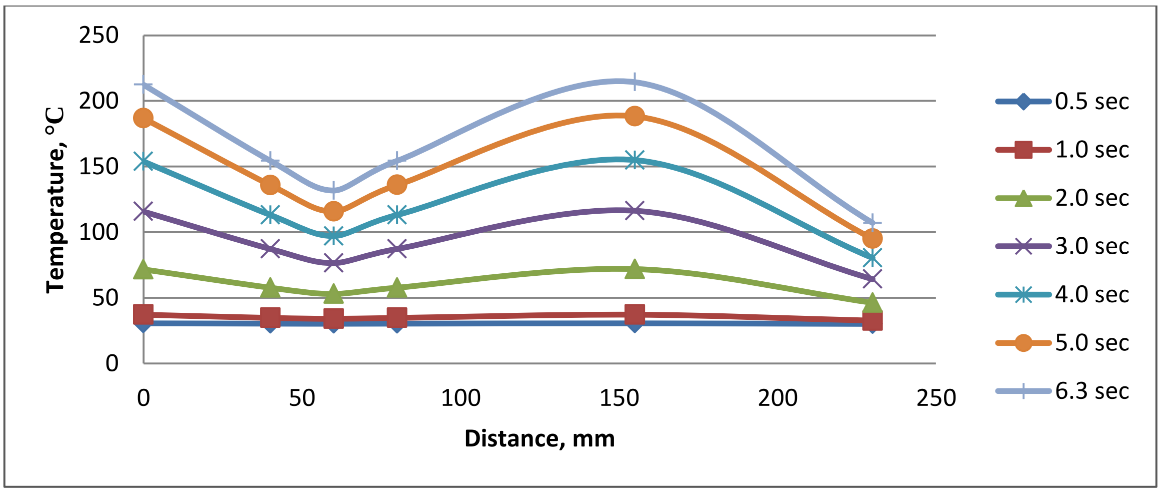


Figure 4.13: The temperature distribution of outer surface of the drum with wall thickness of 15.0 mm

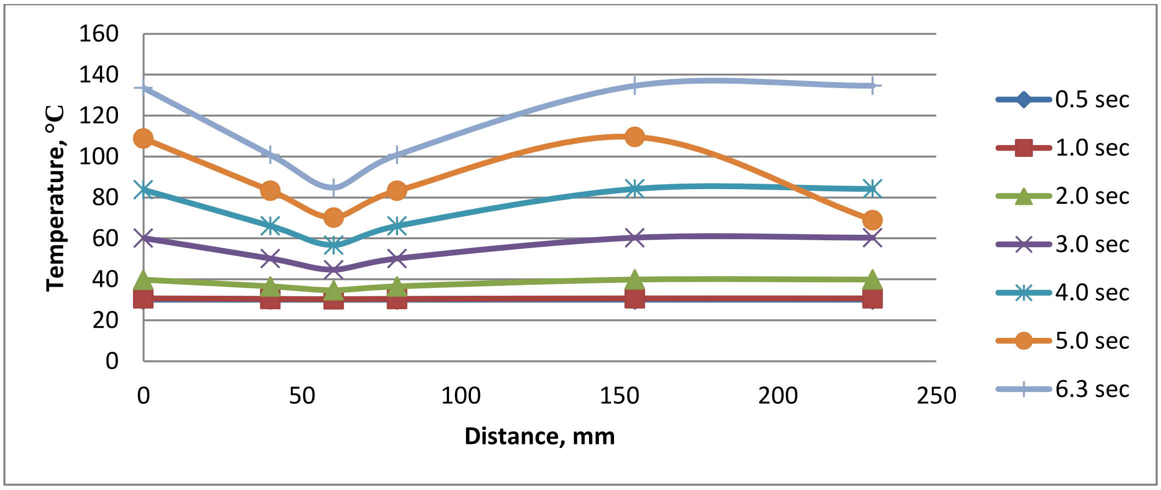


Figure 4.14: The temperature distribution of outer surface of the drum with wall thickness of 17.5 mm

4.3.3. The temperature distributions for Path 3

The temperature distribution along the vertical direction is recorded at the interval of 1.0 s, with additional time of 0.5 s and 6.3 s, along the cross section of the wall across the circumferential fin. **Figure 4.15** shows the location of the points of temperature measurement with different thickness of the drum.

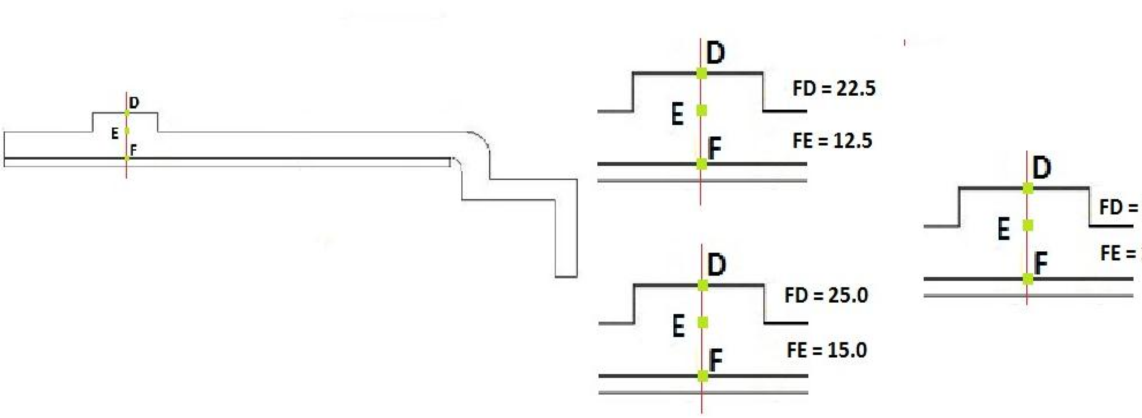


Figure 4.15: the location of the points of temperature measurement with different thickness of the drum

Figure 4.16 to **Figure 4.18** show the temperature distribution for different thickness. Based on these figures, the highest temperature is experienced at distance of 0.0 mm where the contacts happen. The temperature drops as the thickness increase because of the rate of heating at contact surface is higher than the rate of convection to the outer surface.

