International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2015): 6.391

Modelling and Analysis of Multi-Plate Clutch

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Abstract: ***Multi plate clutch is one of the important part in the power transmission systems. Good design of clutch provides better engine performance. Multi plate clutch is most widely used in racing cars and heavy duty vehicle where high torque transmission required and limited space is available. In this project, we have designed a multi plate clutch by using empirical formulae. A model of multi plate clutch has been generated in CATIA V5 and then imported in ANSYS workbench for Automobile Applications. We have conducted structural analysis by varying the friction surfaces material and keeping base material as Steel. By observing the results, comparison is done for materials to validate better lining material for multi plate clutch by doing analysis on clutch with help of ANSYS Workbench software and FEM to find out which material is best for the lining of friction surfaces.***

Keywords*:* Multi-plate clutch, Friction material, SF-MC2, ANSYS, CATIA V5.

1. Introduction

The clutch is a mechanical device, which is used to connect or disconnects the source of power from the remaining parts of the power transmission at the will of the operator. The clutch can connect and disconnect the driving shaft and the driven shaft. An automotive clutch can permit the engine to run without driving the car. Depending on the orientation, speeds, materials, torque produced and finally the use of the whole device, different kinds of clutches are used. This is desirable when the engine is to be started or stopped, or when the gears are to be shifted. It is the link between engine and transmission. When a clutch is at a standstill, clutch is engaged to transfer the torque to the transmission; and when vehicle is in motion, clutch is first disengaged of the drive to allow for gear selection and then again smoothly to power the vehicle.

2. Multi-plate Friction Clutch

Multi plate clutch comes under the category of friction clutch. Multi plate clutch is an extension of single plate type where the number of friction and metal plates is increased. The increase in number of friction surfaces obviously increases the capacity of clutch to transmit torque. Alternatively the size of the clutch is reduced. This type of clutch is used in some racing vehicles where high torque is to be transmitted. Besides, this finds application in case of scooters and motorcycles, where space available is limited.
Torque capacity of the friction clutch depends upon following factors: Coefficient of friction, the diameter of the friction plate, axial thrust applied by the pressure plate. The diameter of the friction plate is restricted by the size of the clutch. The axial force is limited by the amount force the person can apply on the foot pedal to disengage the clutch. So to transmit maximum torque friction material have adequate coefficient of friction.

3. Friction Materials

An axial clutch is one where the mating frictional members are moved in a direction parallel to the shaft. Frictional material is the most important component of a multi plate clutch. Frictional material is responsible for transmitting the torque from the driving shaft to the driven shaft. A wide variety of frictional materials are in use in clutches today. Currently there are certain materials like cork and certain fibre composite materials are in use right now. High performance and cheap alternatives are currently being searched for. Right now factors like cost and availability in large amounts hinder the use of high performance alternatives.

Desirable properties of a frictional materials for clutches:
- The two materials in contact must have a high coefficient of friction.
- The materials in contact must resist wear effects, such as scoring, galling and ablation.
- The friction value should be constant over a range of temperatures and pressures. The materials should be resistant should be resistant to the environment (moisture, dust, pressure)
- The materials should possess good thermal properties, high heat capacity, and good thermal conductivity, withstand high temperatures, able to withstand high contact pressures.
- Good shear strength to transferred friction forces to structure.

3.1. Friction Materials: Sintered Iron

Friction pads are manufactured by sintering blend of powders consisting of heat absorption material along with friction generating & lubricating materials. The powders are blended in optimized proportions & compacted to form a solid flat button of predetermined shape. They are highly durable with harsher engagement characteristics compared to organic linings. **[1]**

Table 1: Properties of Sintered Iron

Material	*Sintered Iron*
Young's Modulus	275.79 N/mm²
Tensile strength	400 N/mm²
Poisson's ratio	0.34
Friction Coefficient	0.25±0.05

3.2. Friction Material: SF-MC2

SF-MC2 is a high performance, high friction, non-metal composite material containing a high percentage of aramid fibre. It can be considered as an alternative for sintered metal materials and offers many advantages. It will resist high energy inputs and is suitable for both dry and oil-immersed applications. It is not abrasive to the counter material, is silent in operation and it will resists high pressures. The wear rate of SF-MC2 is low even at high temperatures. SF-MC2 has higher friction coefficient and higher Kevlar composition when compared with the conventional used friction material. **[1]**

Table 2: Properties of SF-MC2

Material	*SF-MC2*
Young's Modulus	7260±100 N/mm²
Tensile strength	70±5 N/mm²
Poisson's ratio	0.27±0.03
Friction Coefficient	0.50±0.05

4. Specifications of the Clutch

The clutch plate model is based on the clutch used in **Bajaj Pulsar 150 DTS-i**.
Torque (T) = 12.66 N-m @ 6500 rpm
Number of friction surfaces (n) = 9
Inner diameter of the friction plate (Di) = 104 mm
Outer diameter of the friction plate (Do) = 125 mm

