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A Numerical analysis of Friction Plate on Automotive clutch system

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Abstract: *A clutch in automotive transmission systems plays a distinctive role to disengage gearbox from flywheel while engaged to transmit power from flywheel to entire transmission system with zero percentage slip. It is necessitates to increase the performance of clutch in transmission systems. The performance of clutch depends on two factors, material of the clutch system and mechanisms of clutch systems. In this study, Material of the clutch system is taken into account. The single plate clutch is modelled using CREO parametric 2.0 and analysis is done using ANSYS R15.0 Multiphysics software. Detailed explanation of clutches and comparison of different material for clutch is analyzed for deformation and maximum stress. From structural analysis, Aluminium metal matrix composites gives good results.*

Keywords: *Clutch, Finite Element Analysis, Total Deformation, Von-mises stress, Sintered iron, Aluminium metal matrix.*

Introduction

The clutch is a mechanical device, which is used to connect or disconnect the source of power from the remaining parts of the power transmission system at will of the operator. [1] Clutch is classified into positive contact clutches, Friction clutches, electromagnetic clutches and fluid clutches.
Some of the consideration for designing clutch assembly is Suitable Friction Material for friction liner, Sufficient torque transmitting capacity, Engagement should with minimum Shock and jerking, Weight of rotating parts should be low to decrease the inertial forces to increase the sensitivity of application of forces, Suitable provision for changing the friction lining and thermal distribution due to frictional heat should be uniform and the rate of increase of temperature should be less. [1]

In case of clutch the main problem occurs in the clutch material. The material gets damaged and so the maximum performance can't be achieved further. Some important requirements of clutch material is high co-efficient of friction, co-efficient of friction should be remain constant throughout the working temperature of clutch plate, good thermal conductivity for better thermal distribution, remain unaffected by environmental conditions, moisture and dirt particles, high resistance to abrasive and adhesive wear, good resilience to provide good distribution of pressure at the connecting surfaces.[1]
The analysis on wear and thermal stability of friction material can be done in two ways.

- Experimental Way
- Numerical Way

Before the analysis was done only by experimental way. This process takes a long time and economically costly. But after the year 1990 as the computational techniques grown up in a faster manner, so numerical techniques comes into play the major role in the pre manufacturing analysis. The computational analysis always follows mainly Finite Element Analysis Method. In this work the analysis has been done by Finite Element Method only. So some basics on FEA has been described now.
FEA: *Finite Element Analysis (FEA) also called the Finite Element Method (FEM) is a method for numerical solution of field problems.* [2]

FEA deals with a field, which is divided into piecewise continuous manner. The pieces are separated from each other by elements or lines which are joined by each other at a point or node. The elements can be expressed in terms of x, x*y and y in two dimensional plane. They are mainly defined by differential equations and expressions. The finite element term can be explained from this concept only that calculus deals with infinite terms but here elements have some finite length. When the FEA starts, it actually does the Meshing. This is nothing but dividing the entity which is under analysis into a piecewise continuous manner by elements and nodes. Here many types of meshing are available. Some of them are:

- *Structured Meshing*
- *Unstructured Meshing*
- *Hybrid Meshing*

- *2D Meshing*
- *3D Meshing*
- *2.5D Meshing* [3]

Here structured meshing means that all the pieces will align in an identical way. Regular alignment gives accurate analysis. But if the part has some irregular shapes, fillet etc. for that case the meshing becomes unstructured at the edges. So at that points the sizing of meshing should be reduced to get better accurate analysis. In most the cases we can't get entirely structured mesh for complicated structures. So practically the mesh sizing should be taken as the smallest dimension of the entity. For that case probability of formation of unstructured mesh will be less as well as analysis result will come very accurately. From the previous discussion it is clearer that unstructured meshing is nothing but alignment will not be proper. Now the term for hybrid meshing which is nothing but combination of structured and unstructured meshing. This comes for most of the cases. According to orientation of elements and nodes the classification 2D, 3D and 2.5D meshing comes. For 2D analysis 2D meshing is important. In this type of meshing the elements are distributed on a single 2D plane, which can be expressed by x and y co-ordinate system. Another comes 3D meshingwhich is nothing but the elements and nodes are distributed in a 3D space and can be expressed in x, y, and z co-ordinate system. Now comes 2.5D meshing. This is the surface mesh. As the orientation of surface changes the orientation of elements also changes. That's why it is not 2D or 3D meshing, its entity oriented meshing. So it's named like 2.5D meshing.
Now the discussion on different types of mechanical properties have been done. In analysis on ANSYS workbench the most important mechanical properties are discussed below.
Von-Mises Stress and Strain: This is the type of stress-strain principle which is mostly followed by engineers for designing any structure to find its stability while working.
From Distortion energy principle this can be described as below,

