Volume 5, Issue 1, January 2018 ISSN: 2348-8565 (Online)
IJMERT
International Journal of Modern Engineering and Research Technology
Website: http://www.ijmert.org Email: editor.ijmert@gmail.com

Finite Element Analysis of Flange Coupling Using Composite Materials Under Static Condition

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ABSTRACT

A static analysis is performed over given model, so that its behavior can be understood under static condition. Static structural analysis system of ANSYS workbench 16.0 is used, in order to perform analysis work. CATIA V5R20 software is used for modeling. For better result, parts are divided into no. of small elements though finite element method (FEM) used by ANSYS software. For static analysis, different composites materials like E-glass epoxy, boron epoxy, carbon Epoxy and structural steel have been used in order to check the suitability. All materials are compared against different stress and strain parameters. Composite materials lead high strength to mass ratio, high stiffness to mass ratio, high impact resistance, better fatigue resistance etc. After complete analysis work, Boron Epoxy material has been recommended as flange coupling material.

Keywords:— *Epoxy, workbench, E-glass, ANSYS, Flange Coupling*

I. INTRODUCTION

1. Specification of the Problem:

Mass of the flange coupling increase along with strength but increasing of mass not exceed due to space limitations. The flange coupling is to be optimally for following specified design requirements.

2. Design Specifications of the Flange Coupling:

Following dimensions of unprotected rigid flange coupling taken from base paper has been adopted for current study-

3. Selection of Material:

Rigid flange is usually manufactured by casting as it consists of projection and recess. The commonly used material for flange coupling is grey cast iron which is characterized by graphic microstructure causing fracture of the material to have a grey appearance [20]. It is one of the most commonly used form of cast iron and the widely used cast material based on casting properties. It has high compressive strength to its tensile strength and shock resistance. Its mechanical properties are controlled by the size and morphology of the graphite flakes. It also experiences less solidification shrinkage than other cast iron that does not form a graphitic microstructure during casting process. The silicon promotes good corrosion resistance and increase fluidity while casting. It also offers good weld ability.

Table 1. Specification of Flange Coupling

Parameters	Dimension
Diameter of shaft	45 mm
Outside diameter of hub	90 mm
Length of hub	55 mm
Pitch circle diameter of bolts	135 mm
Outside diameter of flange	180 mm
Thickness of flange	20 mm
No. of bolts used	4
Diameter of bolt	10 mm
Length of the shaft	110 mm
Width of key	11.25 mm
Thickness of key	7.5 mm
Length of key	90 mm
Volume of two flanges	1.4579×10^6 mm^3

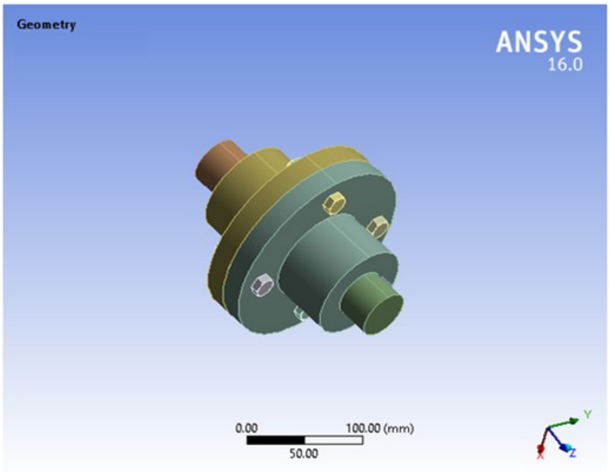

Figure 1. The Solid Model Imported In ANSYS

Nowadays, composite materials are also employing for various engineering components. A composite material is a combination of a matrix and a reinforcement, which when combined gives properties superior to the properties of the individual components. In the case of a composite, the reinforcement is the fibres and is used to fortify the matrix in terms of strength and stiffness. The reinforced fibres can be cut, aligned, placed in different ways to affect the properties of the resulting composite.[4]

The main advantage of most composites materials are in the weight savings. This can be represented as strength to weight ratio. Combination of the reinforcement and the matrix can also be changed easily to meet the required final properties.