5. Analysis of Multi-Plate Clutch with Friction Material

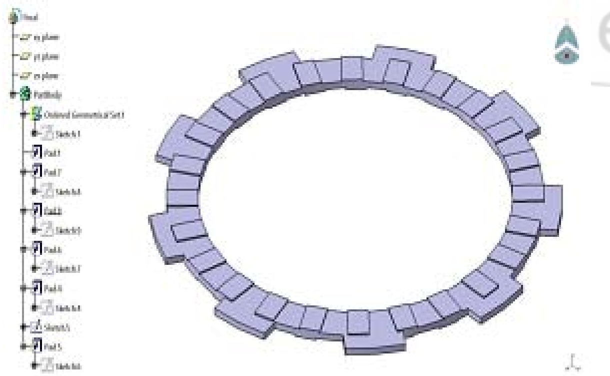

Figure 1: CATIA model of multi plate clutch

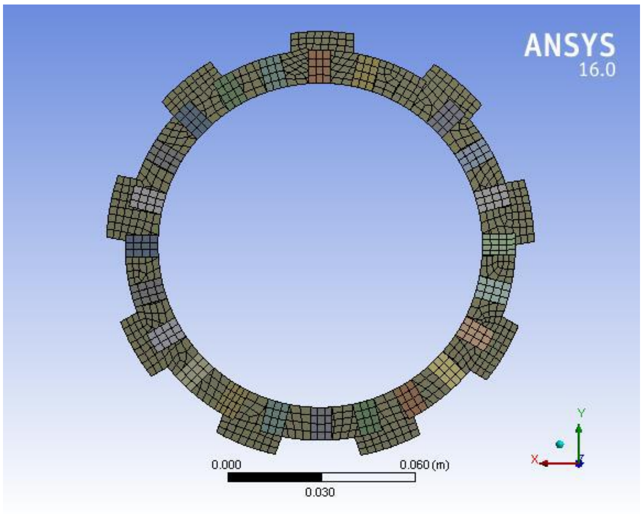

Figure 2: Meshing done on Designed Model

5.1. Analysis of Multi-Plate Clutch with Friction Material as Sintered Iron

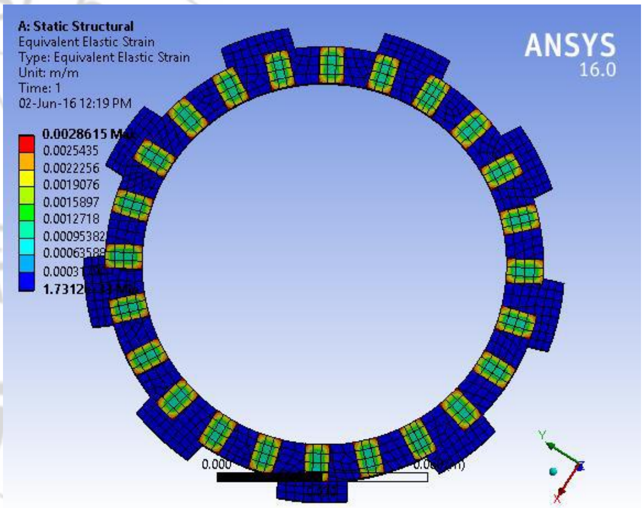

Figure 3: Total Deformation for Sintered Iron Friction

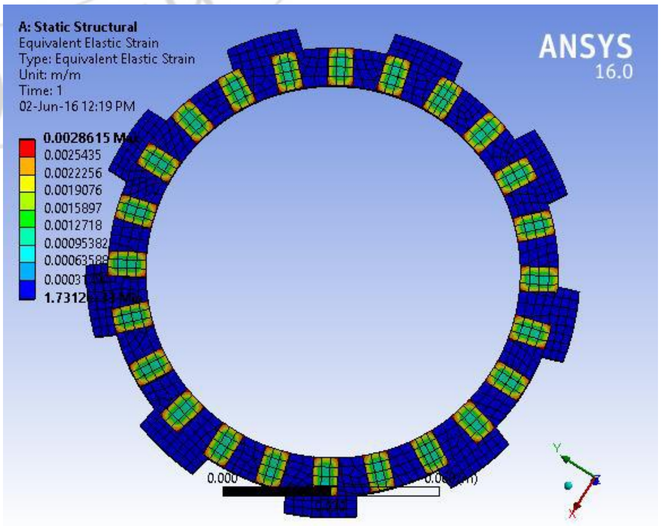

Figure 4: Equivalent Strain for Sintered Iron Friction Material

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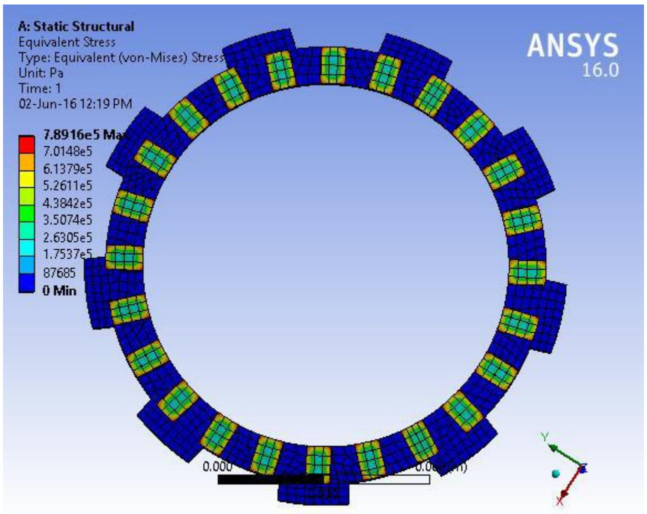