$$((\sigma_1-\sigma_2)^2 + (\sigma_2-\sigma_3)^2 + (\sigma_3-\sigma_1)^2)/2 \geq \sigma_v \text{ [3]}$$

Here if the material be ductile then the condition can be rewritten as,

$$\sigma_{yield} \geq \sigma_v \text{ [3]}$$

The Von-Mises strain is the corresponding strain value of stress.
Total Deformation: It is deformation found in a target body while the application of load in all directions.
Mathematically this can be expressed as following,

$$\epsilon_t^2 = \epsilon_x^2 + \epsilon_y^2 + \epsilon_z^2$$

Literature Review:
The damage and difficulties in the clutch plate increases with the increasing limits of speed. At present many works are going in the field of clutch, especially on clutch plate materials. Rajesh Purohit et al demonstrated that how FEA can deal with an actual component analysis and for a particular design of a clutch component what will be the Stress, Strain and Factor of Safety by FEA. The main motive of the work is to designate the safety factor of the components. [3]

O.I. Abdullah et al described how the heat generated due to friction affects the performance and stability of friction material.Rate of heat rejection is increased by two ways. According to the proposal first is to increase the thickness of pressure plate and second is to increase the exposed area. But economically increasing the exposed area is most suitable. [4]

Al-Shabibi et al investigated alternative method to solve the thermoelastic contact problem with frictional heat generation. Two-dimensional axisymmetric finite element model built to study the temperature field and pressure distribution of two sliding disks. Constant and varying speeds were considered in this analysis.[5]

The effect of coefficient of friction on the clutch slips speed, applied force and friction surface temperatures have been studied. The results of the dynamic thermal model were experimentally validated by Ivanović et al. [6].

Suyog Vitnor et al proposed a temperature distribution in a clutch assembly and main objective of work is to obtain a minimum safe stress value & temperature distribution of friction plate by using analytical & numerical calculation [7].
Yasser Aktiret al highlight the axial vibrational modes of the clutch system and its non-linear axial behavior. It provides a validated finite element model and corresponding methodology to determine the dynamic clutch behavior for studying axial vibrations [8].

Earlier we have used cork, leather as friction material but it is limited to lower speed. After that asbestos originated will provide excellent performance as friction material. But the problem is it is not environmental free and it is banned. In this work four friction materials has taken and structural analysis is done to calculate the total deformation and von-mises stress correspondingly.

FEA Model and Analysis:

In this work a comparative study of various materials used as friction material in friction plate of clutch assembly has been done based on Finite Element Analysis.

First the design parameters of single plate clutch system has been described as follows:

Outer Diameter: D=318mm

Inner Diameter: d=135mm

Intensity of pressure at radius r: p

Total operating force: P

Torque transmitted: M_t

Coefficient of friction: μ

Max pressure intensity at inner radius: p_a

Friction radius: R_f

Material properties are as follows:

Sl. No.	Material	μ(Wet)	Permissible Stress (MPa)	Density(kg/m^3)
1.	Molded Asbestos	0.08	13.8	2000
2.	Sintered Iron	0.10	68.9	6000
3.	Al-MMC F3D20S-T5	0.10194	226.761	2820.6
4.	Al-MMC F3S20S-T61	0.10194	596.7334	2765.2

In this analysis the boundary conditions are as follows:

Pressure applied: 0.95 MPa

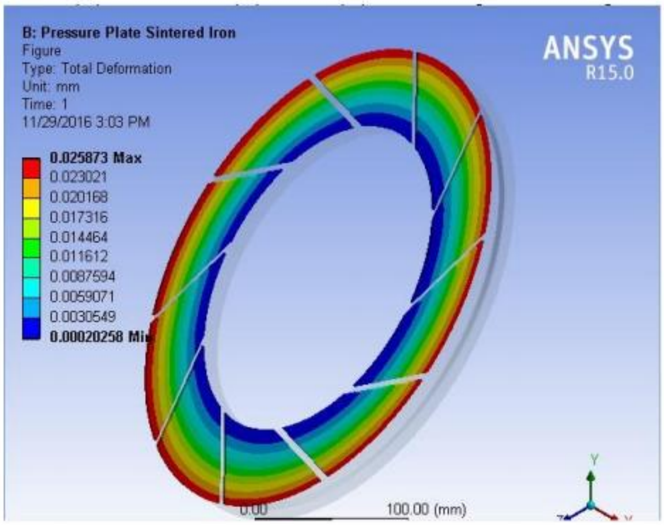
Ambient Temperature: 22 ^{0}C

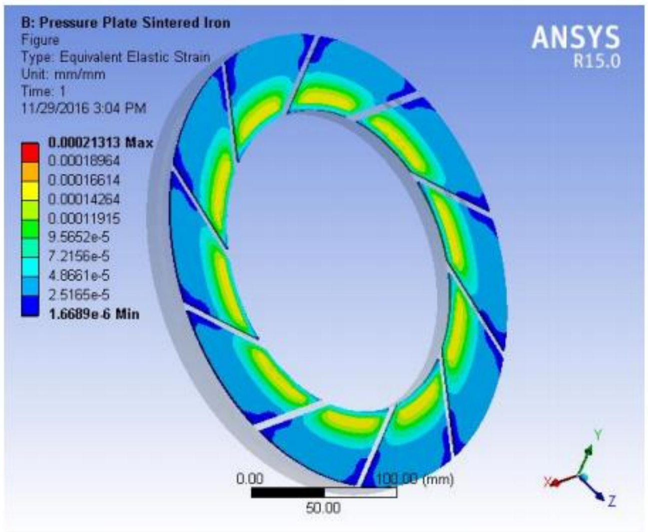
Results for different materials:

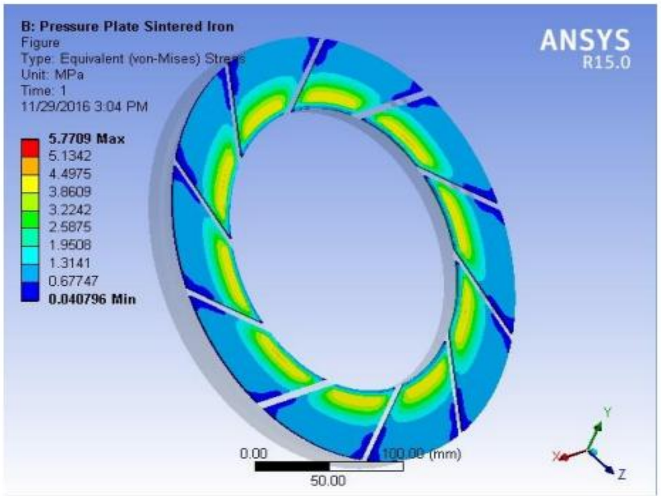
Sl. No.	Material	Total Deformation	Von-Mises Stress	Von-Mises Strain	Total Strain Energy
1.	Molded Asbestos	0.027118mm	0.0053MPa	0.00016147	1.7775 x 10^{-5} mJ
2.	Sintered Iron	0.025873mm	4.4975 MPa	0.00016614	0.0078519 mJ
3.	Al-MMC F3D20S-T5	0.022323mm	16.500 MPa	0.00014503	0.0286700 mJ
4.	Al-MMC F3S20S-T61	0.022780mm	14.647 MPa	0.00014856	0.0338560 mJ

