Design and Analysis of Clutch Using Sintered Iron as a Friction Material

Mamta G. Pawar, Monarch K. Warambhe, Gautam R. Jodh

Abstract*— *Clutch system is among the main systems inside a vehicle. Clutch is a mechanical device located between a vehicle engine and its transmission and provides mechanical coupling between the engine and transmission input shaft. Clutch system comprise of flywheel, clutch disc plate and friction material, pressure plate, clutch cover, diaphragm spring and the linkage necessary to operate the clutch. The clutch engages the transmission gradually by allowing a certain amount of slippage between the flywheel and the transmission input shaft. However, the slipping mechanism of the clutch generates heat energy due to friction between the clutch disc and the flywheel. At high sliding velocity, excessive frictional heat is generated which lead to high temperature rise at the clutch disc surface, and this causes thermo-mechanical problems such as thermal deformations and thermo-elastic instability which can lead to thermal cracking, wear and other mode of failure of the clutch disc component.

In this project, the modeling of clutch is done in detailed using modeling software. After that the FEM analysis is done for sintered iron friction material. The stresses & deformation obtained for this friction material is then compared to analysis software result. The analysis is done for worn out friction disc.

Index Terms* — *Coefficient of friction, von-misses stress, young's modulus and poisons ratio.

I. INTRODUCTION

A clutch is a mechanical device for quickly and easily connecting or disconnecting a pair of rotating coaxial shafts. It is usually placed between the driving motor and the input shaft to a machine, permitting the engine to be started in an unloaded state. Single plate, dry clutch is among the popular type of clutches in use. A clutch is a mechanism designed to disconnect and reconnect driving and driven members. It is a device, which enables one rotary drive shaft to be coupled to another shaft, either when both the shafts are stationary or when there is relative motion between them. The need for the clutch seems mainly from the characteristics of the turning-effort developed by the engine over its lower speed range. When idling, the engine develops insufficient torque for the transmission to be positively engaged. To obtain a smooth engagement, the clutch has to be progressively engaged to take up the drive until the torque transmitted from the engine equals that required to propel the vehicle. Also the clutch disconnects the engine from the transmission to change the gear. The clutch, thus, takes up the drive smoothly and also disengages the drive whenever necessary.

Manuscript received December 2013.

Ms. Mamta. G. Pawar, Department of Mechanical Engineering, Dr. Babasaheb Ambedkar College of Engineering & Research, Nagpur, India.

Mr. Monarch K. Warambhe, Department of Mechanical Engineering, Rajiv Gandhi College Of Engineering and Research, Nagpur, India.

Mr. Gautam. R. Jodh, , Department of Mechanical Engineering, Dr. Babasaheb Ambedkar College of Engineering & Research, Nagpur, India.

II. AUTOMOTIVE CLUTCH SYSTEM

Automotive clutches are located between the engine and the transmission. It provides mechanical coupling between the engine and transmission input shaft. Manual transmission cars need a clutch to enable engaging and disengaging the transmission.

The clutch engages the transmission gradually by allowing a certain amount of slippage between the flywheel and the transmission input shaft (Erjavec 2005).Clutch basically consists of six major parts: flywheel, clutch disc, pressure plate, diaphragm spring, clutch cover and the linkage necessary to operate the clutch (Lee and Cho 2006) as shown in Figure 1.

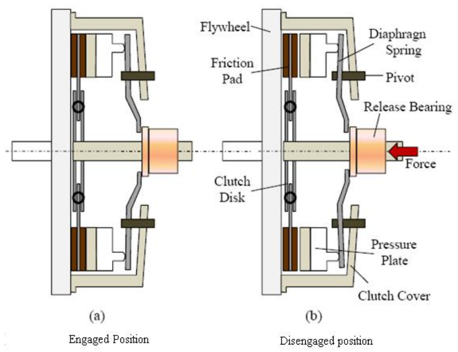


Figure 1. Single plate diaphragm clutch system.

III. LITERATURE REVIEW

In 1885, it was reported that when Karl Friedrich Benz has invented the first commercial gas powered automobile, the famous Tri-Cycle, he also was the first person to invent and use the clutch system to the car (Wikipedia website 2007). Exedy Corp., one of the major players for clutch technology, which manufactured clutches under the brand name of Exedy and Daikin, was reported to produce rigid type disc clutch since 1918, which was a clutch disc with the plate and spline hub secured by rivets (Daikin Clutch website 2007). Until now, clutch manufactures has come out with new and efficient technologies for clutch system to compensate higher torque produced by bigger engine created especially for heavy vehicles.