Figure 5: Equivalent Strain for Sintered Iron Friction Material

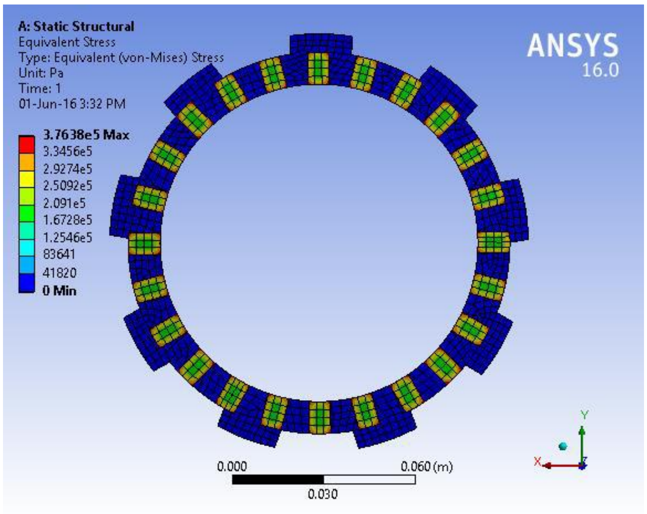

Figure 8: Equivalent Strain for SF-MC2 Friction Material

5.2. Analysis of Multi-Plate Clutch with Friction Material as SF-MC2

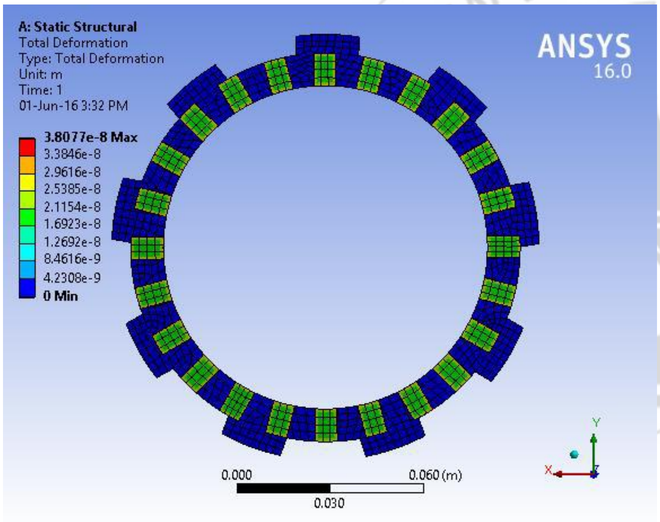

Figure 6: Total Deformation for SF-MC2 Friction Material

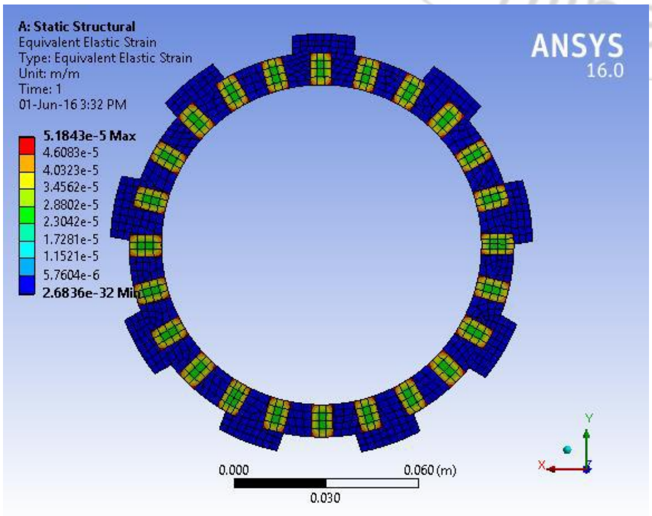

Figure 7: Equivalent Strain for SF-MC2 Friction Material

6. Analytical Calculations

6.1. Analytical Calculations for Sintered Iron Friction Material with Finite Element Method

Rectangular cross-section of the friction material pad is divided into two CST elements which are in plane stress condition. [2][3]

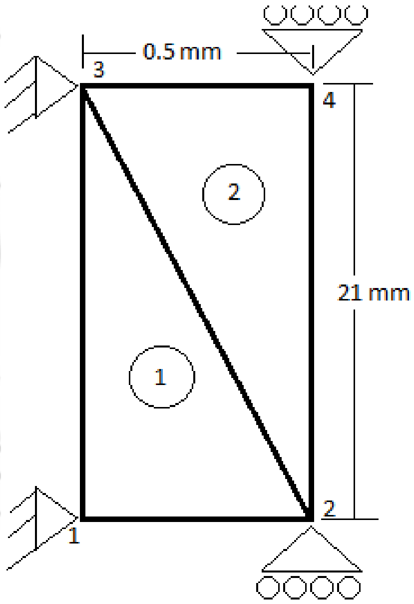

Figure 9: Discretization of the Element

Table 3: Nodes

Elements	**Nodes**		
1	1	2	3
2	2	4	3

E = 275.79 N/mm2
$\nu = 0.34$
$\mu = 0.25$
T = 12.66 N/m
R = 57.25 x 10^{-3} m

Clamping Force [W]:
T = μ n W R
12.66 = 0.25 x 9 x W x 57.25 x 10-3

W = 98.28 N

Element 1

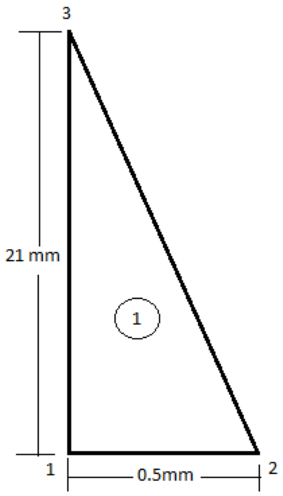

Figure 10: Element 1

Area of Triangle:

$$A = \frac{1}{2}\begin{vmatrix} 1 & x1 & y1 \\ 1 & x2 & y2 \\ 1 & x3 & y3 \end{vmatrix}$$

$$A = \frac{1}{2}\begin{vmatrix} 1 & 0 & 0 \\ 1 & 0.5 & 0 \\ 1 & 0 & 21 \end{vmatrix}$$