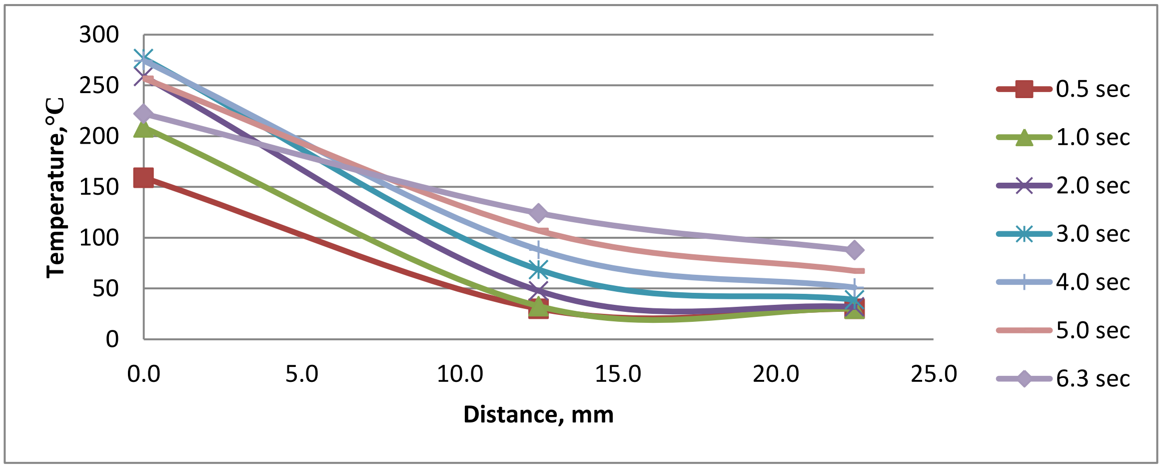


Figure 4.16: The temperature distribution of the cross-section of the drum with wall thickness of 12.5 mm

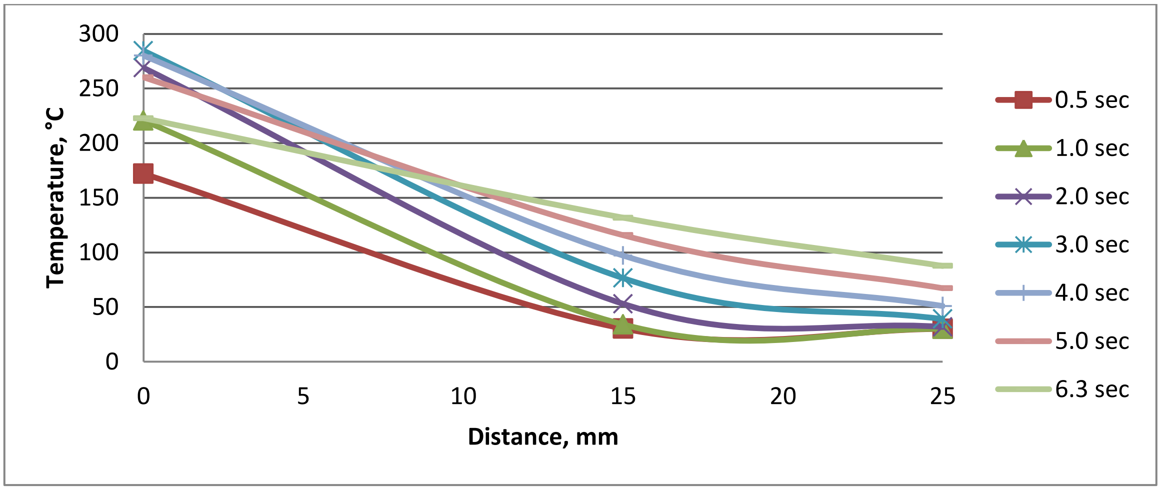


Figure 4.17: The temperature distribution of the cross-section of the drum with wall thickness of 15.0 mm

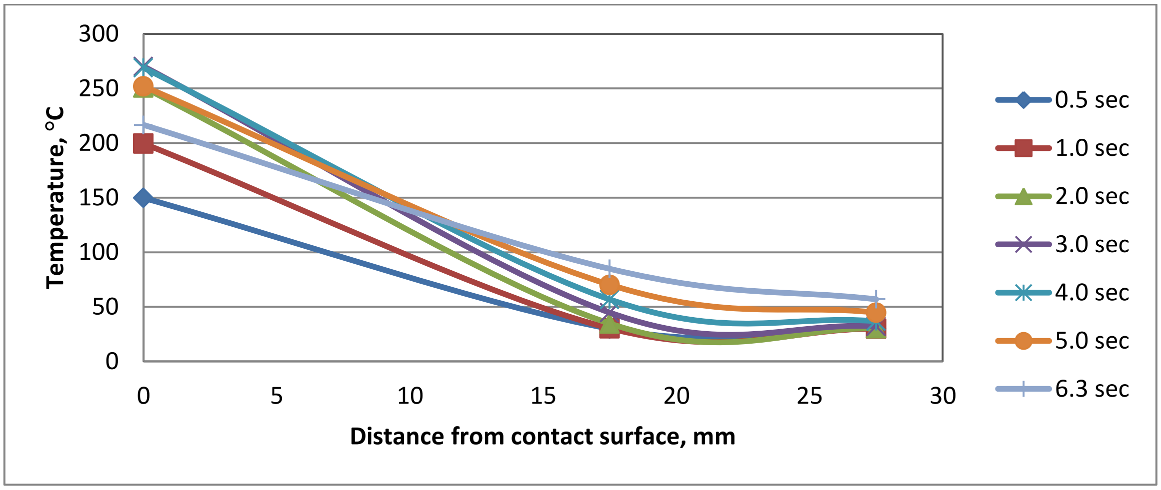


Figure 4.18: The temperature distribution of the cross-section of the drum with wall thickness of 17.5 mm