Table 2. Properties of Materials [2]

S. No.	Property (X-dir)	Grey Cast Iron	Al-Si-Carbide	Structural steel	E-glass / Epoxy	Carbon Epoxy	Boron Epoxy
1.	Elastic Modulus (MPa)	66178.1	115000	200000	50000	126900	204000
2.	Poisson's Ratio	0.27	0.27	0.3	0.3	0.3	0.23
3.	Mass Density (kg/m^3)	7200	2880	7850	2000	1600	2000
4.	Tensile strength (MPa)	151.66	680	250	800	870	1260
5.	Compressive Strength (MPa)	572.17	-	250	800	870	1260
6.	Shear Modulus (MPa)	50000	318.9	76923	5600	6600	5590

4. Analysis of Composite Flange Coupling:

Modeling and meshing Solid modeling gives the 3D appearance of any products. It is the initial step for doing any 3D analysis for a specified problem. In the present work solid modeling of unprotected rigid coupling has been created in **CATIA V5R20** software and analysis work is carried out in **ANSYS 16.0** workbench.

Meshing is the process in which your geometry is spatially discretized into elements and nodes. For mathematically representation of the stiffness and mass distribution of the structure, mesh along with material properties is used. The automatically meshed at solve generated. The default element size is determined based on a number of factors including the overall model size, the proximity of other topologies, body curvature, and the complexity of the feature. Structured meshing method done in ANSYS Workbench is used for meshing the geometry.

TABLE 3. Nodes and Elements for meshing

S.No.	Meshing Parameter	Values
1.	No. of Nodes	131408
2.	No. of Elements	74685

5. Boundary Condition

- Initially, flange coupling is assumed to be in stationary condition. For static analysis, boundary condition is taken from base paper as given below-
- Fixed support is applied on both end faces of hub.
- Pressure of 10 MPa is applied on both faces of flanges.
- Global co-ordinate system is used.
- Total no. of bodies is 14

II. Present Work

Validation is done by comparing the result of base paper with result obtained by finite element analysis. In the present work, analysis is done in **ANSYS workbench 16.0** and compared with result **ANSYS 14.5**. It results in slight difference in the values.

Table 4. Results for Grey Cast Iron for Validation of Work

S. No.	FEA Analysis	Total deformation (mm)	Maximum Shear Stress (MPa)	Equivalent Elastic Strain	Normal Stress (MPa)
1	Current Study	0.0028227	17.708	0.0002029	21.988