A = 5.25 mm^2

Cofactors:

C_{12} = -21

C_{22} = 21

C_{32} = -21

C_{13} = -0.5

C_{23} = 0

C_{33} = -0.5

Stress-Strain Relationship Matrix [D]:

$$[D] = \frac{E}{1-v^2}\begin{bmatrix} 1 & v & 0 \\ v & 1 & 0 \\ 0 & 0 & (1-v)/2 \end{bmatrix}$$

$$[D] = 311.8385\begin{bmatrix} 1 & 0.34 & 0 \\ 0.34 & 1 & 0 \\ 0 & 0 & 0.33 \end{bmatrix}$$

Strain-Displacement Relationship Matrix [B]:

$$[B] = \frac{1}{2A}\begin{bmatrix} C12 & 0 & C22 & 0 & C32 & 0 \\ 0 & C13 & 0 & C23 & 0 & C33 \\ C13 & C12 & C23 & C22 & C32 & C33 \end{bmatrix}$$

$$[B] = 0.0952\begin{bmatrix} -21 & 0 & 21 & 0 & -21 & 0 \\ 0 & -0.5 & 0 & 0 & 0 & -0.5 \\ -0.5 & -21 & 0 & 21 & -0.5 & -21 \end{bmatrix}$$

$$[B]^T = 0.0952\begin{bmatrix} -21 & 0 & -0.5 \\ 0 & -0.5 & -21 \\ 21 & 0 & 0 \\ 0 & 0 & 21 \\ -21 & 0 & -0.5 \\ 0 & -0.5 & -21 \end{bmatrix}$$

Element Stiffness Matrix $[K]_1$:

$[K]_1 = t\,A\,[B]^T[D][B]$

$$= 103.8630\begin{bmatrix} 441.083 & 7.035 & -441 & -3.465 & 441.083 & 7.035 \\ 7.035 & 145.780 & -3.570 & -145.530 & 7.035 & 145.780 \\ -441 & -3.570 & 441 & 0 & -441 & -3.570 \\ -3.465 & -145.530 & 0 & 145.530 & -3.465 & -145.530 \\ 441.083 & 7.035 & -441 & -3.465 & 441.083 & 7.035 \\ 7.035 & 145.780 & -3.570 & -145.530 & 7.035 & 145.780 \end{bmatrix}$$

Element 2

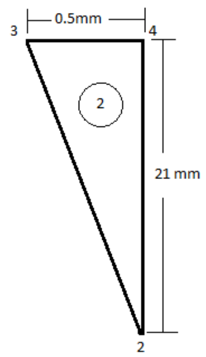

Figure 11: Element 2

Area of Triangle:

$$A = \frac{1}{2}\begin{vmatrix} 1 & x1 & y1 \\ 1 & x2 & y2 \\ 1 & x3 & y3 \end{vmatrix}$$

$$A = \frac{1}{2}\begin{vmatrix} 1 & 0.5 & 0 \\ 1 & 0.5 & 21 \\ 1 & 0 & 21 \end{vmatrix}$$

A = 5.25 mm^2

Cofactors:

C_{12} = 0

C_{22} = 21

C_{32} = -21

C_{13} = -0.5

C_{23} = 0.5

C_{33} = 0

Stress-Strain Relationship Matrix [D]:

$$[D] = \frac{E}{1-v^2}\begin{bmatrix} 1 & v & 0 \\ v & 1 & 0 \\ 0 & 0 & (1-v)/2 \end{bmatrix}$$

$$[D] = 311.8385\begin{bmatrix} 1 & 0.34 & 0 \\ 0.34 & 1 & 0 \\ 0 & 0 & 0.33 \end{bmatrix}$$

Strain-Displacement Relationship Matrix [B]:

$$[B] = \frac{1}{2A}\begin{bmatrix} C12 & 0 & C22 & 0 & C32 & 0 \\ 0 & C13 & 0 & C23 & 0 & C33 \\ C13 & C12 & C23 & C22 & C32 & C33 \end{bmatrix}$$

$$[B] = 0.0952\begin{bmatrix} 0 & 0 & 21 & 0 & -21 & 0 \\ 0 & -0.5 & 0 & 0.5 & 0 & 0 \\ -0.5 & 0 & 0.5 & 21 & 0 & -21 \end{bmatrix}$$

$$[B]^T = 0.0952 \begin{bmatrix} 0 & 0 & -0.5 \\ 0 & -0.5 & 0 \\ 21 & 0 & 0.5 \\ 0 & 0.5 & 21 \\ -21 & 0 & 0 \\ 0 & 0 & -21 \end{bmatrix}$$

Elemental Stiffness Matrix $[K]_2$:

$[K]_2 = t\,A\,[B]^T[D][B]$
$= 103.8630$

$$\begin{bmatrix} 0.083 & 0 & -0.083 & -3.465 & 0 & 3.465 \\ 0 & 0.25 & -3.570 & -0.25 & 3.570 & 0 \\ -0.083 & -3.570 & 441.083 & 7.035 & -441 & -3.465 \\ -3.465 & -0.25 & 7.035 & 145.780 & -3.570 & -145.530 \\ 0 & 3.570 & -441 & -3.570 & 441 & 0 \\ 3.465 & 0 & -3.465 & -145.530 & 0 & 145.530 \end{bmatrix}$$