According to Samir Safarni after gear shift & during the clutch re-engagement the clutch disc allows the transmission of progressive torque through its Axial Stiffness. One of the most important components use in coupling & decoupling of motor & transmission during gear change. One of the most important components used in this process is clutch disc that allows a soft gradual re-engagement of torque transmission. This progressive re-engagement obtained by friction disc characteristics in the axial direction preserves the drivers comfort & avoid mechanical shock **[06].**

According to K. Tripathi, the friction clutch must be design for minimum axial force between the pressure plate & clutch plate. They suggested that for optimum design of friction disc the ratio of inner radius to outer radius should be kept 0.577.There basic design is based on minimum axial force between pressure plate & clutch plate**. [02]**

IV. CLUTCH MATERIALS

The clutch disc is generally made from grey cast iron (Afferante et al. 2003; Poser et al. 2005). This is because grey cast iron has a good wear resistance with high thermal conductivity and the production cost is low compare to other clutch disc materials such as A1-MMC (aluminum-metal matrix composite), carbon composites and ceramic based composites (Terhech et al. 1995; Jang et al. 2003). High thermal conductivity of diffusivity of the material is considered advantageous because heat is then allowed to dissipate at higher rate (Bostwick and Szadkowski 1998). In this project, BS200 or ASTM G2500 grade grey cast iron is selected as the material for the commercial clutch disc. Some properties of the material (BS Grade 200lASTM G2500) are shown in Table below (Heo et al. 2002; CES EduPack 2005).

Table 1. Material Properties of Gray Cast Iron

Structural	
Young's Modulus	120GPa
Poission's Ratio	0.29
Density	7200 kg/m^3
Tensile Strength	220MPa
Shear Modulus	44-54 GPa
Thermal	
Thermal Conductivity	310 W/m.K
Specific Heat	450 J/Kg.K

V. SINTERED FRICITON MATERIL

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. The quality of materials used along with the sintering parameter play an important role in providing the required performance (Aleksandrova et al 1972).Particulate reinforcement gives the necessary WEAR resistant for the sintered matrix (Mustafa Boz & AdemKurtt2007)

A. Wear Coefficient Of Different Friction Material

The different wear coefficient of different friction material is as shown in following table. [11]

Table 2. Typical wear coefficient of clutch friction lining (Against steel/cast iron)

Lining (Pad)Material	**Wear Coefficient , Ko (psi^{-1})**
Asbestos Type-I composite	6.46×10^{-11}
Asbestos Type -II composite	8.09×10^{-11}
Carbon-carbon composite	2.24×10^{-11}
Sintered bronze (dry)	2.42×10^{-11}
Non Asbestos composite (dry)	9.90×10^{-10}
Sintered bronze (wet)	5.02×10^{-13}
Sintered bronze composite	9.31×10^{-11}
Sintered resin composite	3.03×10^{-11}

B. Clutch Friction Surface Failure Mode

Following table shows the various failure modes in clutch & the causes of failure & the effect of that failure on the clutch plate. [11]

Table 3. Failure Mode of Friction Plate

PROBLEM	CHRACTERSTIS	CAUSES
Material Transfer	Friction material adhering to opposing plate often giving rise to excessive wear	Overheating & unsuitable friction material
Distortion	Facing out of flatness after high operating temperature	Unsuitable friction material
Reduced Performance	Decreasing in coefficient of friction giving in a permanent loss in performance	Excess oil or grease on friction material or on the opposing surface
Dishing	Clutch plate distorted into conical shape	Lack of conformability, temperature of the outer region is higher than inner region
Banding or crushing	Loss of friction material at the end of band	Crushing and excessive wear of the friction material
Burst Failure	Material splitting & removed from inner plate	High stresses on facing when working at higher speed
Grooving	Grooving of the facing material on the line of movement	Material transfer to opposing plate

C. Method Of Analysis

The torque that can be transmitted by a clutch is a function of its geometry & the magnitude of the actuating force applied as well the condition of contact prevailing between the members. The applied force can keep the members together with a uniform pressure all over its contact area & the consequent analysis is based on uniform pressure condition.

However as the time progresses some wear takes place between the contacting members & this may alter or vary the contact pressure appropriately and uniform pressure condition may no longer prevail. Hence the analysis here is based on uniform wear condition.

VI. TECHINCAL SPECIFICTIONS OF SINGLE PLATE CLUTCH

Table 4. Technical specification

Specification	Model	Maximum Power	Maximum Torque	Capacity 1988 CC
	TATA 483 DLNA56	48 KW@4500 RPM	115 NM @ 3000RPM	
Pressure plate	Inner Diameter	Outer Diameter	Rim diameter	
	200 mm	230 mm	30 mm	
Friction Plate	Inner Diameter	Outer Diameter	Width	

	128 mm	228	2 mm	
Flywheel	External Diameter	No of Teeth		
	260	122		
Diaphragm Spring	Length	Outer Diameter		
	50 mm	145 mm		

Figure.2 Exploded view of single plate clutch

VII. ANALYSIS OF SINGLE PLATE CLUTCH USING SINTERED IRON AS A FRCITON MATERIAL

A. *Modelling Of Friction Disc*

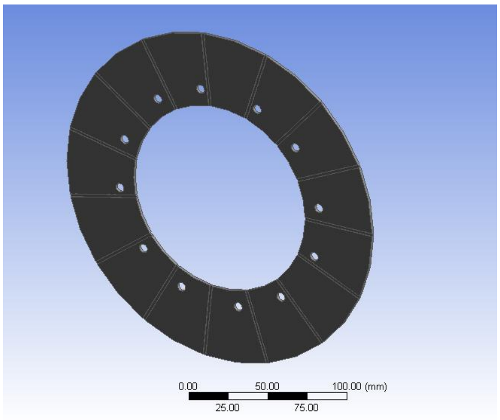


Figure 3. Modelling of Friction Disc

B. *Material Data*

SINTERED-IRON
Table 5. Material Property

Structural	
Young's Modulus	275.79MPa
Poission's Ratio	0.34
Density	6.2gm/cm^3
Thermal Expansion	0.2/^{0}c
Thermal	
Thermal Conductivity	220 W/m^{0}c
Specific Heat	50 J/Kg^0