III. Result and Discussion

3.1. Result for Grey Cast Iron for Validation

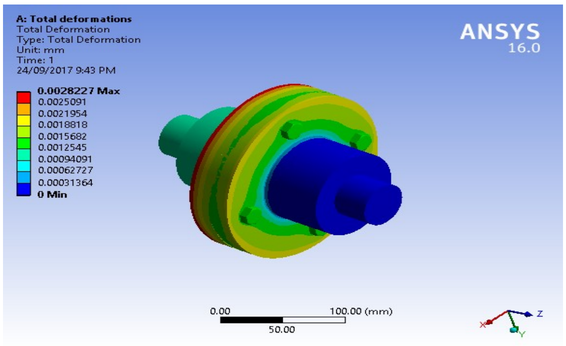

Figure 2. Total Deformations for Grey Cast Iron

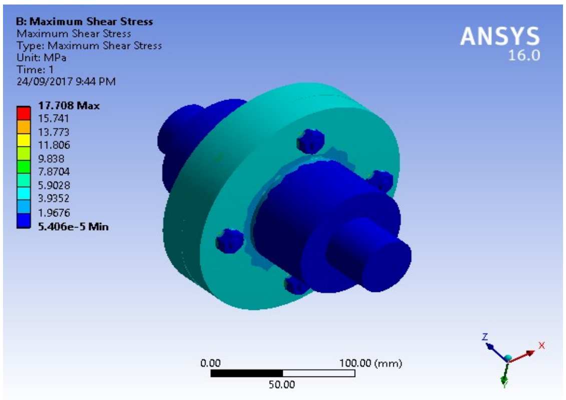

Figure 3. Maximum Shear Stress for Grey Cast Iron

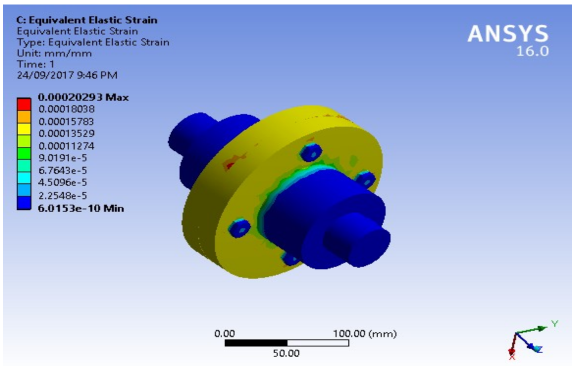

Figure 4. Equivalent Shear Strain for Grey Cast Iron

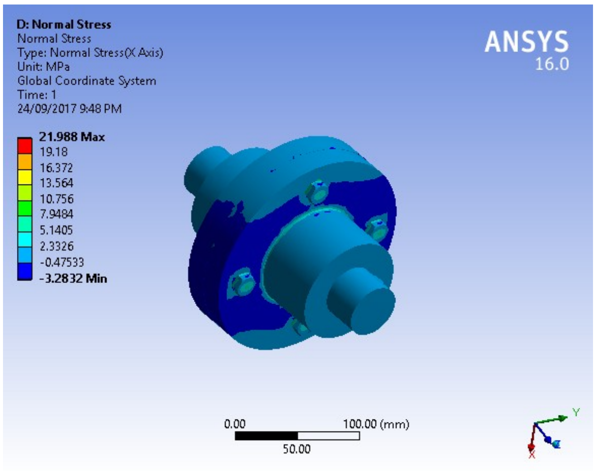

Figure 5. Normal Stress for Grey Cast Iron

3.2. Result of Static Analysis

3.2.1. Result for E-Glass/Epoxy

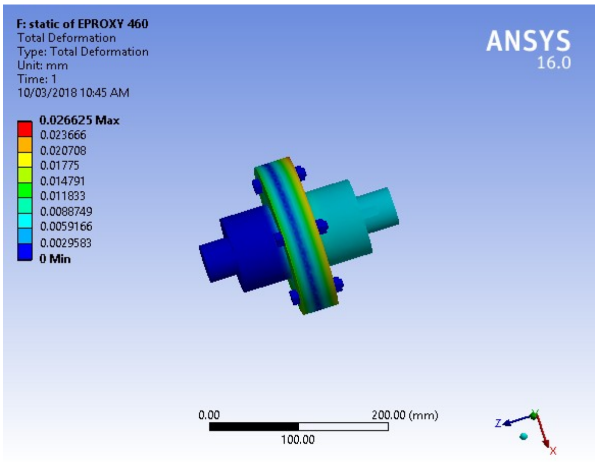

Figure 6. Total Deformation for E-glass/Epoxy

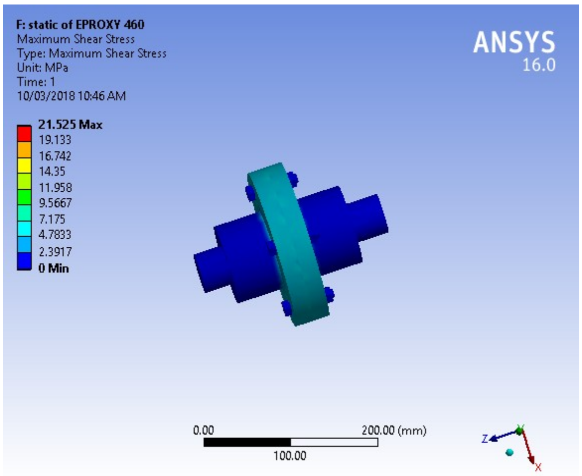

Figure 7. Maximum Shear Stress for E-glass/Epoxy