4.4. Thermal Stress Development

The heat flux applied to the inner surface of the drum will result in the increase of the wall temperature. The temperature distribution is explained in the previous section, where the different thickness of the wall will result in different temperature value but with similar distribution pattern. Because of no expansion or contraction happen, the temperature gradient will result in the thermal stress. In order to investigate the thermal stress development, the same path used in the temperature distribution investigation is used to study the development of thermal stress in the horizontal and vertical direction.

Three nodes are selected to investigate the thermal stress profile. **Figure 4.19** shows the location of the selected nodes.

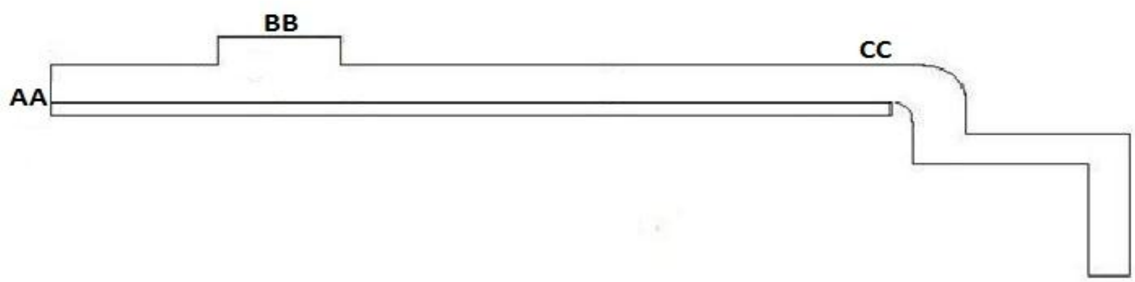


Figure 4.19: The location of the nodes of interest

Based on **Figure 4.20**, the thermal stress at node AA of thickness 12.5 mm is highest and reached its maximum with value of 63.09 MPa at the time of 3.6 s. After time of 3.6 s, the thermal stress drops until 54 MPa. This drop occurs when the contact did not happen, during which the cooling effect took part to spread the heat. The magnitude of node AA is the highest because node AA is directly in contact with the heat flux. In term of the geometry, node BB is located at the most outer part of the rubbing surface, thus the thermal stress at node BB is lower compared to the thermal stress at node AA. The heat that reached node CC also dissipates to parts that are not exposed to the heat flux, thus the thermal stress at node CC is lower. In term of thickness, the higher thickness of the wall will result in the lower thermal stress due to more volume for heat distribution.

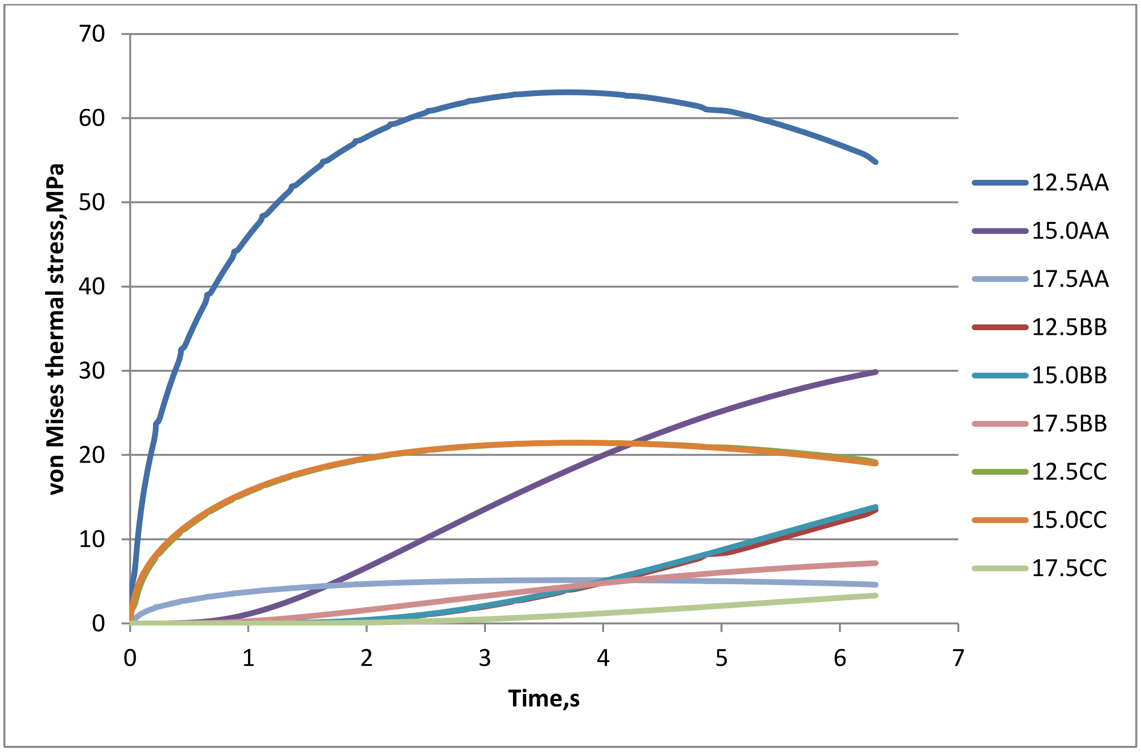


Figure 4.20: The von Mises thermal stress profile at different nodes for 3 thicknesses