C. *Meshed Body*

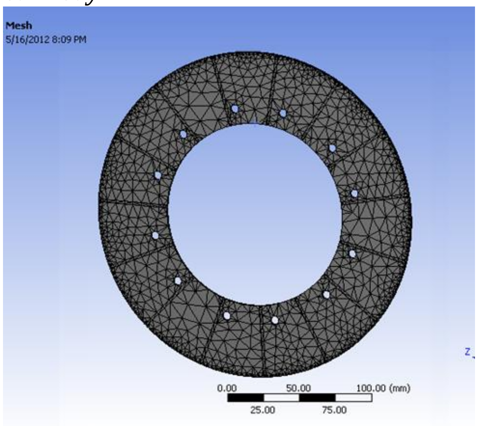


Figure.4. Model > Mesh > Image

D. *Static Structural*

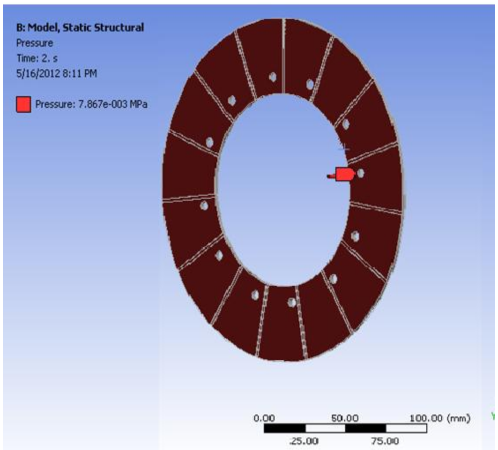


Figure. 5. Model > Static Structural > Pressure > Image

E. *Solution*

Table 6. Model > Static Structural > Solution > Results

Object Name	*Total Deformation*	*Equivalent Stress 2*	*Maximum Shear Stress*	*Normal Elastic Strain*
State	Solved			
Definition				
Type	Total Deformation	Equivalent (von-Mises) Stress	Maximum Shear Stress	Normal Elastic Strain
Orientation				X Axis
Coordinate System				Global Coordinate System
Results				
Minimum	0. mm	3.9462e-004 MPa	2.2781e-004 MPa	-9.4649e-006 mm/mm
Maximum	5.3008e-005 mm	6.6447e-003 MPa	3.6859e-003 MPa	1.2851e-005 mm/mm