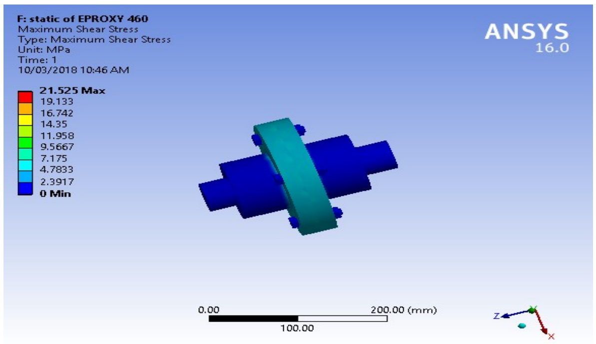

Figure 8. Equivalent Shear Strain For E-glass/Epoxy

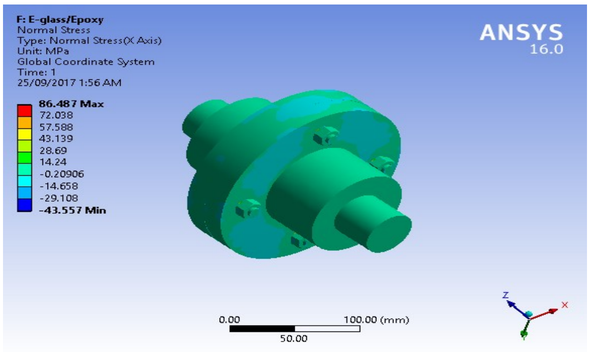

Figure 9. Normal Stress for E-glass/Epoxy

3.2.2. Result for Carbon Epoxy

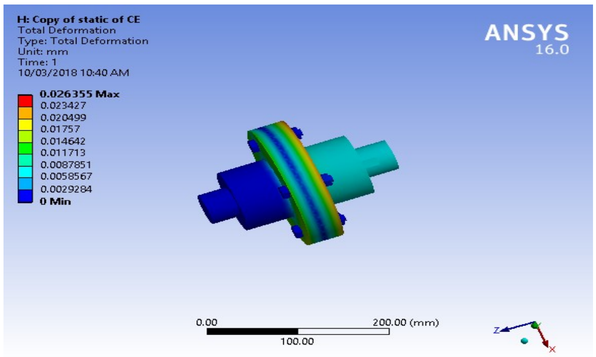

Figure 10. Total Deformations for Carbon Epoxy

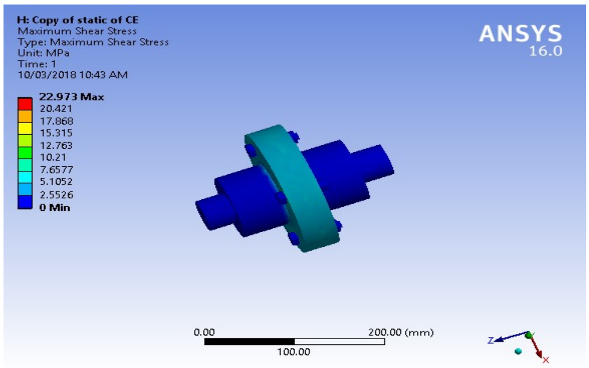

Figure 11. Maximum Shear Stress for Carbon Epoxy

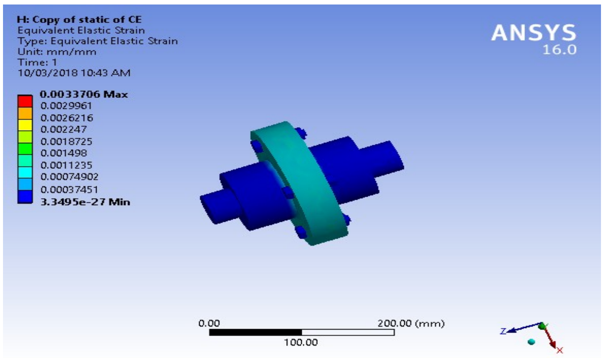

Figure 12. Equivalent Shear Strain for Carbon Epoxy

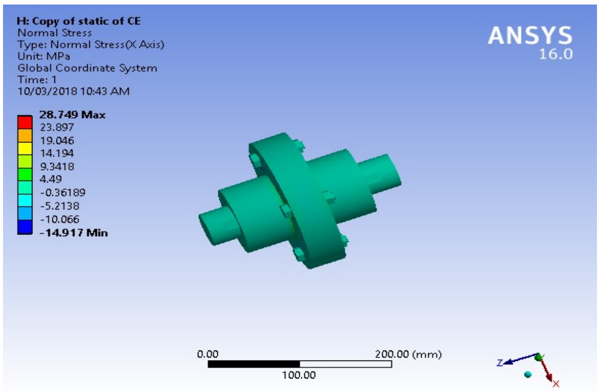

Figure 13. Normal Stress for Carbon Epoxy

3.2.3. Result For Boron Epoxy

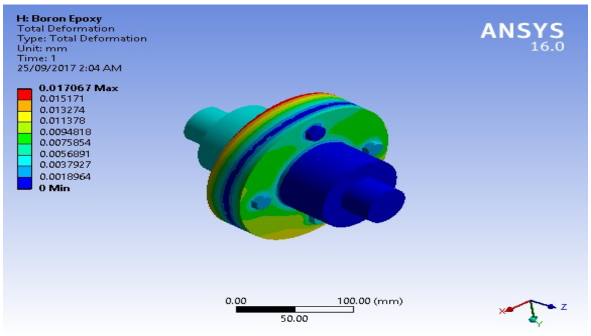

