STRESS EVALUTION OF PIN-ON-DISC UNDER DIFFERENT COMPOSITE MATERIALS BY FINITE ELEMENT METHOD

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Abstract.

The main objective of this work was to evaluate the state of stress and strain in Pin-on-Disc (POD) tribology test setup with structural steel as the tribo elements under self-mated conditions using finite element method (FEM). Structural steel is a major core and structural material in the Prototype Fast Breeder Reactor (PFBR. In PFBR there are many in-core and out-of-core component involving contact pairs undergoing sliding wear during operation as well as maintenance. Estimation of wear during operation of the machine would lead to developing appropriate wear mitigation approaches. However, measurement of in-situ wear in machine components is very difficult, if not impossible. Finite element method (FEM) based numerical modelling of machine operation with appropriate wear models would enable estimation of wear a-priority. As accuracy of calculated wear values strongly depends on the state of stress and strain in the components, accurate modelling of the state of stress and strain is essential. Apart from stress, strain, contact pressure, penetration and what type of friction is present can also be calculated. This simulation will give the exact total deformation and all other details regarding the assembly.

The Finite Element Analysis was performed by using ANSYS 16.0 and various stresses such as maximum principal stresses, Von- Misses stresses, total deflection, total deformation, and penetration, contact pressure, occurred during working condition were evaluated. The results of the simulation depicts the stresses occurred is within the permissible limit of the piston material and the deformation is well within the tolerance limit.

Key Words: *pin-on disc, stress analysis, ANSYS, Contact Elements, wear*

1.1 Introduction

Years of research in Tribology confirm the claim that the friction and wear properties of a given material are not intrinsic, but depend on many factors associated with specific applications. The quantitative values for friction and wear in the form of friction coefficient and wear rate, cited in many engineering textbooks, depend on the following groups of basic parameters: (1) System structure, that is, the relevant components and properties, (2) Operating variables, namely load (voltage), kinematics, temperature and time, (3) Reciprocal interactions of system components.

1.2 Adhesive wear

Adhesive wear is a phenomenon that occurs when two metals rub against each other with sufficient strength to remove material from a hard-to-wear surface. This wear depends on material properties, physical and chemical factors such as corrosive atmosphere or presence of chemicals, and mechanics such as applied speed and load.

The amount of material released by the adhesive wear process can be estimated from the formula proposed by Archard.

$$V_a = K \frac{W}{H} L \tag{1}$$

Where k= wear coefficient, L= sliding distance and H= hardness of the softer material in contact.

Abrasive wear is a very common and, at the same time, very serious type of wear. It arises when two interacting surfaces are in direct physical contact, and one of them is significantly harder than the other. Under the action of a normal load, the asperities on the harder surface penetrate the softer surface thus producing plastic deformations.

The amount of material removed in this process can be estimated from the expression: Simplified,

$$V_{abr} = \frac{2}{\pi}\frac{tan\theta}{H} WL \tag{2}$$

Refined, $$V_{abr} = n^2 P_y E \frac{W^{3/2}}{K^2 H^{3/2}} L \tag{3}$$

Where E= elastic modulus, H= hardness of the softer material, K= fracture toughness, N= work-hardening factor and P= yield strength.

1.3 Wear model (Archard's law)

It is postulated by Archard that the total wear volume is proportional to the real contact area times the sliding distance. A coefficient K which is proportionality constant between real contact area, sliding distance and the we are volume has been introduced,

$$V = KArl = KlW/H \tag{4}$$

Where V = represents the wear volume [m3], K = represents the proportionality constant, Ar= represents the real area of the contact [m2], W = represents the load [N],H = represents the Vickers hardness of the softer surface [Pa] and l = represents the sliding distance [m].

