

Modeling, and FEA of Multi-Plate Clutches by Varying Materials for Optimum Torque Transfer Capacity of TCT System of Green, And Light Vehicles

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Abstract— This paper addresses Modeling and analysis of easily applicable multi-plate clutches to use in twin clutch transmission (TCT) system for green and Light Weight Vehicle. The static and dynamic analysis were developed for a clutch plate by using finite element analysis (FEA). The 3D solid model was done using SOLID WORK 2016 and imported to ANSYS work bench 16 for model analysis. The mathematical modelling was also done using different vastly available materials (i.e. Aluminum alloy 6061, E-Glass Epoxy, and Gray Cast iron); then, by observing the results, comparison was carryout for materials to validate better lining material for multi plate clutches using ANSYS workbench 16 and finally concluded that composite material E-Glass Epoxy has a better friction material for design of multi-plate clutches in TCT system.

Keywords— Green Vehicle, Modeling multi-plate clutches, TCT, Clutch materials, MPC.

I. INTRODUCTION

Clutches are projected for transferring the greatest amount of torque with less heat generation and is one part of the transmission system. Twin clutch transmissions (TCT) have emerged as a viable alternative to conventional planetary automatics and continuously variable transmissions with the development of precise control strategies. TCT can be considered as two lay shaft transmissions in one, Odd gears are connected to first shaft while the even gears are connected to the other shaft. Light Weight and Green Vehicles that use TCT has developed be an excellent and competitive in every situation [1].

Multi-plate clutches in a twin clutch transmission system are the most efficient and to be employed in vehicles to achieve better vehicle fuel economy and comfort. Vehicles that use a manual clutch has not been the preferred choice; due to recently developed automatic twin clutch transmission. Evidences show that racing cars, most electric vehicles, Honda cars and motorcycles have been available with automatic transmission systems [2].

The idea behind automatic Twin-clutch is that a vehicle requires less driver input for any transmission system. The TCT as its name implies uses two clutches to change gears. The transmission can be used in fully automatic mode, with a computer determining gear shifts.

TCT, is available both in Wet and dry type Twin clutch transmission system, is more preferable, and has been developed to meet the very high torque capacity and to have more efficiency. Comparison of Wet, and Dry type clutches with their advantages and disadvantages has been done in [3, 5-8].

Good Characteristics of Clutches with high torque capacity, low weight, easy packaging, less noise, vibrations and Harshness (Good NVH characteristics), Longlife and High energy density as described in [4]

II. MATERIAL OF MULTI-PLATE CLUTCH

To specify and limit number of materials to be used for the clutch analysis have be done by comparison of some material properties; Material selection property is used for the expected clutch disc materials and its mechanical property mostly used by different literatures.

Table.1: comparison of better materials based on its Mechanical property [9].

Material types	Specific Strength	Yield Strength (Mpa)	Elastic Modulus(GPa)
E-Glass Epoxy	28.4	1270	28
Aluminum Alloy	4.8	275	69.7
ceramics	6.7	457	33
Gray Cast Iron	19.1	720	24.1
Silicon Carbide	57	1710	63
Kevlar 49	23.8	370	72
organics	17	270	28

The material property shown in Table 1 indicates that E-Glass Epoxy, Silicon Carbide, and Alloy Materials are better materials in resisting for yield when load is applying on them. But, it is clear that Silicon Carbide is a tool material which is very costly. So, it is not recommended to use in clutch.

From the above listed materials Aluminum Alloy, Gray Cast Iron and E-Glass Epoxy were better candidate materials for design of friction clutches of TCT. But, this is not the only way for selection. Beside, Finite element analysis should be done using ANSYS Work Bench depending on the properties of materials to identify which

material is better. The properties of the frictional lining are important factors in the design of the clutches. So, typical characteristics of some widely used friction linings materials are given in table 2. The mechanical property of the selected materials are also shown in table 3. As shown in table 3 of properties of material, the density of E-glass Epoxy UD is lower than that of Aluminum alloy, and Gray Cast Iron. Since the density is the ratio of mass to its volume ($\rho = m/v$), and increase in mass is proportional to the density. So, Gray Cast Iron has more weight than aluminum alloy, and E-Glass Epoxy with the lowest weight of materials [10].

Table.2: properties of candidate clutch lining materials.