4.4.1. The thermal stress in horizontal direction for Path 1

The stress at the interval of 1.0 s, with additional of 0.5 s and 6.3 s are recorded along the path in order to investigate the thermal stress in the horizontal direction of the rubbing surface. **Figure 4.21** shows the dimension of the cross section of the drum with the location the points of stress measurement

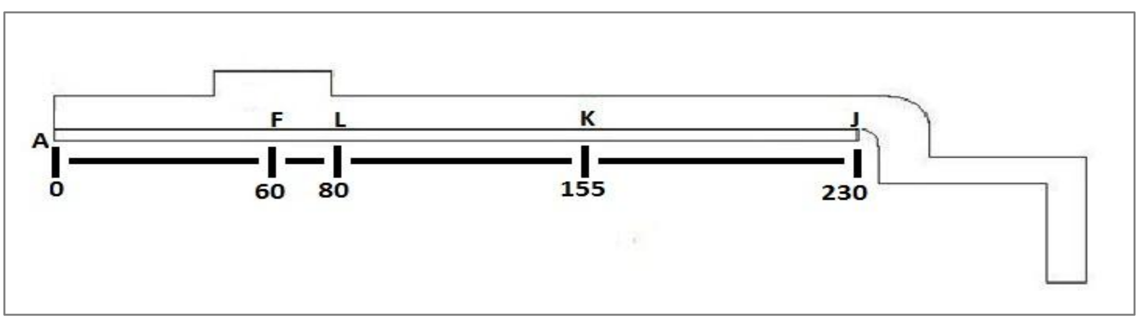


Figure 4.21: The dimension of the cross section of the drum with the location of the points of stress measurement for Path 1

Figure 4.22 to **Figure 4.24** show the thermal stress for thickness of 12.5 mm,15.0 mm and 17.5 mm. Based on these figures, the thermal stress is slightly higher at distance of 60 mm due to presence of the fin. As the distance increase, the thermal stress remain constant and drops at 155 mm. This drop happens because of the heat dissipation to the parts that are not exposed to the heat flux. In terms of different thickness, the stress is slightly different, with higher thickness results in lower thermal stress.