Figure 14. Total Deformations for Boron Epoxy

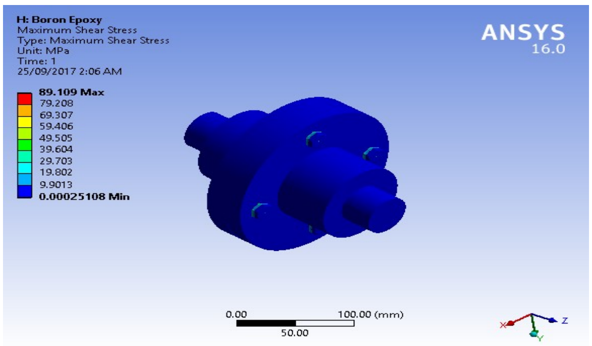

Figure 15. Maximum Shear Stress for Boron Epoxy

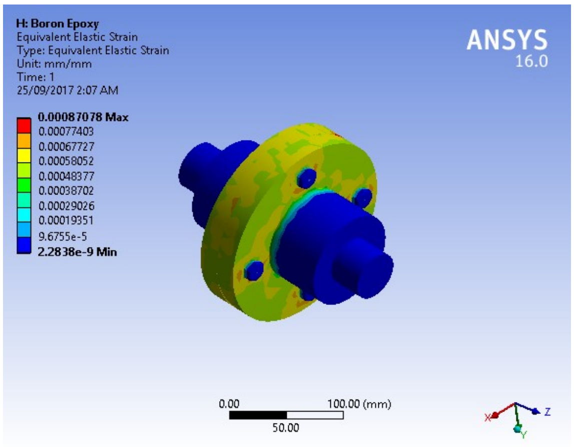

Figure 16. Normal Stress for Boron Epoxy

3.3 Comparison of Results Analysis under Static Condition.

Table 8.1 shows the results obtained from Finite Element Analysis using different materials. These materials include structural

3.3.1 Comparison of Results for Static Analysis

Steel, E-glass/Epoxy, Carbon Epoxy and Boron Epoxy in addition with grey cast iron and Al-Si-Carbide. Structure analysis of all materials has been calculated for same boundary condition as mentioned earlier.