Materials combination		Aluminum Alloy 6061	Gray Cast Iron	E-Glass Epoxy
Dynamic coefficient of friction	Dry	0.25 – 0.45	0.15 – 0.25	0.25 – 0.45
	Wet	0.06 – 0.09	0.03 – 0.06	0.06 – 0.09
Maximum pressure MPa		345 - 690	690 - 720	345 - 690
Maximum temperature 0C		2104 - 260	260	204 - 206

Table.3: Mechanical properties of selected materials

Materials combination	Aluminum Alloy 6061	Gray Cast Iron	E-Glass Epoxy
Young's Modulus (Mpa)	68900	120000	27600
Density(Kg/m ³)	2700	7200	1900
Poisson's ratio	0.33	0.29	0.34
Friction coefficient	0.23	0.28	0.48
Tensile strength (Mpa)	276	220	124

III. NUMERICAL OF ANALYSIS

The numerical analysis of the TCT multi plate clutch was done in which the applied force can keep the members together with a uniform pressure all over its contact area and the consequent analysis is based on uniform pressure condition. However as the time progresses some wear takes place between the contacting members and this may alter or vary the contact pressure appropriately and uniform pressure condition may no longer prevail. Hence the

analysis was calculated based on uniform wear condition and uniform pressure theory.

The maximum torque which can be transmitted by the friction clutch for uniform pressure theory is given by the formula in equation 1.

$$T_{\max} = n\pi\mu p_a r(R^2 - r^2) \quad (1)$$

Where R and r are external and internal radius of the clutch respectively.

The objective function, F1 and new objective function in deterministic F_d is also formulated in equation 2 and 3 as:

$$F_1 = \left(\frac{1}{T_{\max}} \right) = \frac{1}{n\pi\mu p_a r (R^2 - r^2)} \quad (2)$$

$$F_d = F_1 + \left[\sum_{i=1}^n \left(\frac{\partial F_1}{\partial R_j} \right)^2 \sigma_{R_j}^2 \right]^{\frac{1}{2}} \quad (3)$$

The Constrained equation also formulated in equation 4, if the constraint equation g_j in equation 4 is satisfied with a probability p_j then the normal variation for probability p_j is given then, the new constraint equation in deterministic form is given in equation. And finally problem reduces to minimize the objective function given by equation (2) satisfying constraint equation (4).

$$g_j = \Phi_j(\rho_j) \left[\sum_{i=1}^n \left(\frac{\partial g_j}{\partial R_j} \right)^2 \sigma_{R_j}^2 \right]^{\frac{1}{2}} \quad (4)$$

To design the multi plate friction clutch for maximum torque transmitting capacity, given by equation 1 and 2 can be calculated from a given values i.e. $\mu = 0.48$, $n=1$,

$$P_a = 0.35 \text{ N/mm}^2$$

$$F1 = \frac{1}{1 * 0.48 * \pi * 0.35 * 10^6 * r (R^2 - r^2)} = 7.8 * 10^{-7} / (R^2 r - r^3)$$

If the design parameters D and d are taken as random variables following normal distribution and the standard deviations are $\sigma_D = 0.01D$ and $\sigma_d = 0.01d$ respectively, then the new objective function in deterministic form, from equation 3 is:

$$F_d = \frac{7.8 * 10^{-7}}{(R^2 r - r^3)} + \frac{0.03 * 10^{-6} R^2 r}{(R^2 r - r^3)} + \frac{7.8 * 10^{-6} (R^2 r - r^3)}{(R^2 r - r^3)^2} = \frac{7.8 * 10^{-7}}{(R^2 r - r^3)}$$

Substitute the calculated parameters in to equation 4 and gives; $g_j = \frac{1.73r}{R}$ (5)

If the constraint equation is satisfied with a probability of 99.99%, then for $p_j = 99.99\%$. The normal variants from table is 5. Using equation (12) the constraint equation in deterministic form is: $g_j d = 1.733 r/R - 0.087R \leq 1$ Hence the problem reduces to minimize objective function given by equation (4) satisfying constraint equation (5). If the torsion is only considered as active constraint then the degree of difficulty will be zero.

The number of friction surfaces, since there are two multi plate clutches the number of friction surface is $(n + n - 1)$ which is 1; then the maximum torque increased n times. So, to deliver 5KW power, 135Nm torque, at a speed of 1000-5000rpm, using the candidate materials, design calculations include,

Let's use the power delivery of the vehicle as 5KW and at a specified initial speed of 5000rpm. But the torque transferred by the clutch would be calculated for analysis of loads and maximum pressure with new specifications.