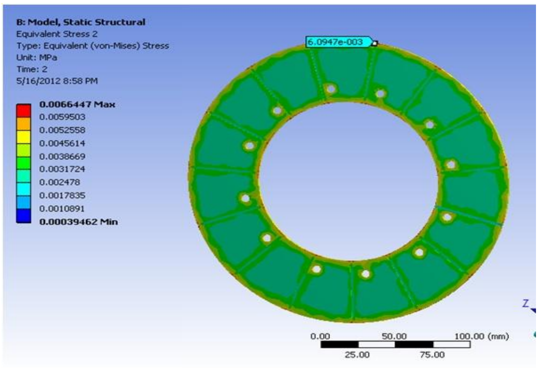


Figure 6. Model > Static Structural > Solution > Equivalent Stress 1 > Image

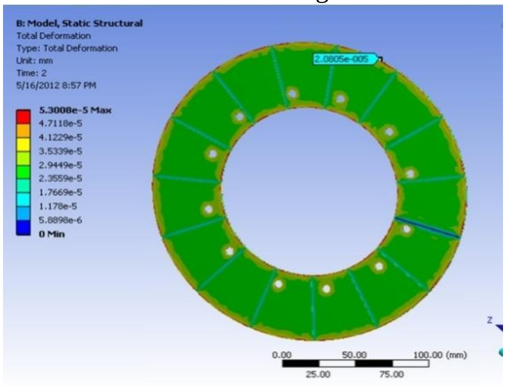


Figure 7. Model > Static Structural > Solution > Total Deformation > Image

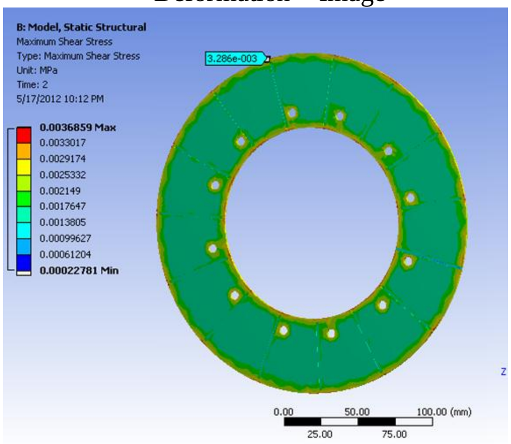


Figure 8. Model > Static Structural > Solution > Maximum Shear Stress > Image

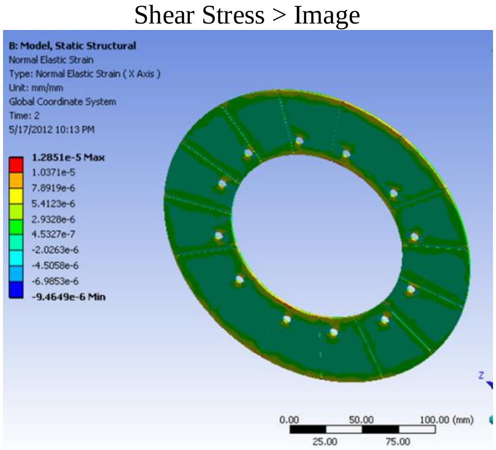
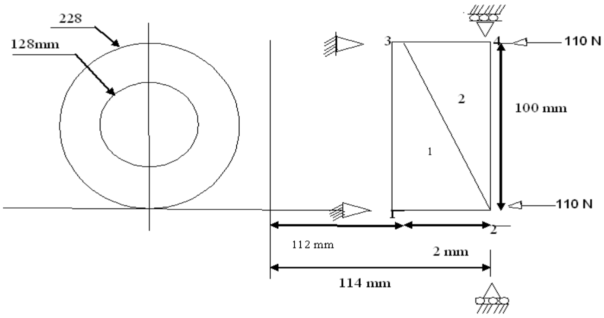


Figure.9.Model > Static Structural > Solution > Normal Elastic Strain > Image

VIII. FINITE ELEMENT METHOD USING SINTERED IRON AS A FRICTION MATERIAL

Calculation Data:
Assuming maximum force applied on clutch pedal = 110 N for 75 mm pedal travel
With the help of booster the applied force is transferred 2 times to the friction material
Therefore, Force becomes F= 2 ×110 =220 N
Total force is divided into two parts,
Therefore F1 =F2 =110 N
KEVLAR AS A FRCTION MATERIAL
Young’s Modulus (E) =275.79 Mpa
Poisson’s Ratio =0.34
Density = 6.2gm/cm^3

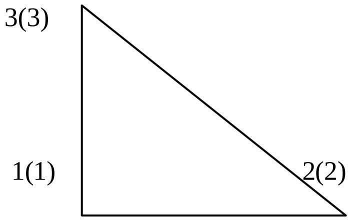
Step 1 Discretization: Dividing the part into two CST elements as shown below



Step 2 Element Connectivity Table

	Local Nodes			
Element No.	(1)	(2)	(3)	Global Nodes
1	1	2	3	
2	2	4	3	

Step 3 Consider Element 1



Coordinates of CST element are:
X1= 112, y1=0
X2 =114, y2 =0
X3 = 112, y3= 100

$$\text{Jacobian J} = \begin{vmatrix} x_{13} & y_{13} \\ x_{23} & y_{23} \end{vmatrix} = \begin{vmatrix} 0 & -100 \\ 2 & -100 \end{vmatrix} \qquad |J| =$$

100 x 2=200

$$\text{Area of Triangle} = \frac{1}{2}\,|J| = 100\text{mm}^2$$

Radius of Centroid, R1 = X1 + X2 +X3
= (112 +114 +112)/3
=112.8

Shape Function
N1+N2+N3 =1

N1 =1/3
N2=1/3
N3=1/3

Step 4 Stiffness matrix of element 1:

$$K^1 = t \times A \times B^T \times D \times B$$

Where D matrix is strain transformation matrix

$$D1 = \frac{E(1-v)}{(1+v)(1-2v)} \begin{bmatrix} 1 & v/1-v & 0 & v/1-v \\ v/1-v & 1 & 0 & v/1-v \\ 0 & 0 & 1-2v/2(1-v) & 0 \\ v/1-v & v/1-v & 0 & 1 \end{bmatrix}$$

$$= 275.79(1-0.34)/\{(1+0.34)(1-2(0.34)\} \begin{bmatrix} 1 & 0.5152 & 0 & 0.5152 \\ 0.5152 & 1 & 0 & 0.5152 \\ 0 & 0 & 0.1228 & 0 \\ 0.5152 & 0.5252 & 0 & 1 \end{bmatrix}$$

$$=4.24510e2 \begin{bmatrix} 1 & 0.5152 & 0 & 0.5152 \\ 0.5152 & 1 & 0 & 0.5152 \\ 0 & 0 & 0.1228 & 0 \\ 0.5152 & 0.5252 & 0 & 1 \end{bmatrix}$$

Where B = strain displacement matrix

$$B1 = \begin{bmatrix} y_{23}/J1 & 0 & y_{31}/J1 & 0 & y_{12}/J1 & 0 \\ 0 & x_{32}/J1 & 0 & x_{13}/J1 & 0 & x_{21}/J1 \\ x_{32} & y_{23}/J1 & x_{13}/J1 & y_{31}/J1 & x_{21}/J1 & y_{12}/J1 \\ N/R1 & 0 & N2/R1 & 0 & N3/R1 & 0 \end{bmatrix}$$

$$\begin{bmatrix} -0.5 & 0 & 0.5 & 0 & 0 & 0 \\ 0 & -0.01 & 0 & 0 & 0 & 0.01 \\ -0.01 & -0.5 & 0 & 0.5 & 0.01 & 0 \\ 0.00296 & 0 & 0.00296 & 0 & 0.00296 & 0 \end{bmatrix}$$