Table 5. Comparison of Results for Static Analysis

S. No.	Material	Total Deforma-tion (mm)	Maxi-mum Shear Stress (MPa)	Equivalent Elastic Strain	Nor-mal Stress (MPa)
1	Boron Epoxy	0.020793	15.172	0.0025239	18.743
2	Grey Cast Iron	0.0025	18.832	0.00019652	21.325
3	E-glass/ Epoxy	0.026625	21.525	0.0031124	27.083
4	Carbon Epoxy	0.026335	22.421	0.0033706	28.749
5	Al-Si-Carbide	0.33509	105.57	0.019	134.35

Table 6 Strength to Weight Ratio for all the Materials

S. No.	Materi-als	Ulti-mate Strength (KPa)	(kg/m^3)	Mass (kg)	Weight (N)	Strength to weight ratio (K/mm^2)
1	Grey Cast Iron	151.66 × 10^3	7200	10.4969	102.9745	1487
2	Al-Si-Carbide	680 × 10^3	2880	4.1987	41.1892	16585
3	E-glass/ Epoxy	800 × 10^3	2000	2.9158	28.6039	28571
4	Carbon Epoxy	870 × 10^3	1600	2.3326	22.8828	39545
5	Boron Epoxy	1260 × 10^3	2000	2.9158	28.6039	43448

Design requirement for flange coupling requires calculation of shear stress, deformation, high strength to weight ratio including less material cost and good tensile and shear strength.

All new three materials i.e. E-glass/Epoxy, Carbon Epoxy, and Boron Epoxy have been tested on all these condition. Table 6 shows that strength to weight ratio for the grey cast iron and Al-Si-carbide given in base paper. Among all of these strength to weight ratio for Boron Epoxy is more than all other materials i.e. 43448. It is depicted that Boron Epoxy material can be used instead of other materials. The benefit of using the Epoxy material is high strength to weight ratio means less cost, good tensile and shear strength.

3.3.2 Comparison between Strength to Weight Ratio & Ulti Stress for Difference Composite Materials

Figure 17 and 18 are showing relation between strength to weight ratio vs ultimate strength and density of different materials respectively.

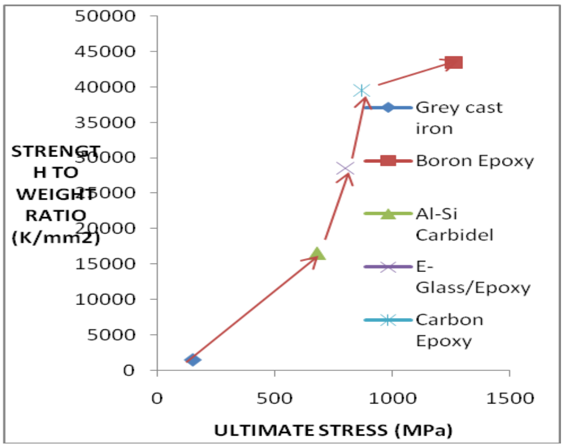

Figure 17. Comparison of Strength to Weight Ratio for Different Materials

From the above Figure 17, it is found that with increase in ultimate strength of a material, strength to weight ratio increases. It results in high strength of material with less weight. Therefore considerable weight of coupling system can be reduced.