So, using twin multi-plate clutch is using the number of friction surfaces to be one. Then, the total torque transfer

$$\text{would be; } T_t = \frac{60P}{2\pi\omega} \quad (6)$$

Where T_t = a total torque transfer, P = a maximum power carried by a clutch, ω = speed in rpm

Then using eq.6 above;

$$\text{Then, using the number of friction surfaces } n=1: T = T_t/n = 10/1 = 10\text{Nm} \quad (7)$$

Now, from uniform wear theory, the clumping force W

$$W = 2\pi (P_{\max} \times D_1) \times (D_2 - D_1) \quad (8)$$

Table.4: numerical results and given parametric with different materials from the above formulas

Material	Maximum pressure (P)	Clumping force (W)	Torque Transfer (T)	Coefficient of friction μ	No of friction surface (n)	Mean radius of friction surface (R)	Speed
E-Glass Epoxy	0.00037MPa	119 N	10Nm	0.48	1	0.175m	5000rpm
Gray cast iron	0.0043Mpa	204 N	10Nm	0.28	1	0.175m	5000rpm
Aluminum alloy	0.0053MPa	248N	10Nm	0.23	1	0.175m	5000rpm

IV. RESULTS AND DISCUSSIONS

The maximum pressure obtained by numerical analysis as tabulated in table 4 was applied on the friction plate and results were obtained in Ansys work bench and stress and deformation values in figure -----are compared for the said

materials. Figure 1 shows that the exploded and the meshed model of the plate. The boundary condition and load of the plate is applied as depicted in figure 2 below like applied the pressure and fixed supports.

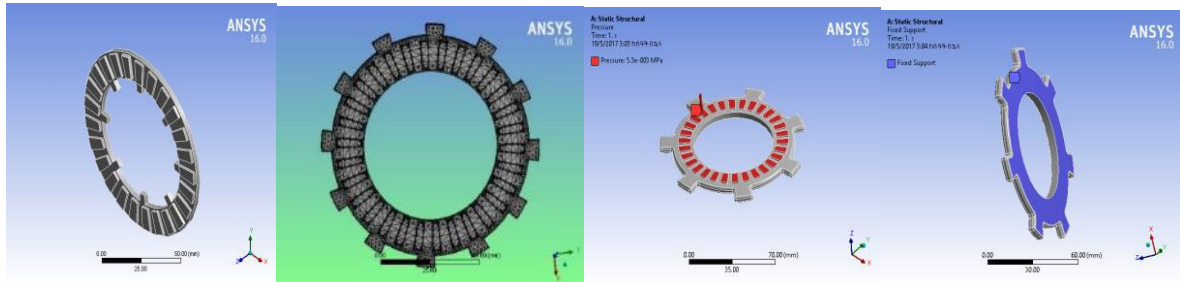


Fig.1: Export and Meshed Figure 2: Load and boundary conditions

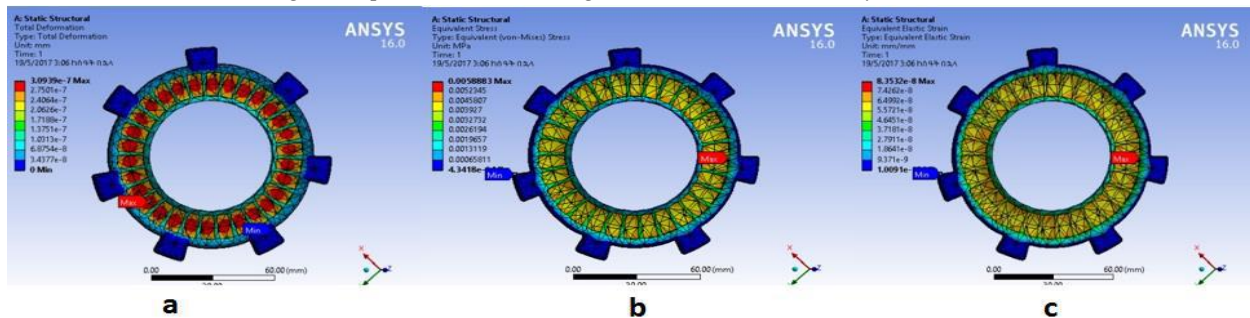


Figure 3: Aluminum alloy as friction material for external spline (a) Total deformation; (b) Equivalent Stress; (c) Equivalent strain