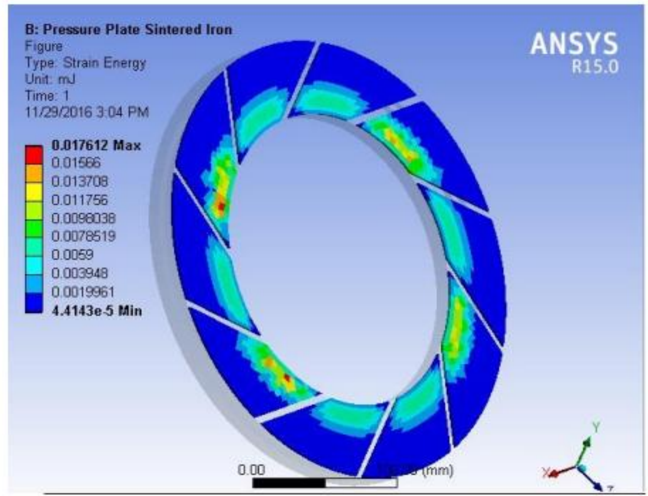
Graphical images of the analysis are as follows:

1. Sintered Iron:

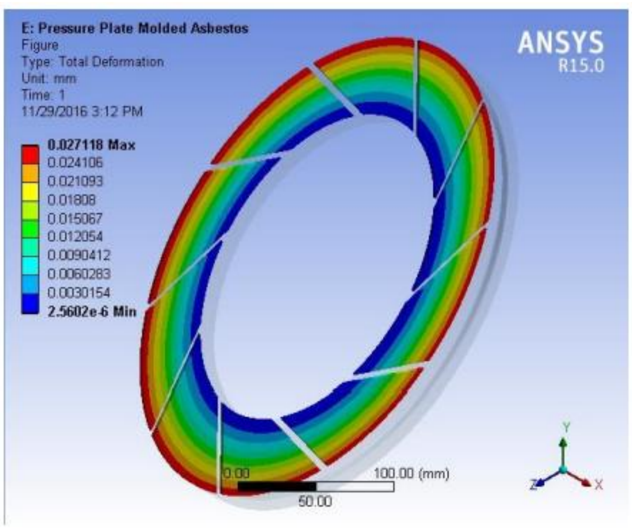


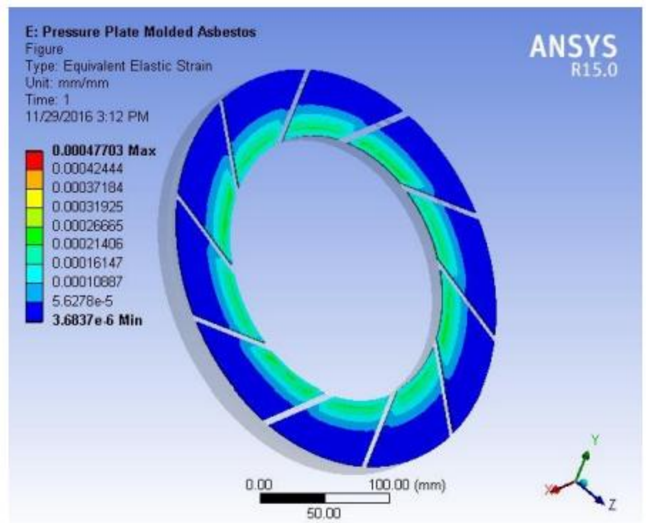


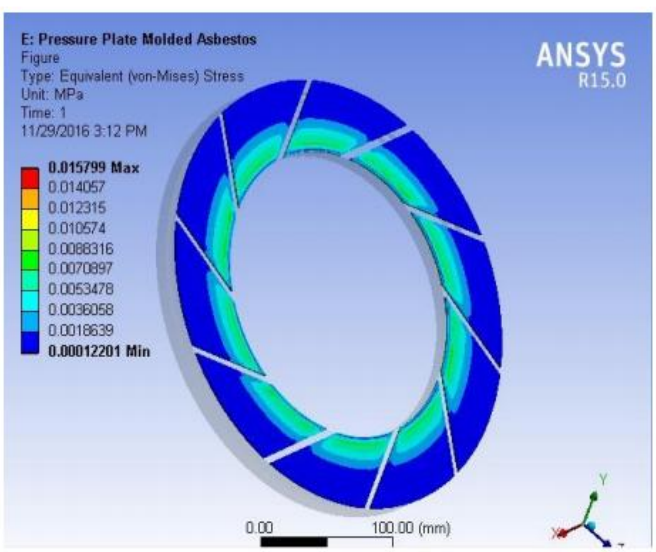


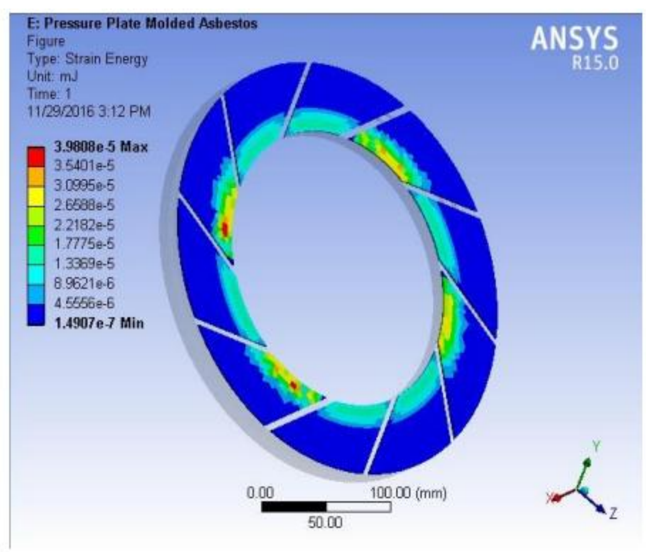


2. Molded Asbestos:

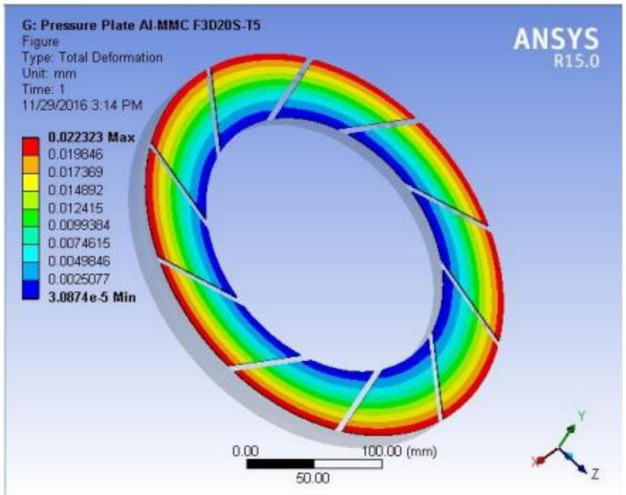


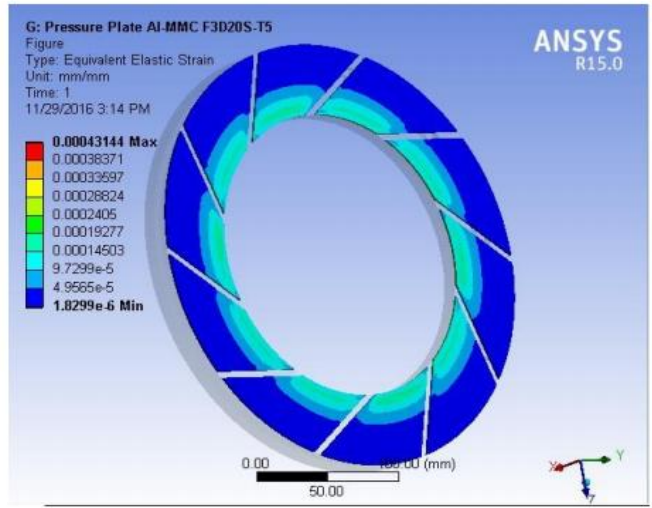


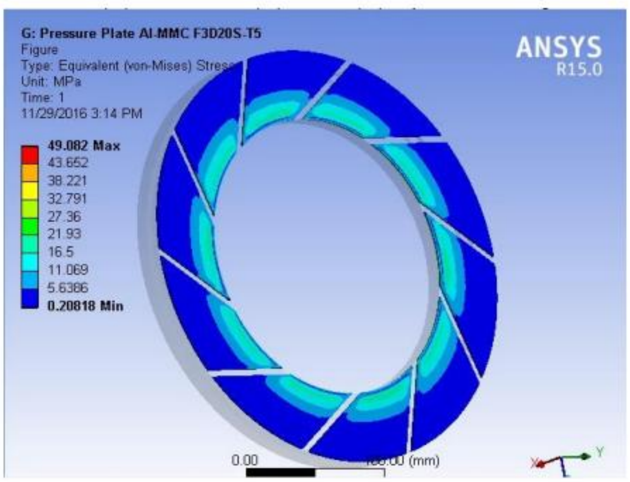


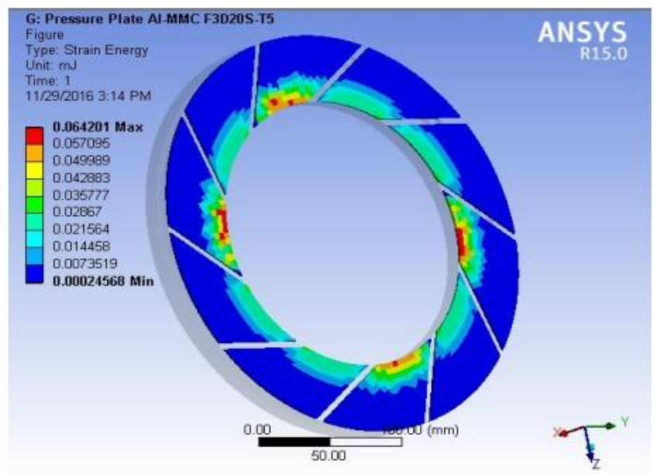


3. Al-MMC F3D20S-T5:

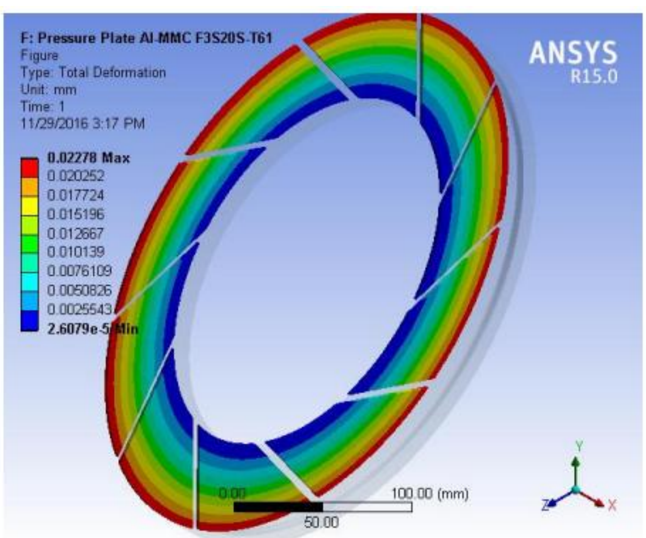


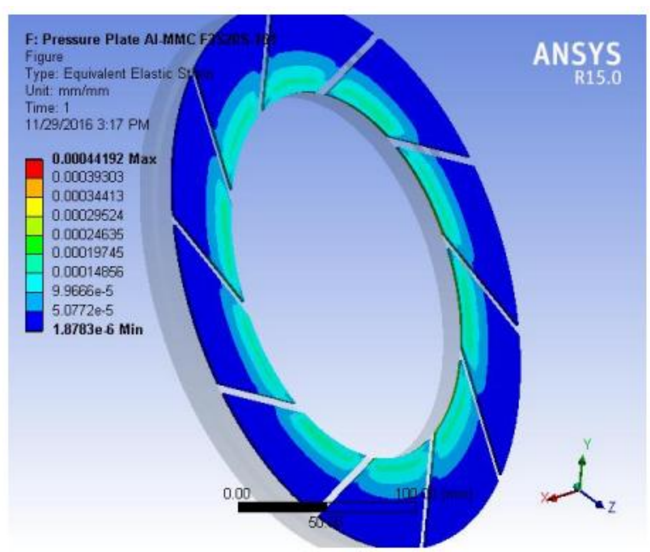


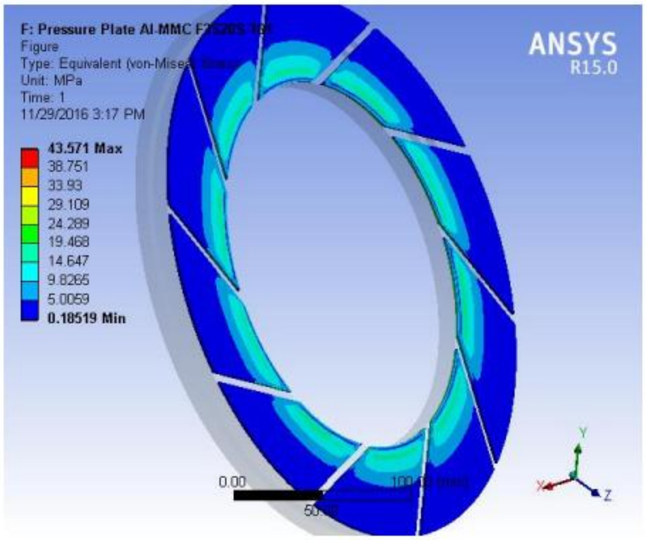


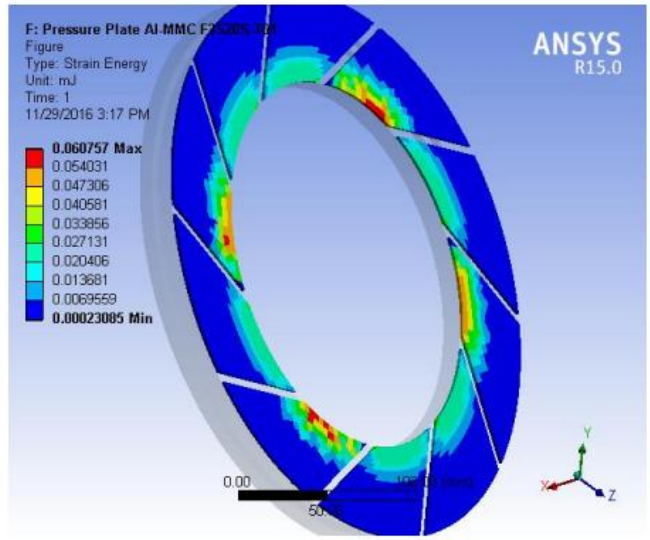


Al-MMC F3S20S-T61:









Thereafter the calculation for torque supplied by each material of friction plate is mandatory. So the calculation is given below,

1. $P = p \times$ Area of application of pressure
2. $M_t = \mu \times P \times R_f$
3. $R_f = (D+d)/4$

Here as the design is same for all materials, so the result will vary based on the material dependent parameters. Here this parameter is Coefficient of friction (μ). Now the general calculation is as follows:

1. $P = 0.95$ MPa x $3.14 \times ((318^2 - 135^2)/4) = 61821.92925$ N
2. $R_f = (318+135)/4 = 113.25$mm
3. $M_t = \mu \times 61821.92925 \times 113.25 = (7001333.488 \times \mu)$ N-mm

So considering the materials as follows:

- Molded Asbestos Steel:
  $M_t = 7001333.488 \times 0.08 = 560106.679$ N-mm
- Sintered Metal Steel:
  $M_t = 7001333.488 \times 0.10 = 700133.3488$N-mm
- Al-MMC F3D20S-T5:
  $M_t = 7001333.488 \times 0.10194 = 713715.9358$ N-mm
- Al-MMC F3S20S-T61:
  $M_t = 7001333.488 \times 0.10194 = 713715.9358$N-mm

Considering the above all results on the basis of torque transmission both the Aluminum Metal Matrix are suitable, but on the basis of amount of total deformationAl-MMC F3D20S-T5 deforms the least (0.022323mm) with the application of same force.

Hence from the above discussion it has been proved that Aluminum Metal Matrix composite material Al-MMC F3D20S-T5 is the most suitable material can be used in friction lining of friction plate of a single plate clutch system.

CONCLUSION

Friction plate in friction clutch assembly is modelled using CREO parametric 2.0 Software and finite element analysis is performed to calculate total deformation and von- Mises stress for four different materials. From total deformation plots, Aluminium metal matrix composites shows a least deformation when compared to sintered iron and molded asbestos. Toque transmission capacity is also calculated, it is found that aluminium metal matrix composites shows maximum torque transmission compared to sintered metal steel and molded asbestos steel. The Von- Mises stress showed that the designed friction clutch plate is safe.

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