Global Stiffness Matrix [K]:

$$[K] = 103.8630 \begin{bmatrix} 441.083 & 7.035 & -441 & -3.465 & 441.083 & 7.035 & 0 & 0 \\ 7.035 & 145.780 & -3.570 & -145.530 & 7.035 & 145.780 & 0 & 0 \\ -441 & -3.570 & 441.083 & 0 & -441 & -0.105 & -0.083 & -3.465 \\ -3.465 & -145.530 & 0 & -145.780 & 0.105 & -145.530 & -3.570 & -0.25 \\ 441.083 & 7.035 & -441 & 0.105 & 882.083 & 7.035 & -441 & -3.570 \\ 7.035 & 145.780 & -0.105 & -145.530 & 7.035 & 291.31 & -3.465 & -145.530 \\ 0 & 0 & -0.083 & -3.570 & -441 & -3.465 & 441.083 & 7.035 \\ 0 & 0 & -3.465 & -0.25 & -3.570 & -145.530 & 7.035 & 145.780 \end{bmatrix}$$

Displacement Matrix [U]:

$$[U] = \begin{bmatrix} U1x \\ U1y \\ U2x \\ U2y \\ U3x \\ U3y \\ U4x \\ U4y \end{bmatrix}$$

Force Matrix [F]:

$$[F] = \begin{bmatrix} 0 \\ 0 \\ 98.28 \\ 0 \\ 0 \\ 0 \\ 98.28 \\ 0 \end{bmatrix}$$

Global Equation:

[K] [U] = [F]

$$103.8630 \begin{bmatrix} 441.083 & 7.035 & -441 & -3.465 & 441.083 & 7.035 & 0 & 0 \\ 7.035 & 145.780 & -3.570 & -145.530 & 7.035 & 145.780 & 0 & 0 \\ -441 & -3.570 & 441.083 & 0 & -441 & -0.105 & -0.083 & -3.465 \\ -3.465 & -145.530 & 0 & -145.780 & 0.105 & -145.530 & -3.570 & -0.25 \\ 441.083 & 7.035 & -441 & 0.105 & 882.083 & 7.035 & -441 & -3.570 \\ 7.035 & 145.780 & -0.105 & -145.530 & 7.035 & 291.31 & -3.465 & -145.530 \\ 0 & 0 & -0.083 & -3.570 & -441 & -3.465 & 441.083 & 7.035 \\ 0 & 0 & -3.465 & -0.25 & -3.570 & -145.530 & 7.035 & 145.780 \end{bmatrix} \begin{bmatrix} U1x \\ U1y \\ U2x \\ U2y \\ U3x \\ U3y \\ U4x \\ U4y \end{bmatrix}$$

$$= \begin{bmatrix} 0 \\ 0 \\ 98.28 \\ 0 \\ 0 \\ 0 \\ 98.28 \\ 0 \end{bmatrix}$$

Applying Boundary conditions:
U1x = U1y = U2y = U3x = U3y = U4y = 0
F1x = F1y = F2y = F3x = F3y = F4y = 0

$$103.8630 \begin{bmatrix} 441.083 & -0.083 \\ -0.083 & 441.083 \end{bmatrix} \begin{bmatrix} U2x \\ U4x \end{bmatrix} = \begin{bmatrix} 98.28 \\ 98.28 \end{bmatrix}$$

$$\begin{bmatrix} 441.083 & -0.083 \\ -0.083 & 441.083 \end{bmatrix} \begin{bmatrix} U2x \\ U4x \end{bmatrix} = \begin{bmatrix} 0.946246 \\ 0.946246 \end{bmatrix}$$

U2x = 2.145682×10^{-3} mm
U4x = 2.145682×10^{-3} mm

Elemental Strain $\{\epsilon\}_1$:

$\{\epsilon\}_1 = [B]_1[U]$
$= 0.0952$

$$\begin{bmatrix} -21 & 0 & 21 & 0 & -21 & 0 \\ 0 & -0.5 & 0 & 0 & 0 & -0.5 \\ -0.5 & -21 & 0 & 21 & -0.5 & -21 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 2.145682 \text{ x } 10\text{^}(-3) \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

$$\{\epsilon\}_1 = \begin{bmatrix} 4.289647 \text{ x } 10\text{^}(-3) \\ 0 \\ 0 \end{bmatrix} \text{ mm/mm}$$

Elemental Strain $\{\epsilon\}_2$:

$\{\epsilon\}_2 = [B]_2[U]$
$= 0.0952$

$$\begin{bmatrix} 0 & 0 & 21 & 0 & -21 & 0 \\ 0 & -0.5 & 0 & 0.5 & 0 & 0 \\ -0.5 & 0 & 0.5 & 21 & 0 & -21 \end{bmatrix} \begin{bmatrix} 2.145682 \text{ x } 10\text{^}(-3) \\ 0 \\ 2.145682 \text{ x } 10\text{^}(-3) \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

$$\{\epsilon\}_2 = \begin{bmatrix} 4.289647 \text{ x } 10\text{^}(-3) \\ 0 \\ 0 \end{bmatrix} \text{ mm/mm}$$

Elemental Stress $[\sigma]_1$:

$[\sigma]_1 = [D]\,\{\epsilon\}_1$
$= 311.8385$

$$\begin{bmatrix} 1 & 0.34 & 0 \\ 0.34 & 1 & 0 \\ 0 & 0 & 0.33 \end{bmatrix} \begin{bmatrix} 4.289647 \text{ x } 10\text{^}(-3) \\ 0 \\ 0 \end{bmatrix}$$

$$[\sigma]_1 = \begin{bmatrix} 1.337677 \\ 0.454810 \\ 0 \end{bmatrix} \text{ N/mm}^2$$

Elemental Stress $[\sigma]_2$:

$[\sigma]_2 = [D]\,\{\epsilon\}_2$
$= 311.8385$

$$\begin{bmatrix} 1 & 0.34 & 0 \\ 0.34 & 1 & 0 \\ 0 & 0 & 0.33 \end{bmatrix} \begin{bmatrix} 4.289647 \text{ x } 10\text{^}(-3) \\ 0 \\ 0 \end{bmatrix}$$

$$[\sigma]_2 = \begin{bmatrix} 0.937677 \\ 0.454810 \\ 0 \end{bmatrix} \text{N/mm}^2$$

6.2. Analytical Calculations for SF-MC2 Friction Material with Finite Element Method

Rectangular cross-section of the friction material pad is divided into two CST elements which are in plane stress condition. **[2][3]**

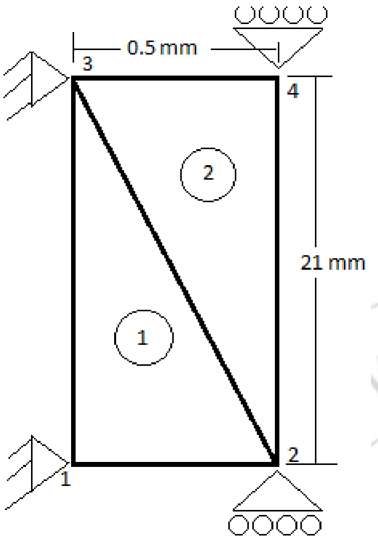

Figure 12: Discretization of the Element

Table 4: Nodes

Elements	Nodes		
1	1	2	3
2	2	4	3

E = 7260 N/mm^2
v = 0.27
μ = 0.5
T = 12.66 N/m
R = 57.25 x 10^{-3} m

Clamping Force [W]:
T = μ n W R
12.66 = 0.5 x 9 x W x 57.25 x 10^{-3}
W = 49.14 N

Element 1

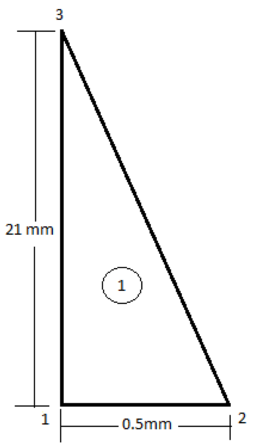

Figure 13: Element 1

Area of Triangle:

$$A = \frac{1}{2}\begin{vmatrix} 1 & x1 & y1 \\ 1 & x2 & y2 \\ 1 & x3 & y3 \end{vmatrix}$$

$$A = \frac{1}{2}\begin{vmatrix} 1 & 0 & 0 \\ 1 & 0.5 & 0 \\ 1 & 0 & 21 \end{vmatrix}$$

A = 5.25 mm^2

Cofactors:

C_{12} = -21
C_{22} = 21
C_{32} = -21
C_{13} = -0.5
C_{23} = 0
C_{33} = -0.5

Stress-Strain Relationship Matrix [D]:

$$[D] = \frac{E}{1-v^2}\begin{bmatrix} 1 & v & 0 \\ v & 1 & 0 \\ 0 & 0 & (1-v)/2 \end{bmatrix}$$

$$[D] = 7830.8704 \begin{bmatrix} 1 & 0.27 & 0 \\ 0.27 & 1 & 0 \\ 0 & 0 & 0.365 \end{bmatrix}$$

Strain-Displacement Relationship Matrix [B]:

$$[B] = \frac{1}{2A}\begin{bmatrix} C12 & 0 & C22 & 0 & C32 & 0 \\ 0 & C13 & 0 & C23 & 0 & C33 \\ C13 & C12 & C23 & C22 & C32 & C33 \end{bmatrix}$$

$$[B] = 0.0952 \begin{bmatrix} -21 & 0 & 21 & 0 & -21 & 0 \\ 0 & -0.5 & 0 & 0 & 0 & -0.5 \\ -0.5 & -21 & 0 & 21 & -0.5 & -21 \end{bmatrix}$$

$$[B]^T = 0.0952 \begin{bmatrix} -21 & 0 & -0.5 \\ 0 & -0.5 & -21 \\ 21 & 0 & 0 \\ 0 & 0 & 21 \\ -21 & 0 & -0.5 \\ 0 & -0.5 & -21 \end{bmatrix}$$

Element Stiffness Matrix $[K]_1$:

$$[K]_1 = t\,A\,[B]^T [D] [B]$$

$$= 2608.2023 \begin{bmatrix} 441.092 & 6.678 & -441 & -3.843 & 441.092 & 6.678 \\ 6.668 & 161.215 & -2.835 & -160.965 & 3.833 & 161.215 \\ -441 & -2.835 & 441 & 0 & -441 & -2.835 \\ -3.833 & -160.965 & 0 & 160.965 & -3.833 & -160.965 \\ 441.092 & 6.678 & -441 & -3.843 & 441.092 & 6.678 \\ 6.668 & 161.215 & -2.835 & -160.965 & 6.668 & 161.215 \end{bmatrix}$$

Element 2

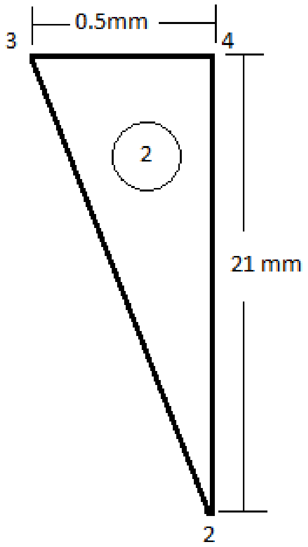

Figure 14: Element 2

Area of Triangle:

$$A = \frac{1}{2}\begin{vmatrix} 1 & x1 & y1 \\ 1 & x2 & y2 \\ 1 & x3 & y3 \end{vmatrix}$$

$$A = \frac{1}{2}\begin{vmatrix} 1 & 0.5 & 0 \\ 1 & 0.5 & 21 \\ 1 & 0 & 21 \end{vmatrix}$$