Transpose of Strain Displacement Matrix (B^T)

$$B^T = \begin{bmatrix} -0.5 & 0 & -0.01 & 0.00296 \\ 0 & -0.01 & -0.5 & 0 \\ 0.5 & 0 & 0 & 0.00296 \\ 0 & 0 & 0.5 & 0 \\ 0 & 0 & 0.01 & 0.00296 \\ 0 & 0.01 & 0 & 0 \end{bmatrix}$$

$$B^T 2 \times D2 = \begin{bmatrix} -0.5 & 0 & -0.01 & 0.00296 \\ 0 & -0.01 & -0.5 & 0 \\ 0.5 & 0 & 0 & 0.00296 \\ 0 & 0 & 0.5 & 0 \\ 0 & 0 & 0.01 & 0.00296 \\ 0 & 0.01 & 0 & 0 \end{bmatrix} \begin{bmatrix} 4.2449 & 2.1867 & 0 & 2.1867 \\ 2.1867 & 4.2449 & 0 & 2.1867 \\ 0 & 0 & 1.0289 & 0 \\ 2.1867 & 2.1867 & 0 & 4.2449 \end{bmatrix}$$

$$= 10e2 \begin{bmatrix} -2.11597 & -1.08687 & -0.01029 & -1.08078 \\ -0.021867 & -0.042449 & -0.51445 & -0.021867 \\ 2.1289 & 0.006473 & 0 & 1.09335 \\ 0 & 0 & 0.51445 & 0 \\ 0.006473 & 0.006473 & 0.010289 & 0.01256 \\ 0.021867 & 0.042449 & 0 & 0.021867 \end{bmatrix}$$

Stiffness matrix for element No.01

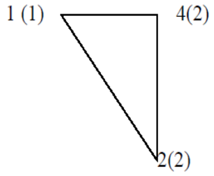
$$K1 = 2\Pi R1 \times A1 \times B^T 1 \times D1 \times B1$$

$$= 2\pi \times 113 \times 100 \times 10\ e2$$

$$=7.09910e6 \begin{bmatrix} 1.05488 & 0.01601 & -1.06118 & -0.005145 & -0.0033 & -0.01086 \\ 0.01601 & 0.2576 & -0.010998 & -0.2572 & -0.005209 & -0.00042449 \\ -1.0612 & -0.0006473 & 1.0677 & 0 & 0.003236 & 0.00006473 \\ -0.0051445 & -0.2572 & 0 & 0.2572 & 0.0051445 & 0 \\ -0.003302 & -0.005209 & 0.0032736 & 0.0051445 & 0.00010289 & 0.00006473 \\ -0.01086 & -0.00042449 & 0.01099 & 0 & 0.000064726 & 0.00042449 \end{bmatrix}$$

$$= 10e6 \begin{bmatrix} 7.38416 & 0.11207 & -7.42826 & -0.036 & -0.0231 & -0.07602 \\ 0.11207 & 1.8032 & -0.0769 & -1.8018 & -0.03646 & -0.002971 \\ -7.4287 & -0.000453 & 7.4739 & 0 & 0.02265 & 0.000453 \\ -0.036 & -1.8004 & 0 & 1.8004 & 0.036 & 0 \\ -0.0231 & -0.03646 & 0.0229 & 0.036 & 0.00072023 & 0.0004531 \\ -0.07602 & -0.00297 & 0.07693 & 0 & 0.000453 & 0.002971 \end{bmatrix}$$

Step 5 Consider Element 2.



Coordinates of CST element are:

$x_1 = 114 \qquad y_1 = 0$

$x_2 = 114 \qquad y_2 = 100$

$x_3 = 112 \qquad y_3 = 100$

$$\text{Jacobian } J = \begin{vmatrix} x_{13} & y_{13} \\ x_{23} & y_{23} \end{vmatrix} = \begin{vmatrix} 2 & -100 \\ 2 & 0 \end{vmatrix} \qquad |J| = 100\text{x } 2 = 200$$

$$\text{Area of Triangle} = \frac{1}{2}\ |J| = 100\ mm^2$$

Radius of Centroid, R1 = X1 + X2 +X3

= (114 +114 +112)/3

=113.3

Shape Function

N1+N2+N3 =1

N1 =1/3

N2=1/3

N3=1/3

Strain Displacement Matrix for element no 02

$$B2 = \begin{bmatrix} y_{23}/J1 & 0 & y_{31}/J1 & 0 & y_{12}/J1 & 0 \\ 0 & x_{32}/J1 & 0 & x_{13}/J1 & 0 & x_{21}/J1 \\ x_{32} & y_{23}/J1 & x_{13}/J1 & y_{31}/J1 & x_{21}/J1 & y_{12}/J1 \\ N/R1 & 0 & N2/R1 & 0 & N3/R1 & 0 \end{bmatrix}$$

$$= \begin{bmatrix} 0 & 0 & 0.5 & 0 & -0.5 & 0 \\ 0 & -0.01 & 0 & 0.01 & 0 & 0 \\ -0.01 & 0 & 0.01 & -0.5 & 0 & -0.5 \\ 0.00294 & 0 & 0.00294 & 0 & 0.00294 & 0 \end{bmatrix}$$

$$B^T = \begin{bmatrix} 0 & 0 & -0.01 & 0.00294 \\ 0 & -0.01 & 0 & 0 \\ 0.5 & 0 & 0.01 & 0.00294 \\ 0 & 0.01 & -0.5 & 0 \\ -0.5 & 0 & 0 & 0.00294 \\ 0 & 0 & -0.5 & 0 \end{bmatrix}$$