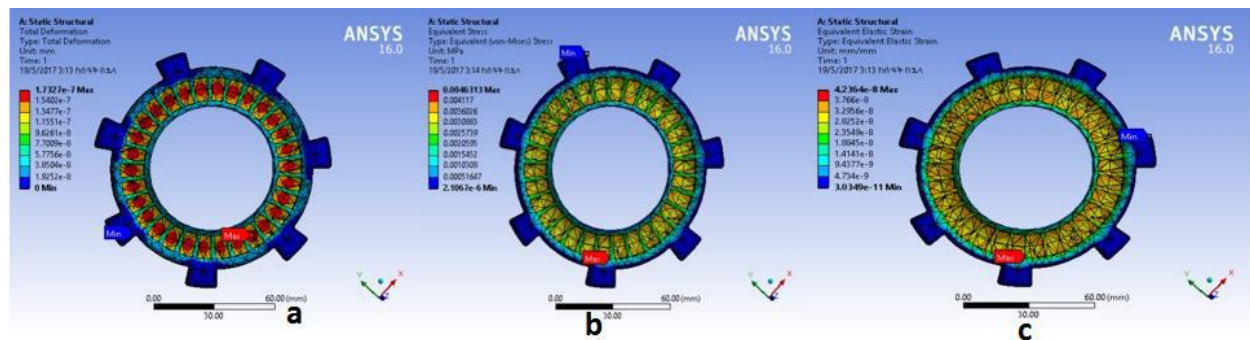


Fig.4: Gray Cast Iron as friction material for external splines MPC (a) applied maximum pressure; (b) total deformation; (c) Equivalent stress

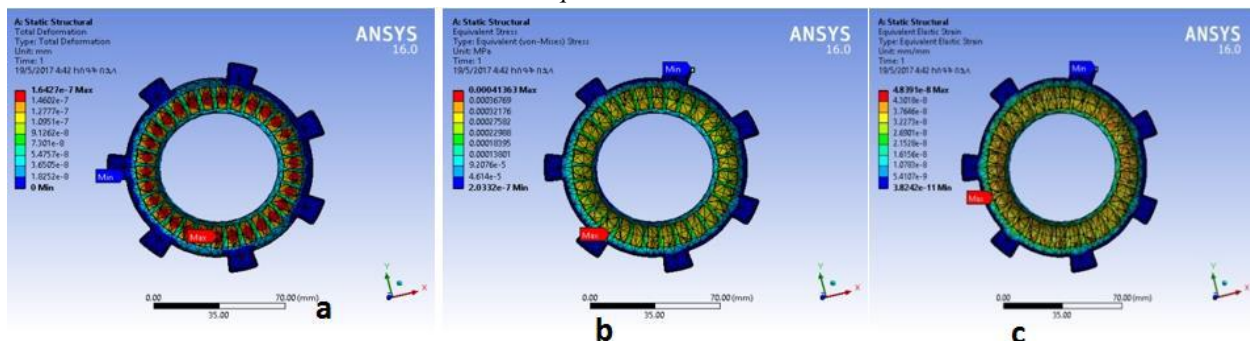


Fig.5: E-Glass Epoxy as friction material for external splines MPC (a) Applied maximum pressure; (b) total deformation; (c) Equivalent stress

The same case for dynamic analysis was done and the static and dynamic analysis of external spline values are tabulated in the table 5 and 6 respectively.

Table.5: External spline FEA /Ansys result (static)

Selected materials	Total deformation (mm)	Equivalent elastic strain (mm/mm)	Equivalent Stress (MPa)
Aluminum alloy	3.0939×10^{-7}	8.3532×10^{-8}	0.00588
E-glass Epoxy UD	1.6427×10^{-7}	4.8391×10^{-8}	0.00041
Gray Cast Iron	1.7327×10^{-7}	4.2364×10^{-8}	0.00463

Table.6: External spline FEA/ANSYS result (Dynamic)

Selected materials	Total deformation (mm)	Equivalent elastic strain (mm/mm)	Equivalent Stress (MPa)
Aluminum alloy	3.0433×10^{-5}	7.0744×10^{-7}	0.0487
E-glass Epoxy UD	1.6118×10^{-5}	4.9203×10^{-7}	0.0049
Gray Cast Iron	1.6702×10^{-5}	4.0124×10^{-7}	0.0432

The above analysis is the external spline friction material for different candidates of material, in the same case the internal spline of friction material will analyzed both static and dynamic once. From figure 6 – figure 9 shown the static analysis of internal spline for aluminum alloy, gray cast iron and E-glass Epoxy using Ansys workbench. In same manner dynamic analysis is tabulated below.