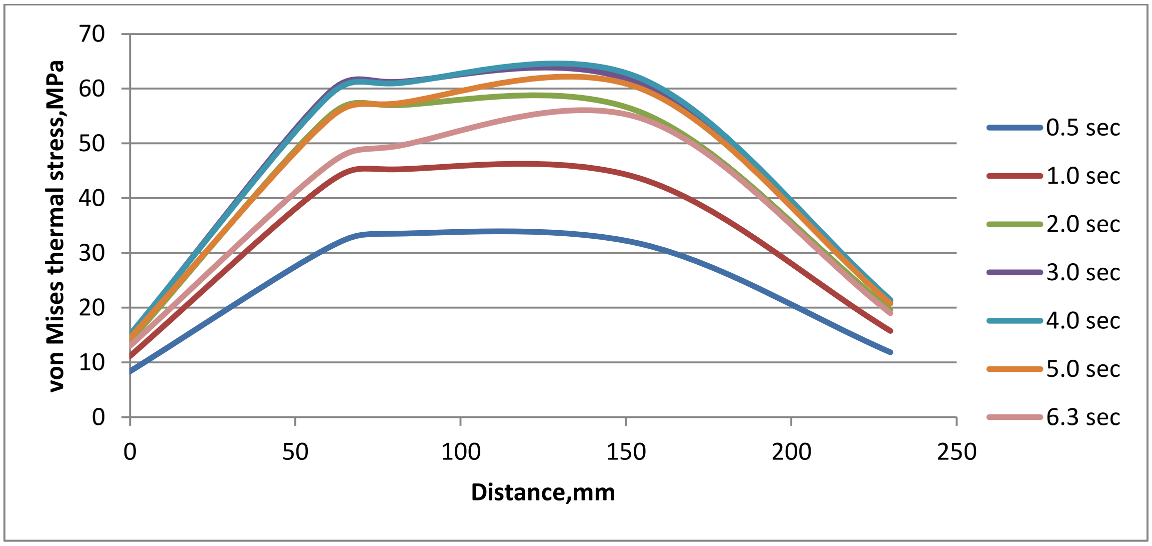


Figure 4.22: The von Mises thermal stress for Path 1 for thickness of 12.5 mm

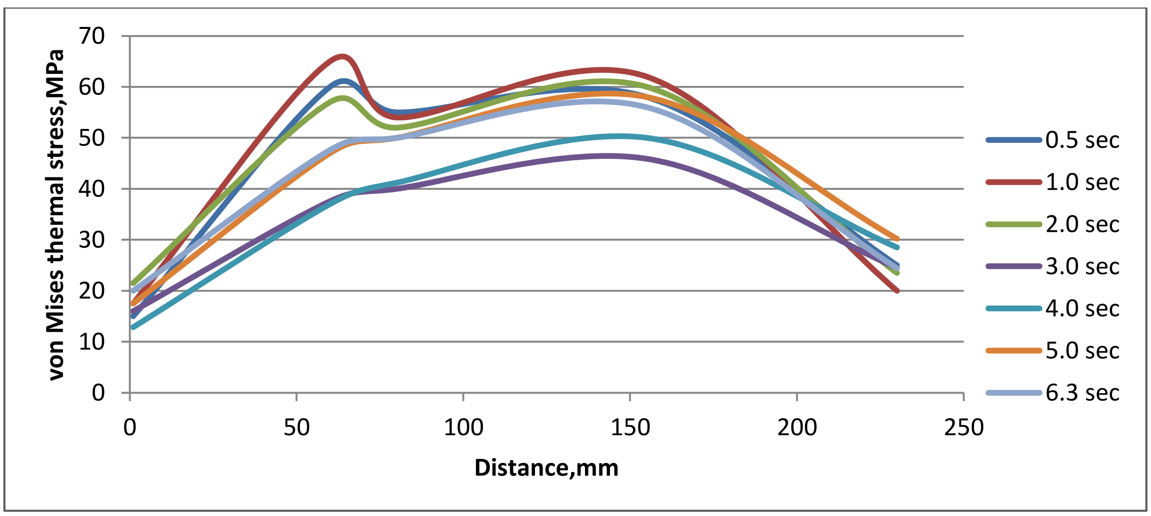


Figure 4.23: The von Mises thermal stress for Path 1 for thickness of 15.0 mm

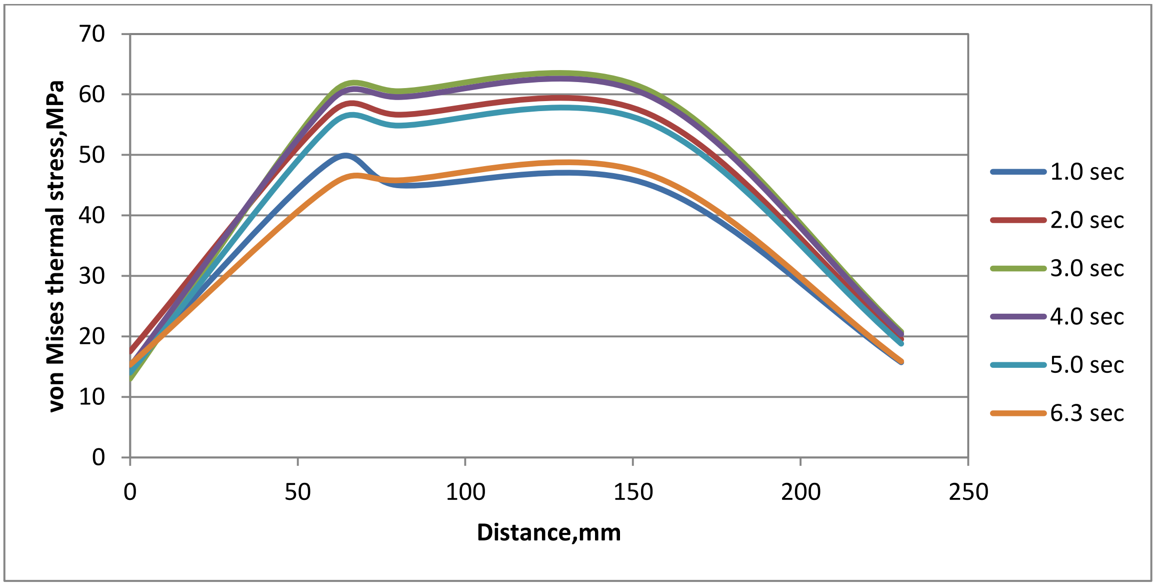


Figure 4.24: The von Mises thermal stress for Path 1 for thickness of 17.5 mm

4.4.2. The thermal stress in horizontal direction for Path 2

The thermal stress at the interval of 1.0 s, with additional time of 0.5 s and 6.3 s, are recorded along the path in order to investigate the thermal stress in the horizontal direction of the rubbing surface. **Figure 4.25** shows the dimension of the cross sectional of the drum with the location of the points of stress measurement for Path 2.

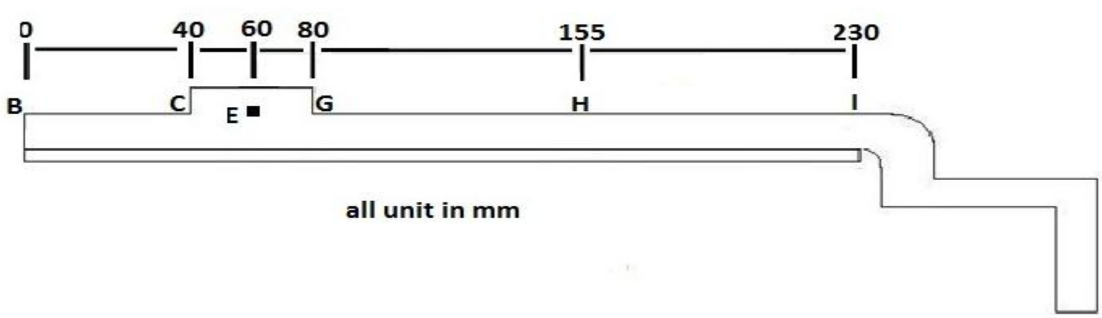


Figure 4.25: The dimension of the cross section of the drum with the location the points of stress measurement for Path 2

Based on **Figure 4.26** to **Figure 4.28**, the thermal stress along the outer surface of the wall is decreasing along the line. At the distance of 60 mm, the thermal stress exhibit huge drop because of the presence of the fin. Then, the thermal stress rise again and drops again at the end of the line because of the heat already transferred from hot to cool molecules before the changes of geometry. In term of thickness, the higher thickness exhibits the lower thermal stress due to lower temperature change. This is because more time is taken for the heat to reach the outer surface due to more volume for heat to dissipate.