D1=D2

$$B^T \times D2 = \begin{bmatrix} 0 & 0 & -0.01 & 0.00294 \\ 0 & -0.01 & 0 & 0 \\ 0.5 & 0 & 0.01 & 0.00294 \\ 0 & 0.01 & -0.5 & 0 \\ -0.5 & 0 & 0 & 0.00294 \\ 0 & 0 & -0.5 & 0 \end{bmatrix} \begin{bmatrix} 4.2449 & 2.1867 & 0 & 2.1867 \\ 2.1867 & 4.2449 & 0 & 2.1867 \\ 0 & 0 & 1.0289 & 0 \\ 2.1867 & 2.1867 & 0 & 4.2449 \end{bmatrix}$$

$$= 10e2 \begin{bmatrix} 0.006429 & 0.006429 & -0.01029 & 0.01248 \\ -0.02187 & -0.04245 & 0 & -0.02187 \\ 2.1289 & 1.0998 & 0.01029 & 1.1058 \\ 0.02187 & 0.04245 & -0.05245 & 0.02187 \\ -2.11602 & -1.0869 & 0 & -1.0809 \\ 0 & 0 & -0.5145 & 0 \end{bmatrix}$$

$$B^T \times D2 \times B2 = \begin{bmatrix} 0.006429 & 0.006429 & -0.01029 & 0.01248 \\ -0.02187 & -0.04245 & 0 & -0.02187 \\ 2.1289 & 1.0998 & 0.01029 & 1.1058 \\ 0.02187 & 0.04245 & -0.05245 & 0.02187 \\ -2.11602 & -1.0869 & 0 & -1.0809 \\ 0 & 0 & -0.5145 & 0 \end{bmatrix}$$

$$= 10e2 \begin{bmatrix} 0.0001396 & -0.00006429 & 0.003148 & 0.0052 & 0.003251 & 0.005145 \\ 0.00006429 & -0.00004245 & 0.01087 & -0.0004245 & -0.01099 & 0 \\ 0.003148 & -0.010998 & 1.0678 & 0.005853 & 1.0677 & -0.005145 \\ 0.005209 & -0.0004245 & 0.005854 & 0.2576 & 0.01099 & 0.2573 \\ -0.003178 & 0.01087 & -1.06118 & -0.01086 & -1.06118 & 0 \\ 0.005145 & 0 & -0.005145 & -0.25725 & 0 & 0.25725 \end{bmatrix}$$

$$K^2 = 2 \times \Pi \times R2 \times A \times B^T \times D2 \times B2$$

$$= 2 \times \pi \times 113.3 \times 100 \times e2$$

$$= \begin{bmatrix} 0.0001396 & -0.00006429 & 0.003148 & 0.0052 & 0.003251 & 0.005145 \\ 0.00006429 & -0.00004245 & 0.01087 & -0.0004245 & -0.01099 & 0 \\ 0.003148 & -0.010998 & 1.0678 & 0.005853 & 1.0677 & -0.005145 \\ 0.005209 & -0.0004245 & 0.005854 & 0.2576 & 0.01099 & 0.2573 \\ -0.003178 & 0.01087 & -1.06118 & -0.01086 & -1.06118 & 0 \\ 0.005145 & 0 & -0.005145 & -0.25725 & 0 & 0.25725 \end{bmatrix}$$

$$\begin{array}{cc} & \begin{array}{cccccc} 2x & 2y & 4x & 4y & 3x & 3y \end{array} \\ K2 = 7.119e6 & \begin{bmatrix} 0.0001396 & -0.00006429 & 0.003148 & 0.0052 & 0.003251 & 0.005145 \\ 0.00006429 & -0.00004245 & 0.01087 & -0.0004245 & -0.01099 & 0 \\ 0.003148 & -0.010998 & 1.0678 & 0.005853 & 1.0677 & -0.005145 \\ 0.005209 & -0.0004245 & 0.005854 & 0.2576 & 0.01099 & 0.2573 \\ -0.003178 & 0.01087 & -1.06118 & -0.01086 & -1.06118 & 0 \\ 0.005145 & 0 & -0.005145 & -0.25725 & 0 & 0.25725 \end{bmatrix} \end{array}$$

$$= 10e6 \begin{bmatrix} 0.009772 & -0.00045 & 0.022 & 0.0364 & 0.0228 & 0.036 \\ 0.00045 & -0.002972 & 0.076 & -0.00297 & -0.0769 & 0 \\ 0.022 & -0.0769 & 7.4746 & 0.04097 & 7.4739 & -0.036 \\ 0.03646 & -0.002972 & 0.04098 & 1.8032 & 0.07693 & 0 \\ -0.02225 & 0.0761 & -7.4283 & -0.0761 & -7.4283 & 0 \\ 0.036 & 0 & -0.036 & -1.8 & 0 & 1.8 \end{bmatrix}$$