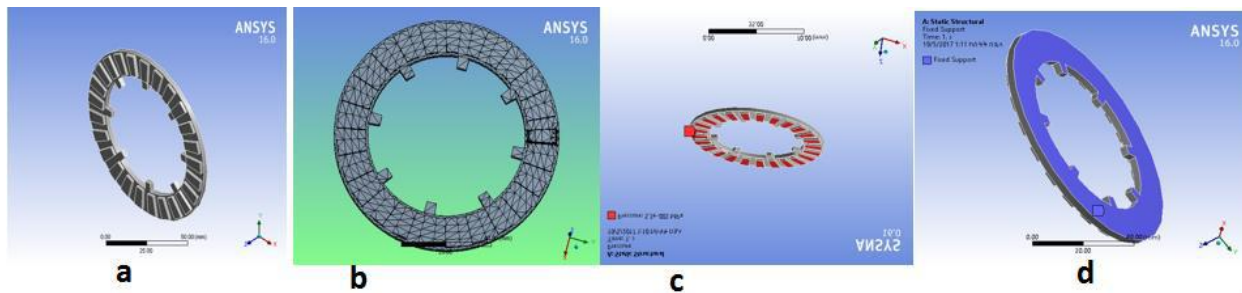


Fig.6: internal splines MPC a) Export from Solid work b) meshed model C) boundary conditions fixed support d) applied Load

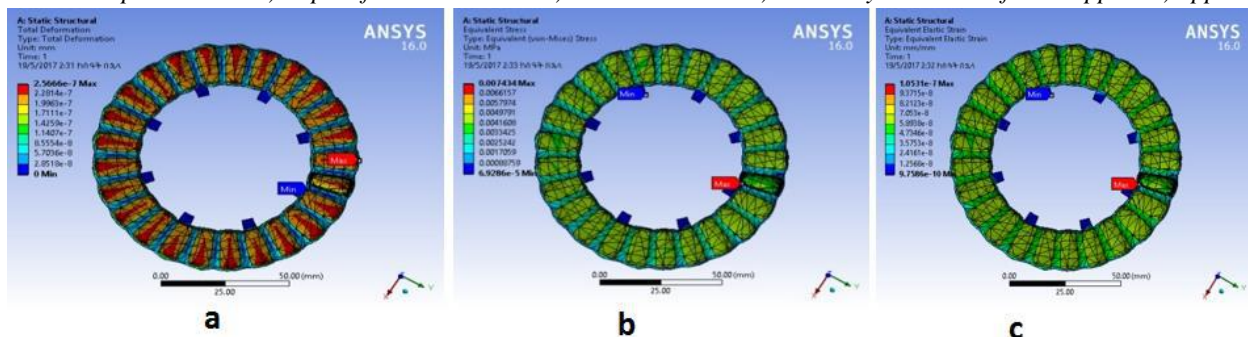


Fig.7: aluminum alloy as a friction material for internal splines MPC; (a) Total deformation; (b) Equivalent stress; (c) Equivalent strain

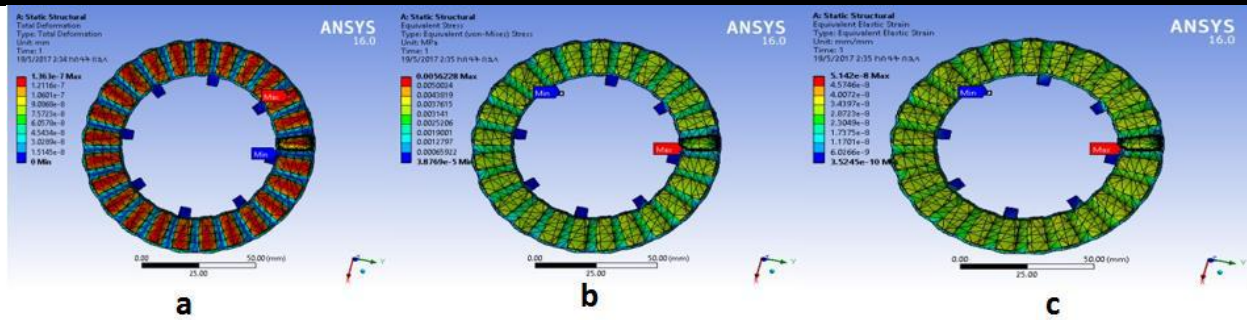


Fig.8: Gray cast iron as a friction material for internal splines MPC (a) total deformation; (b) Equivalent stress; (c) Eq. strain