3.3.3 Comparison between Strength to Weight Ratio & Density for Different Materials

Comparison between Strength to Weight Ratio & Density for Different Materials

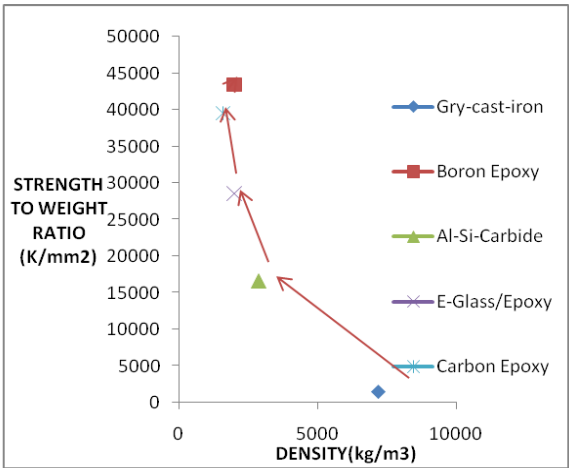

Figure 18. Comparison between Strength to Weight Ratio & Density for Different Materials

Density and strength to weight ratio are inversely proportional. From Figure 18 it is clear that as density decreases, strength to weight ratio increases. Composite material has advantage of low density as compare to another metals. In above graph, Carbon epoxy has lowest density of 1600 kg/m^3 having strength to weight ratio 372974. But Boron Epoxy material has highest strength to weight ratio that is 432247 with density of 2000 kg/m^3. Except composite materials, metals contain high density, which result in heavy weight of coupling. Therefore, composite material can be used as alternatives of metals.

3.3.4. Comparison between Ultimate Strength & Density for Different Materials

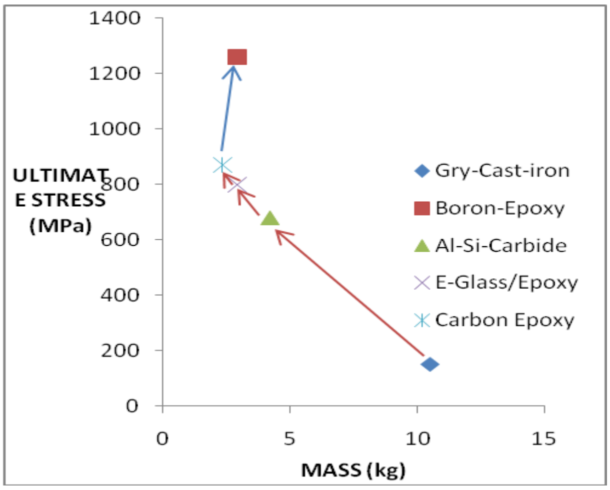

Figure 19, Comparison between Ultimate Strength & Density for Different Materials

Figure 19 is shown relation between ultimate stresses vs masses. this is cleared by this graph boron epoxy has small weight 2.9kg with highest ultimate stress 1200Mpa. It is also proved that composite materials has lowest weight with higher strength as compare to gre-cast-iron and Al-Si-Carbide. Because gry cast iron have 10.4969kg mass with 151.66Mpa ultimate strength. Therefore, composite material can be used as alternatives of metals for flange coupling

IV. Conclusion

Following are the conclusion which have been found from all the above cases-

1. Among all the materials, Boron epoxy material is found to be most suitable for flange coupling.
2. Boron epoxy material has largest strength to weight ratio along with highest ultimate stress i.e. 1260 MPa.
3. For a given strength, boron epoxy requires least material
4. For the safety purpose, protected flange coupling can be used. The thickness of the protective circumferential flange (t_p) is taken as 0.25d. For current model it is 11.25 mm.
5. Composite materials can be used as alternatives of heavy metals for engineering applications.

V. Future Scope

Following steps can be taken for future study-

1. Optimization can also be done with speed variation, keeping torque constant and/or varying speed and torque both.
2. In the above work, static and dynamic analysis has been performed. Above model can be checked against vibration analysis, fatigue analysis and buckling analysis.
3. Above work is based on Finite Element Method. This can be also done with analytical and experimental method.

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