$$\begin{array}{cc} & \begin{array}{cccccccc} 1x & 1y & 2x & 2y & 3x & 3y & 4x & 4y \end{array} \\ K^G = 10e7 & \begin{bmatrix} 16.25 & 0.212 & -13.96 & -0.034 & -0.57 & -0.20 & 0 & 0 \\ 0.775 & 0.22 & -0.212 & -1.717 & -0.0036 & -0.0056 & 0 & 0 \\ -13.95 & -0.212 & 7.4836 & -0.00124 & -1.46 & -0.165 & 0.022 & 73 \\ 0.0342 & -0.17 & -0.00124 & 1.773 & 19 & -4 & -54 & -4 \\ -0.612 & -0.00468 & 0 & -0.165 & -10000 & 0 & -13.95 & 0 \\ -0.21 & -0.0056 & 0.246 & 0 & 0 & 3650 & 0 & 3650 \\ 0 & 0 & 0.022 & -0.212 & -10000 & -73 & 7.4836 & -19 \\ 0 & 0 & -0.0468 & -0.0056 & -0.212 & 3650 & -19 & 3754 \end{bmatrix} \end{array}$$

Step 8 Nodal Force Matrix:

$$F = \begin{bmatrix} 0 \\ 0 \\ 110 \\ 0 \\ 0 \\ 0 \\ 110 \\ 0 \end{bmatrix} \text{N}$$

$$\begin{bmatrix} 0 & 0 & 0.5 & 0 & -0.5 & 0 \\ 0 & -0.01 & 0 & 0.01 & 0 & 0 \\ -0.01 & 0 & 0.01 & -0.5 & 0 & -0.5 \\ 0.00294 & 0 & 0.00294 & 0 & 0.00294 & 0 \end{bmatrix}$$

Step 9 Nodal Displacement Matrix:

$$u = \begin{bmatrix} u_{1x} \\ u_{1y} \\ u_{2x} \\ u_{2y} \\ u_{3x} \\ u_{3y} \\ u_{4x} \\ u_{4y} \end{bmatrix} \text{mm}$$

Step 10 By Principle of mini potential energy

$$F = K^G \times u$$

$$\begin{array}{ccc} & \begin{array}{cccccccc} 1x & 1y & 2x & 2y & 3x & 3y & 4x & 4y \end{array} & \\ \begin{bmatrix} 0 \\ 0 \\ 110 \\ 0 \\ 0 \\ 0 \\ 110 \\ 0 \end{bmatrix} = & \begin{bmatrix} 16.25 & 0.212 & -13.96 & -0.034 & -0.57 & -0.20 & 0 & 0 \\ 0.775 & 0.22 & -0.212 & -1.717 & -0.0036 & -0.0056 & 0 & 0 \\ -13.95 & -0.212 & 7.4836 & -0.00124 & -1.46 & -0.165 & 0.022 & 73 \\ 0.0342 & -0.17 & -0.00124 & 1.773 & 19 & -4 & -54 & -4 \\ -0.612 & -0.00468 & 0 & -0.165 & -10000 & 0 & -13.95 & 0 \\ -0.21 & -0.0056 & 0.246 & 0 & 0 & 3650 & 0 & 3650 \\ 0 & 0 & 0.022 & -0.212 & -10000 & -73 & 7.4836 & -19 \\ 0 & 0 & -0.0468 & -0.0056 & -0.212 & 3650 & -19 & 3754 \end{bmatrix} & \begin{bmatrix} u_{1x} \\ u_{1y} \\ u_{2x} \\ u_{2y} \\ u_{3x} \\ u_{3y} \\ u_{4x} \\ u_{4y} \end{bmatrix} \end{array}$$

Step 11 Applying Boundary Conditions

$$u1x = 0$$

$$u1Y = 0$$

$$u2y = 0$$

$$u_{3x} = 0$$

$$u_{3y} = 0$$

$$u4y = 0$$

By Gauss elimination method canceling 1x, 1y, 2y, 3x, 3y,4y rows and columns

On solving we get, Nodal displacements as

Step 12 Stresses in Each Element

Stress in element 1, $\sigma^1 = D1 \times B1 \times u$

$$u_{2x} = 0.393 \times 10^{-4}\, mm$$

$$u_{4x} = 0.183 \times 10^{-4}\, mm$$

$$= \begin{bmatrix} -2.11598 & -0.02187 & 2.1289 & 0 & 0.06473 & 0.02019 \\ -1.087 & -0.04245 & 1.0998 & 0 & 0.006473 & 0.04245 \\ -0.0103 & -0.5145 & 0 & 0.5145 & 0.0103 & 0 \\ -1.0808 & -0.0219 & 1.1059 & 0 & 0.01256 & 0.0219 \end{bmatrix} \begin{bmatrix} u1x \\ u1y \\ u2x \\ u2y \\ u3x \\ u3y \end{bmatrix}$$

$$\sigma^1 = \begin{bmatrix} 6.237 \\ 3.22 \\ 0.00 \\ 3.24 \end{bmatrix} \text{Mpa}$$