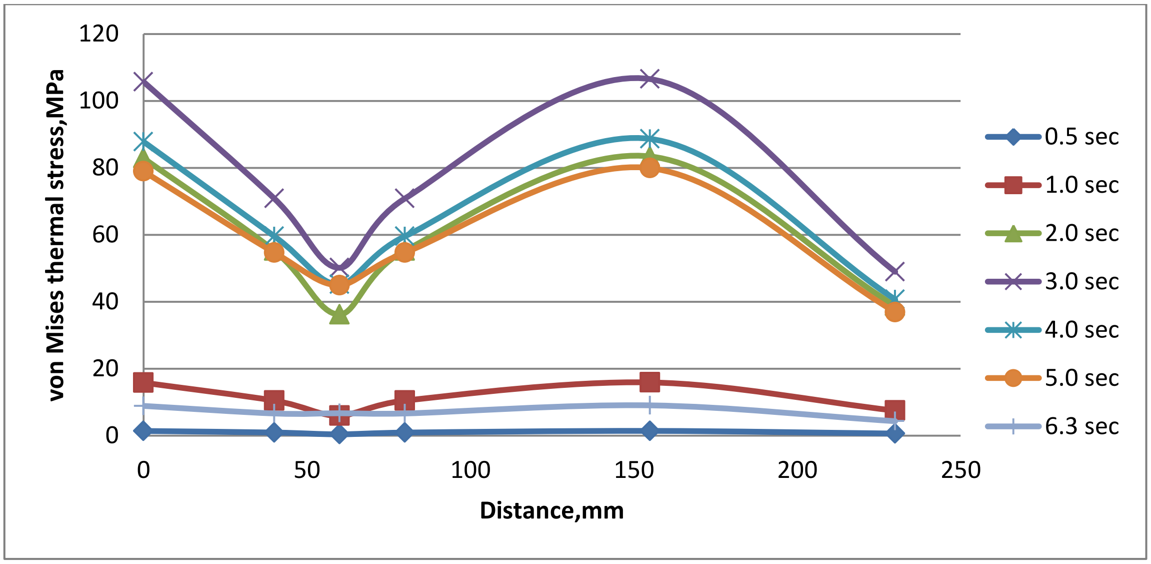


Figure 4.26: The von Mises thermal stress for Path 2 for thickness of 12.5 mm

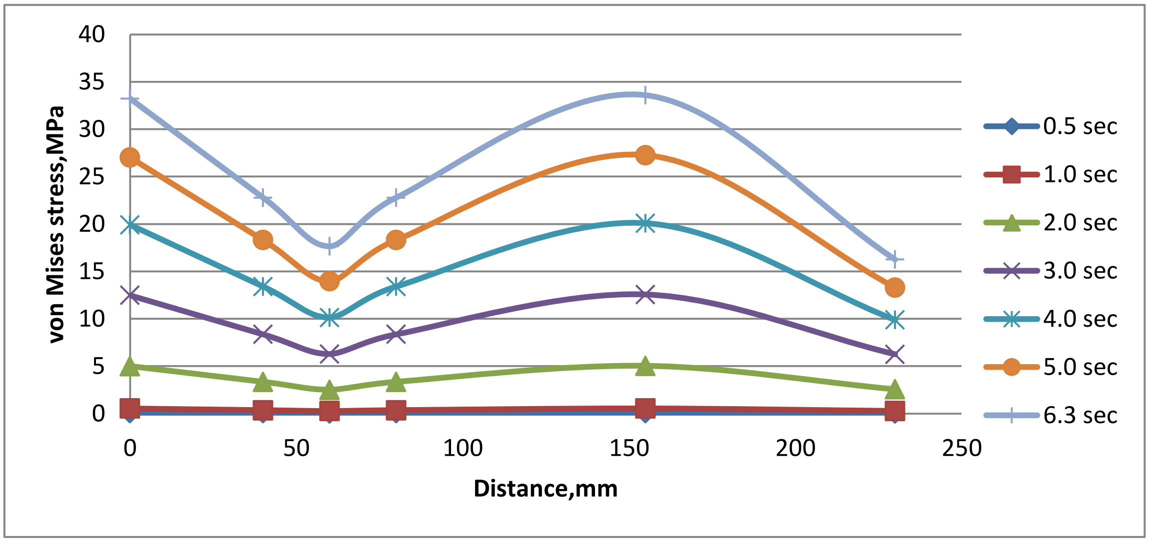


Figure 4.27: The von Mises thermal stress for Path 2 for thickness of 15.0 mm

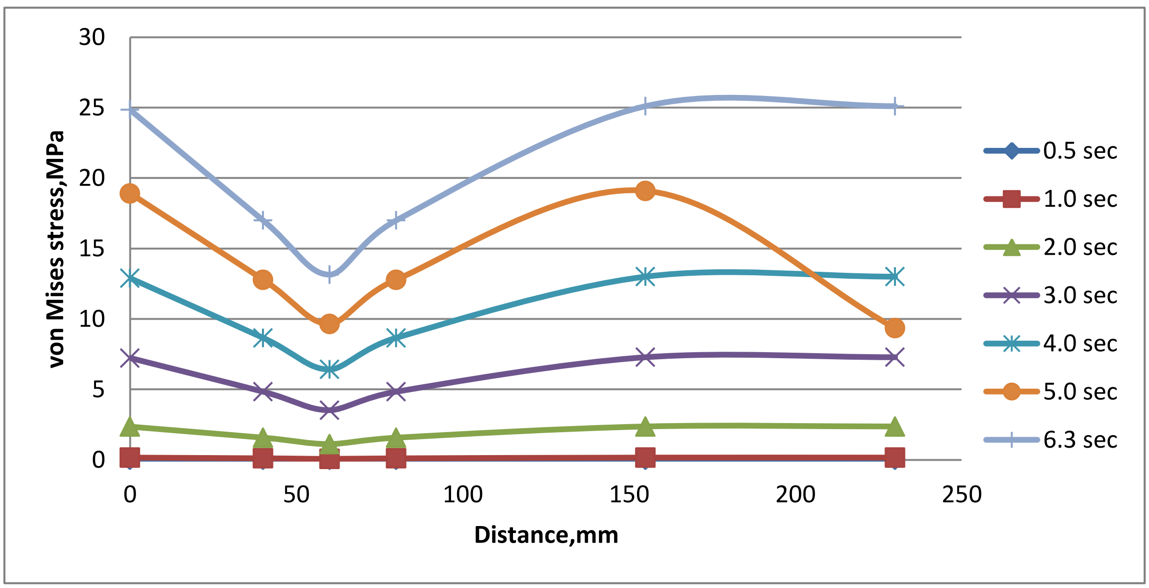


Figure 4.28: The von Mises thermal stress for Path 2 for thickness of 17.5 mm

4.4.3. The thermal stress along Path 3

The thermal stress along the vertical direction is calculated for the interval of 1.0 s, with additional time of 0.5 s and 6.3 s along the cross-section of the wall across the circumferential fin. **Figure 4.2** shows the location of the points of stress measurement with different thickness of the drum.