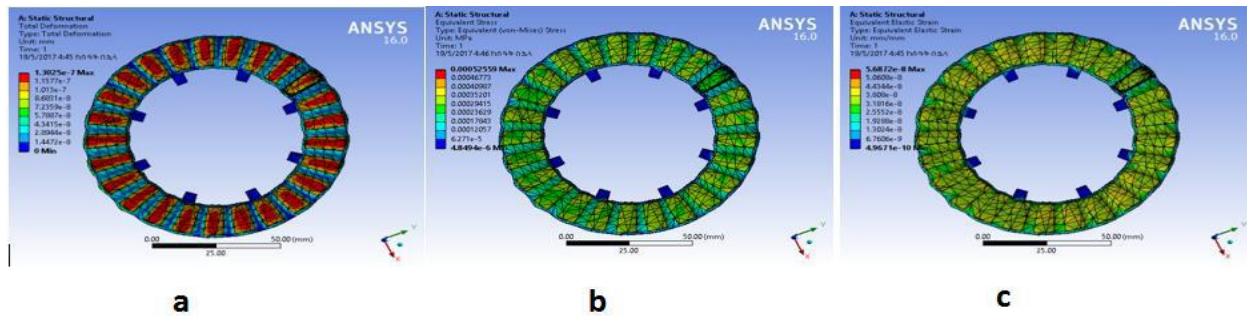


Fig.9: E-Glass Epoxy as a friction material for internal spline (a) total deformation; (b) Equivalent stress; (c) equivalent strain

The static and dynamic analysis of internal spline of friction material values were tabulated in the table 7 and 8 respectively.

Table.7: internal spline FEA/ANSYS result (static)

Selected materials	Total deformation (mm)	Equivalent elastic strain (mm/mm)	Equivalent Stress (Mpa)
Aluminum alloy	2.5666×10^{-7}	1.0531×10^{-7}	0.007434
E-glass Epoxy UD	1.3025×10^{-7}	5.6872×10^{-8}	0.000525
Gray Cast Iron	1.363×10^{-7}	5.142×10^{-8}	0.005623

Table.8: internal spline FEA/ANSYS result (Dynamic)

Selected materials	Total deformation (mm)	Equivalent elastic strain (mm/mm)	Equivalent Stress (MPa)
Aluminum alloy	5.94×10^{-5}	2.633×10^{-6}	0.18659
E-glass Epoxy UD	3.22×10^{-5}	1.717×10^{-6}	0.01658
Gray Cast Iron	3.21×10^{-5}	1.408×10^{-6}	0.15456

As we can observed from the tabulated results shown in table 5,6,7 and 8 of external and internal spline MPCs of the selected materials that; the total deformation, equivalent strain, equivalent stress for clutch plate with E-Glass Epoxy as a friction material has less than that of Aluminum alloy and Gray Cast Iron. For same input torque stress developed in clutch plate with friction material of E-Glass Epoxy has less compared to Cast Iron and aluminum alloy not only this

but also Epoxy UD has the lowest in weight than that of existing commercial clutch materials mostly Gray Cast Iron. Hence it is concluded that the clutch plate with friction material E-Glass Epoxy UD gives better performance than that of Gray Cast Iron and Aluminum alloy.

It is also observed that total deformation, equivalent stress and equivalent strain of E-glass Epoxy UD material were in the permissible range for the ideal friction material

compared to the theoretical calculations. E-glass Epoxy UD has the low total deformation when compared to the existing conventional Gray Cast Iron friction material. Hence, it is concluded that E-glass Epoxy UD serves as a better friction material than Gray Cast Iron, and aluminum alloy and gives better clutch performance.

V. CONCLUSION

From the ANSYS Workbench structural simulation and analysis in FEM is a key to facilitate the assessment of structural analysis of clutch plate which provides relatively simple method for analyzing of material strength. Besides, the analysis shows that increase in tensile yield strength of material, the maximum equivalent stress decrease and similarly the deformation rate decreases. The final result shows that E-Glass Epoxy materials have minimum deformation in their applied load and pressure conditions than other materials used, it also have high wear resistance property and lower weight than existing Gray Cast Iron, and aluminum alloy materials. Besides these, the weight of E-Glass Epoxy material is 72% lower than that of Gray Cast Iron and 26% lower than Aluminum Alloy Materials. So, this makes Epoxy Materials to be better for clutching.

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