Stress in element 2, $\sigma^2 = D2 \times B2 \times u$

$$= \begin{bmatrix} 0.006429 & -0.021867 & 2.1289 & 0.0219 & -2.116 & 0 \\ 0.006429 & -0.0425 & 1.0997 & 0.04245 & -1.0869 & 0 \\ -0.010289 & 0 & 0.01029 & -0.5145 & 0 & -0.514 \\ 0.0125 & -0.02187 & 1.1058 & 0.02187 & -1.0809 & 0 \end{bmatrix} \begin{bmatrix} u2x \\ u2y \\ u4x \\ u4y \\ u3x \\ u3y \end{bmatrix}$$

$$\sigma^2 = \begin{bmatrix} 5.915 \\ 2.031 \\ -0.001641 \\ 2.06 \end{bmatrix} \text{N/mm}^2$$

RESULT:

Total deformation is found to be 0.293× 10^{-4} mm & stress is found to be 6.237 × 10^{-3} Mpa

RESULT VALIDATION BY USING ANSYS RESULT FOR SINTERED IRON

Pressure = Force /Area N/mm^2

Pressure = 220 / 27960

= 0.007869 Mpa

Now this pressure in applied on the friction disc to fine total deformation & von-misses stresses. The following results are obtained.

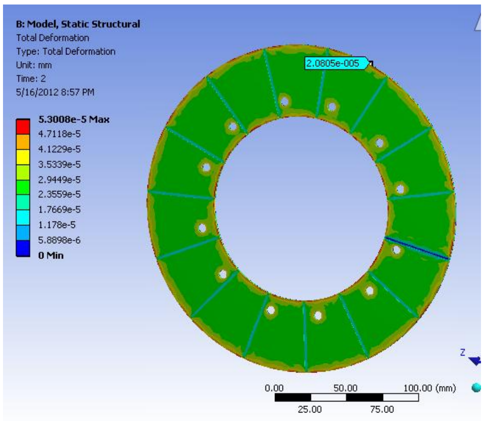


Figure.10.Total Deformation

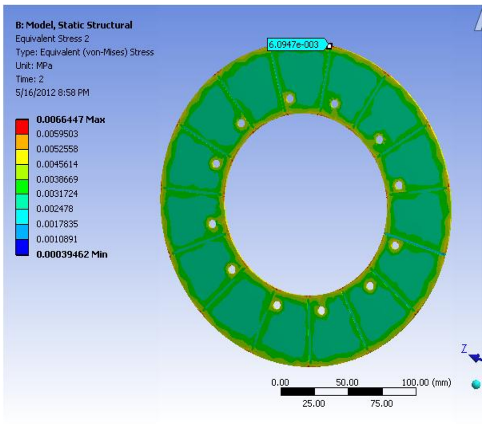


Figure.11.Equivalent Stress

RESULT: - The total deformation is 5.308 × 10^{-5} mm and Von-misses stresses 0.0066447 Mpa.

IX.CONCLUSION

In single 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. Generally clutch is in engaged position but when peddle is pressed clutch is disengaged & at that time there is sudden increase in temperature. Due to friction between mating part some part of friction material get wear out.

So for designing of clutch disc one should know the wear rate of that material which are used in clutch disc & common failure problem associated with clutch Again when some force is acting on clutch disc there must be some deformation due to temperature variation & stresses developed in clutch disc. That should be within the permissible limit.

In this project after designing of clutch disc, the analysis is done by varying the friction material & following conclusion is drawn.

The stresses using Kevlar as a friction material & sintered iron is near about same.

Torque transmission capacity of sintered-iron friction material is 350 to 400N which is more than Kevlar.

Total deformation in Kevlar material is less than sintered-iron friction material.

Sintered-iron material can sustain higher temperature.

By applying the maximum force i.e, 220 N of the friction plate of single plate clutch, after analytical calculations & software analysis the following observations can be obtained.

SINTERED –IRON (FRICTION MATERIAL)		
Analytical Calculation		Software Analysis
Total Deformation	0.393 × 10-4 mm Or 3.93 × 10-5 mm	0.5308 ×10-4 mm or 5.308 × 10-5 mm
Stresses	0.6237 × 10-4N/ mm2 6.237 × 10-5Mpa	0.00664 Mpa

REFERENCES

[1] Machine Design II, by Prof. K.Gopinath & Prof. M. M. Mayuram
[2] K Tripathi, "Design Optimization of Friction Clutch "
[3] United States Patent Office On - "Auxiliary drive clutch mechanism "
[4] Arvind vadiraj "Engagement characteristic of friction pad for the commercial vehicle clutch system " , vol 35 part 5,October 2010 page no 585-595,Indian Academy Of Science
[5] Samir Safarni & Emmanuel Bellenger." Numerical modeling of

automotive riveted clutch disc for contact pressure verification ".
[6] Mechanical Design Handbook by Thomas A.Dow, Chaper 17
[7] Abdullah M-AL-Shabibi, "Thermo-mechancial behavior of automotive break & clutch system".
[8] Han W, Yi S-J "A study of shift control using the clutch pressure pattern in automatic transmission "Proceedings of the I MECH E Part D Journal of Automobile Engineering, Volume 217, Number 4, 1 April 2003, pp. 289-298(10).
[9] J.R.Barber," International Journal of mechanical Sciences and the Journal of Thermal Stresses, "Department of Mechanical Engineering University of Michigan, 2002.
[10] "Modelling And Assembly Of Single Plate Friction Clutch Of An Automobile" Dr.Prafull S. Thakre, volume 2, Issue II/ March, 12.PP1-4, Indian Streams Research Journal.
[11] NSWC-06 Handbook Part B-Chapter 11.