$A = 5.25\ mm^2$

Cofactors:

$C_{12} = 0$
$C_{22} = 21$
$C_{32} = -21$
$C_{13} = -0.5$
$C_{23} = 0.5$
$C_{33} = 0$

Stress-Strain Relationship Matrix [D]:

$$[D] = \frac{E}{1-v^2}\begin{bmatrix} 1 & v & 0 \\ v & 1 & 0 \\ 0 & 0 & (1-v)/2 \end{bmatrix}$$

$$[D] = 7830.8704\begin{bmatrix} 1 & 0.27 & 0 \\ 0.27 & 1 & 0 \\ 0 & 0 & 0.365 \end{bmatrix}$$

Strain-Displacement Relationship Matrix [B]:

$$[B] = \frac{1}{2A}\begin{bmatrix} C12 & 0 & C22 & 0 & C32 & 0 \\ 0 & C13 & 0 & C23 & 0 & C33 \\ C13 & C12 & C23 & C22 & C32 & C33 \end{bmatrix}$$

$$[B] = 0.0952\begin{bmatrix} 0 & 0 & 21 & 0 & -21 & 0 \\ 0 & -0.5 & 0 & 0.5 & 0 & 0 \\ -0.5 & 0 & 0.5 & 21 & 0 & -21 \end{bmatrix}$$

$$[B]^T = 0.0952\begin{bmatrix} 0 & 0 & -0.5 \\ 0 & -0.5 & 0 \\ 21 & 0 & 0.5 \\ 0 & 0.5 & 21 \\ -21 & 0 & 0 \\ 0 & 0 & -21 \end{bmatrix}$$

Elemental Stiffness Matrix $[K]_2$:
$[K]_2 = t\,A\,[B]^T[D][B]$

$$= 2608.2023\begin{bmatrix} 0.092 & 0 & -0.092 & -3.843 & 0 & 3.843 \\ 0 & 0.25 & -2.835 & -0.25 & 2.835 & 0 \\ -0.092 & -2.835 & 441.092 & 6.678 & -441 & -3.843 \\ -3.833 & -0.25 & 6.668 & 161.215 & -2.835 & -160.965 \\ 0 & 2.835 & -441 & -2.835 & 441 & 0 \\ 3.833 & 0 & -3.833 & -160.965 & 0 & 160.965 \end{bmatrix}$$

Global Stiffness Matrix [K]:

$$[K] = 2608.2023\begin{bmatrix} 441.092 & 6.678 & -441 & -3.843 & 441.092 & 6.678 & 0 & 0 \\ 6.668 & 160.215 & -2.835 & -160.965 & 3.833 & 161.215 & 0 & 0 \\ -441 & -2.835 & 441.092 & 0 & -441 & 0.998 & -0.092 & -3.843 \\ -3.833 & -160.965 & 0 & 161.215 & -3.833 & -160.965 & -2.835 & -0.25 \\ 441.092 & 6.678 & -441 & -0.998 & 882.092 & 6.678 & -441 & -2.835 \\ 6.668 & 160.215 & 0.998 & -160.965 & 10.501 & 322.18 & -3.833 & -160.965 \\ 0 & 0 & -0.092 & -2.835 & -441 & -3.843 & 441.092 & 6.678 \\ 0 & 0 & -3.833 & 0.25 & -2.835 & -160.965 & 6.668 & 161.215 \end{bmatrix}$$

Displacement Matrix [U]:

$$[U] = \begin{bmatrix} U1x \\ U1y \\ U2x \\ U2y \\ U3x \\ U3y \\ U4x \\ U4y \end{bmatrix}$$

Force Matrix [F]:

$$[F] = \begin{bmatrix} 0 \\ 0 \\ 136.503 \\ 0 \\ 0 \\ 0 \\ 136.503 \\ 0 \end{bmatrix}$$

Global Equation:

[K] [U] = [F]

$$2608.2023\begin{bmatrix} 441.092 & 6.678 & -441 & -3.843 & 441.092 & 6.678 & 0 & 0 \\ 6.668 & 160.215 & -2.835 & -160.965 & 3.833 & 161.215 & 0 & 0 \\ -441 & -2.835 & 441.092 & 0 & -441 & 0.998 & -0.092 & -3.843 \\ -3.833 & -160.965 & 0 & 161.215 & -0.998 & -160.965 & -2.835 & -0.25 \\ 441.092 & 6.678 & -441 & -0.998 & 882.092 & 6.678 & -441 & -2.835 \\ 6.668 & 160.215 & 0.998 & -160.965 & 10.501 & 322.18 & -3.833 & -160.965 \\ 0 & 0 & -0.092 & -2.835 & -441 & -3.843 & 441.092 & 6.678 \\ 0 & 0 & -3.833 & 0.25 & -2.835 & -160.965 & 6.668 & 161.215 \end{bmatrix}\begin{bmatrix} U1x \\ U1y \\ U2x \\ U2y \\ U3x \\ U3y \\ U4x \\ U4y \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 49.14 \\ 0 \\ 0 \\ 0 \\ 49.14 \\ 0 \end{bmatrix}$$