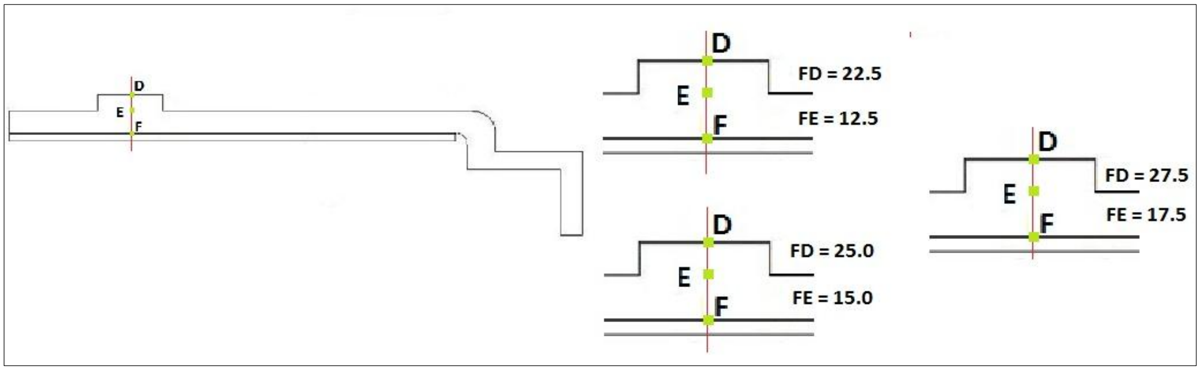


Figure 4.29: The location of the points of stress measurement for different thickness for Path 3

Figure 4.30 to **Figure 4.32** show the thermal stress of the drum brake in term of different thickness. Based on the figures, the thermal stress is highest at the first point, where the rubbing surface is located. As the distance increase, the thermal stress decrease gradually. At node E, the stress is constant and the stress slowly decrease until the outer surface is reached where the stress is slightly lower than at node E. At node E, the heat flux applied is slightly similar to the rate of heat transfer throughout the drum body, thus resulting to decrease of the stress.