Applying Boundary conditions:
U1x = U1y = U2y = U3x = U3y = U4y = 0
F1x = F1y = F2y = F3x = F3y = F4y = 0

$$2608.2023 \begin{bmatrix} 441.092 & -0.092 \\ -0.092 & 441.092 \end{bmatrix} \begin{bmatrix} U2x \\ U4x \end{bmatrix} = \begin{bmatrix} 49.14 \\ 49.14 \end{bmatrix}$$

$$\begin{bmatrix} 441.092 & -0.092 \\ -0.092 & 441.092 \end{bmatrix} \begin{bmatrix} U2x \\ U4x \end{bmatrix} = \begin{bmatrix} 0.0188405 \\ 0.0188405 \end{bmatrix}$$

U2x = 4.27222×10^{-5} mm
U4x = 4.27222×10^{-5} mm

Elemental Strain $\{\epsilon\}_1$:

$\{\epsilon\}_1 = [B]_1[U]$
= 0.0952

$$\begin{bmatrix} -21 & 0 & 21 & 0 & -21 & 0 \\ 0 & -0.5 & 0 & 0 & 0 & -0.5 \\ -0.5 & -21 & 0 & 21 & -0.5 & -21 \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 4.27222 \text{ x } 10\text{^}(-5) \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

$$\{\epsilon\}_1 = \begin{bmatrix} 8.5410266 \text{ x } 10\text{^}(-5) \\ 0 \\ 0 \end{bmatrix} \text{mm/mm}$$

Elemental Strain $\{\epsilon\}_2$:

$\{\epsilon\}_2 = [B]_2[U]$
= 0.0952

$$\begin{bmatrix} 0 & 0 & 21 & 0 & -21 & 0 \\ 0 & -0.5 & 0 & 0.5 & 0 & 0 \\ -0.5 & 0 & 0.5 & 21 & 0 & -21 \end{bmatrix} \begin{bmatrix} 4.27222 \text{ x } 10\text{^}(-5) \\ 0 \\ 4.27222 \text{ x } 10\text{^}(-5) \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

$$\{\epsilon\}_2 = \begin{bmatrix} 8.5410266 \text{ x } 10\text{^}(-5) \\ 0 \\ 0 \end{bmatrix} \text{mm/mm}$$

Elemental Stress $[\sigma]_1$:

$[\sigma]_1 = [D]\ \{\epsilon\}_1$

$$= 7830.8704 \begin{bmatrix} 1 & 0.27 & 0 \\ 0.27 & 1 & 0 \\ 0 & 0 & 0.365 \end{bmatrix} \begin{bmatrix} 8.5410266 \text{ x } 10\text{^}(-5) \\ 0 \\ 0 \end{bmatrix}$$

$$[\sigma]_1 = \begin{bmatrix} 0.66883 \\ 0.180585 \\ 0 \end{bmatrix} \text{N/mm}^2$$

Elemental Stress $[\sigma]_2$:

$[\sigma]_2 = [D]\ \{\epsilon\}_2$

$$= 7830.8704 \begin{bmatrix} 1 & 0.27 & 0 \\ 0.27 & 1 & 0 \\ 0 & 0 & 0.365 \end{bmatrix} \begin{bmatrix} 8.5410266 \text{ x } 10\text{^}(-5) \\ 0 \\ 0 \end{bmatrix}$$

$$[\sigma]_2 = \begin{bmatrix} 0.66883 \\ 0.180585 \\ 0 \end{bmatrix} \text{N/mm}^2$$

7. Results

Total deformation for sintered iron is 2.2761e-6 m and that of SF-MC2 is 3.8077e-8 m through ANSYS Simulation Workbench 16 and the values obtained for the same through analytical calculations are 2.1456e-6 m for sintered iron and 4.2722e-8 m for SF-MC2. Equivalent Strain for sintered iron is 2.861e-3m/m and that of SF-MC2 is 5.1843e-5 m/m through ANSYS Simulation Workbench 16 and the values obtained for the same through analytical calculations are 4.2896e-3 m/m for sintered iron and 8.5410e-5 m/m for SF-MC2. Equivalent Stress for sintered iron is 7.8916e5 Pa and that of SF-MC2 is 3.7638e5 Pa through ANSYS Simulation Workbench 16 and the values obtained for the same through analytical calculations are 9.3767e5 Pa for sintered iron and 6.6883e5Pa for SF-MC2. Also the results have been tabulated below:

Table 5: Result table for Sintered iron

Material- Sintered iron	Total Deformation (m)	Equivalent Strain (Von-Mises) (m/m)	Equivalent Stress (Von-Mises) (Pa)
ANSYS results	2.2761e-6	2.8615e-3	7.8916e5
Analytical	2.1456e-6	4.2896e-3	9.3767e5

Table 6: Result table for SF-MC2

Material- SF-MC2	Total Deformation (m)	Equivalent Strain (Von-Mises) (m/m)	Equivalent Stress (Von-Mises) (Pa)
ANSYS results	3.8077e-8	5.1843e-5	3.7638e5
Analytical	4.2722e-8	8.5410e-5	6.6883e5

8. Conclusion

In multi plate clutch, friction plate plays very important role in torque transmission from engine to transmission system. So the friction material property is very important in clutch. From the above tables, it is clear that SF-MC2 is a better friction material than Sintered Iron. It is also observed that total deformation, equivalent strain and equivalent strain of SF-MC2 is in the permissible range for the ideal friction material. SF-MC2 has the low total deformation when compared to the conventional friction material. Also, the stress induced in SF-MC2 material is far less than that developed in Sintered Iron friction material. Hence, it is concluded that SF-MC2 serves as a better friction material than Sintered Iron and gives better clutch performance.

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