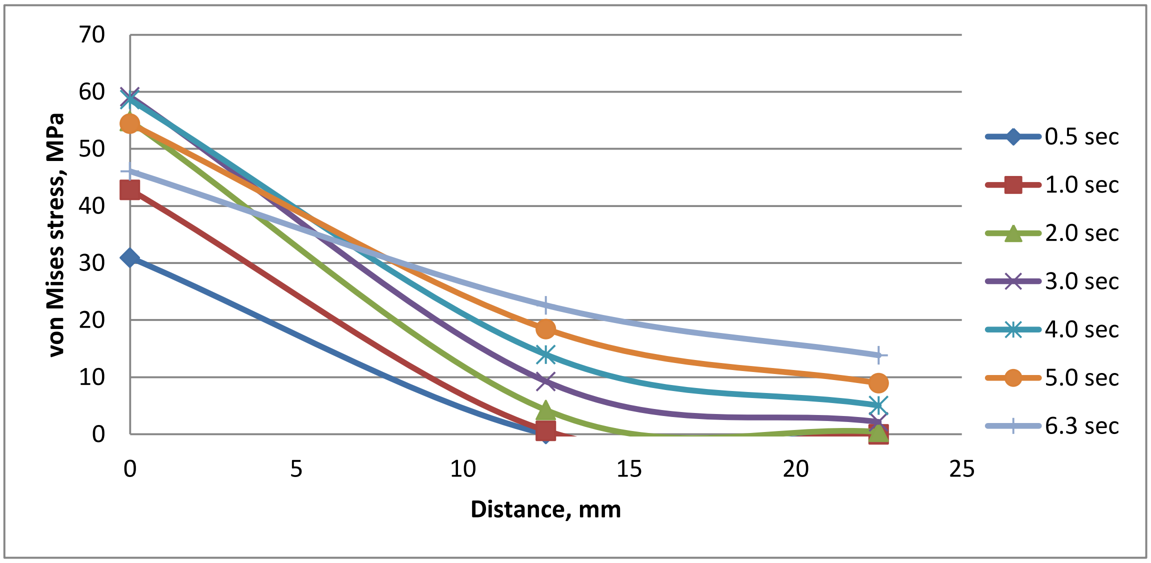


Figure 4.30: The von Mises thermal stress for Path 3 for thickness of 12.5 mm

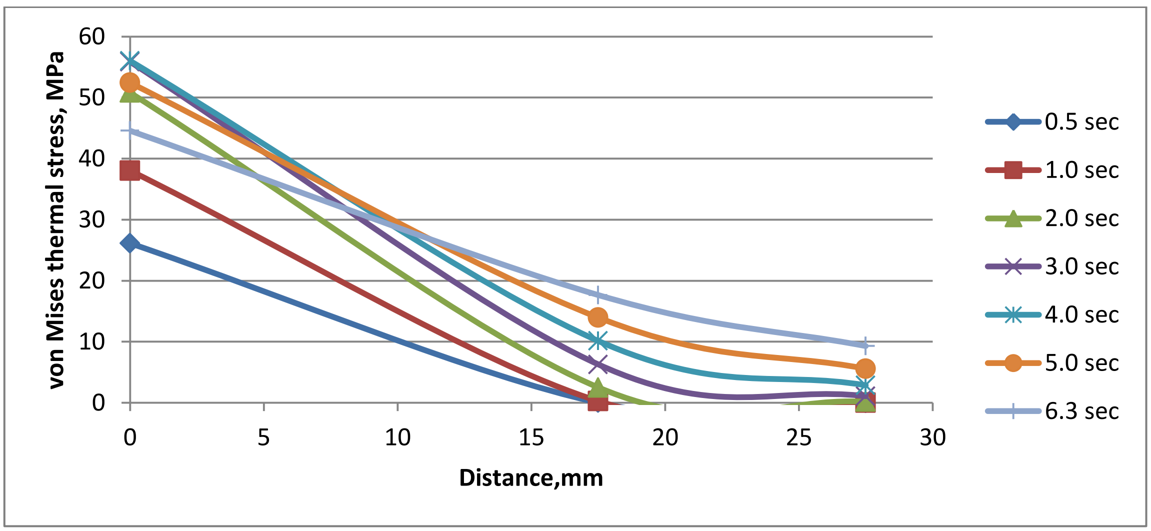


Figure 4.31: The von Mises thermal stress for Path 3 for thickness of 15.0 mm

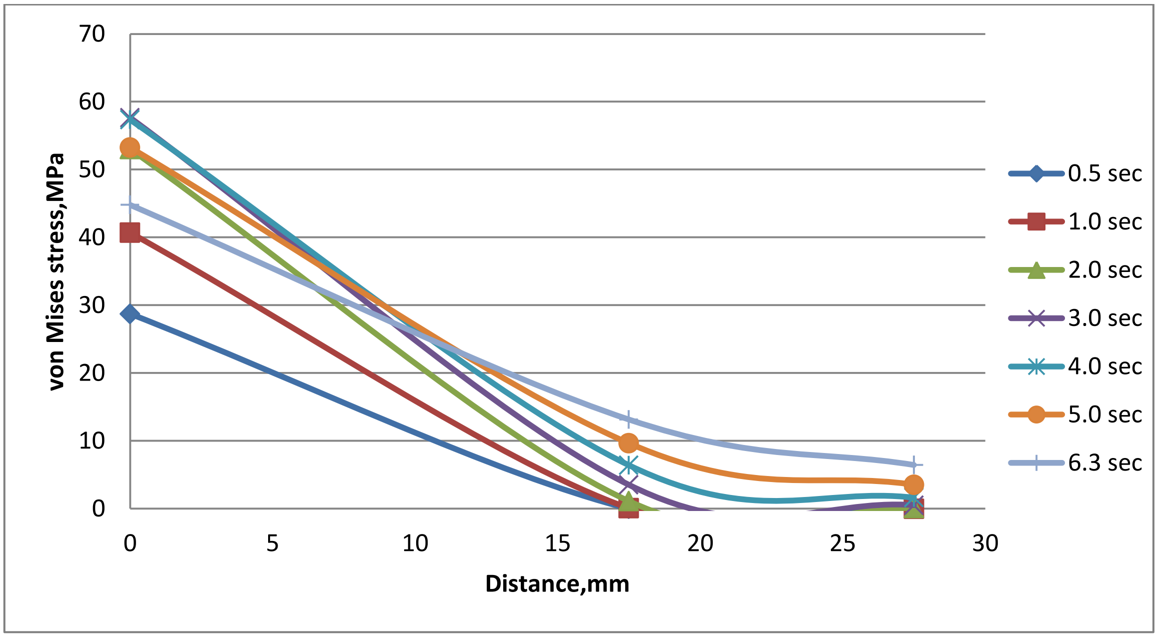


Figure 4.32: The von Mises thermal stress for Path 3 for thickness of 17.5 mm

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1. CONCLUSIONS

- The estimated time taken to fully stop the vehicle from the maximum velocity, which is 160 km/h, is 6.302 s and the vehicle cover almost 50.0 m of ground.
- During this time period, maximum temperature on drum rubbing surface is up to 292.58 °C at the time of 3.6 s.
- In the case of deceleration of 0.7G with an initial vehicle speed of 160km/h, equal to 44.4 m/s, the maximum kinetic energy generated is 590 kJ.
- The temperature at inner surface is unequally distributed along the heating line where the brake lining and the drum brake make contact. At the presence of the circumferential fin, the temperature is lower due to heat dissipation to the fin.
- The temperature distribution at the outer surface is equally distributed along the line with slightly lower value due to the presence of the fin. But the temperature level will change as there is geometry variant with different thickness.
- Different thickness of drum brake gives different magnitude of temperature distribution as well as thermal stress. Based on the results, with higher value of wall thickness, lower value of temperature as well as thermal stress is observed.
- Stopping the vehicle from its maximum velocity will create a thermal environment on the friction surface with an excessively high surface temperature.

5.2. RECOMMENDATIONS

The following recommendations are presented to further improve the understanding on the thermal stress distribution on a brake drum of a small vehicle

1. For further study, different material such as Aluminum Oxide and Stainless Steel can be used in order to investigate the temperature distribution and thermal stress.
2. Further study to improvise the design of the drum brake is required to enhance the thermal stress and to reduce the impact of cooling and heating to the drum brake in order to increase the life span of the drum brake.

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