1.4 Contact Mechanics - Point Contact

a) Consider rigid objects A and B as shown in Fig 1.1 that make contact over region R
b) Contact pressures P(x) >= 0 for all x ∈ R
c) If R is a planar region, with uniform friction and uniform normal, then all pressure distributions over R are equivalent to
    - A combination of forces on convex hull of R

- If R is polygonal, a combination of forces on the *vertices* of the convex hull of R

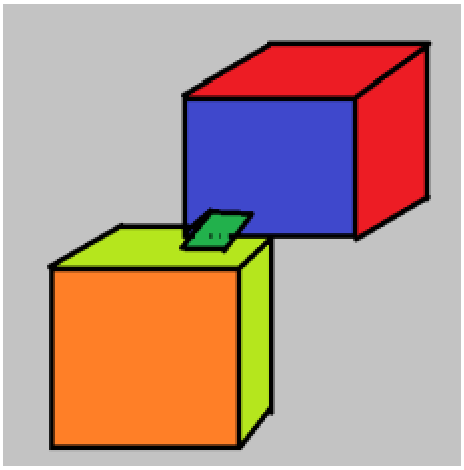

Fig1.1 Point Contact

1.5 Literature Survey

SumitKhot, Utpal Borah [1] said that main objective of this work is to evaluate the state of stress and stress in the setting of pin-on-disk tribology test (POD). 316LN stainless steel austenitic as a friction element under self-mating conditions using the finite element (FEM) method.

U. S. Ramakanth; Putti. Srinivasa Rao [2] presents the research examined the influence of sic and fly ash on the wear behaviour of Aluminium 7075/5 and weight percentage of hybrid complex. Aluminium alloy 7075 strengthened with sic-fly ash were examined. The effectiveness of integration of sic in the composite for obtaining wear reduction is investigated in this study.YunfengZhang.etal. [3-8] presents the analyze the stress field distribution and change the friction surface law to obtain the mechanism and characteristics of the worn pair. The theoretical stress model of the pin-on-disk pair was observed according to the semi-elastic elastic model, and the finite element model was built using ABAQUS software.Gonzalez, A. Martin [9] studied the Contact surface nodes are moved in the normal direction, and pin geometry and mesh elements are updated automatically. This model includes several other important features such as Coulomb friction, plastic behavior that depends on the temperature of the pin, and the formation of heat on the contact surface due to plastic deformation on the pin. The thermo mechanical coupling equation that carries all the steps is integrated using the Abacus Standard code. Louis Ferranti Jr., Ronald W. Armstrong [10] present the, continuous indentation tests are usually used to measure the modulus of elasticity of a material according to the unloading response of a plastic curve. The test results show that the solid aluminum elastic modulus has a value and is quite consistent with the value of the handbook.

1.6 Methodology

ANSYS (version 19.4.0) is a finite element program used to simulate real technical problems. The software solves the problem using three different stages: pre-processing, resolution, and post-processing. There are 10 modules that are defined in this software. In the preprocessing phase, you create geometry and prepare FEM models, determine the types of elements, material properties, and interactions. During the solution phase, ANSYS software generates a mesh that describes the behavior of each node and element and calculates unknown values for output field variables such as total deformation, strain stress, friction behaviour, pressure distribution, wear rate, wear rate, wear pressure, contact pressure, etc. You. The post-processing stage is visualization. At this stage, you can analyze and plan the results.

ANSYS is a software application used for the modeling and analysis (pre-processing) of components and machine assemblies as well as visualizing the results of finite element analysis. This is a general purpose finite element analyzer with an implicit integration scheme. This runs as a background process and performs actual numerical calculations. After the simulation is complete, the results can be monitored at the post-processing stage. ANSYS is also used to display, plot and process data. There are 9 modules to perform analysis in ANSYS.

1.7 Stress Analysis on Pin-On Disk of A380 Composite Material

To conduct wear simulation on ANSYS software the contact analysis is performed following five basic steps and it was shown in below with Fig 1.2. Select whether the contact analysis is on ANSYS Parametric Design Language (APDL) or Workbench in this thesis the wear simulation is conducted on ANSYS Workbench.

a. Create the model **geometry**
   The model was design using basic **sketch and dimensioning**. The pin on disk track diameter inner to outer diameter dimensions are 80mm and 140mm and thickness of the disc is 5mm.The pin dimensions are 40mm length and 10mm diameter.

b. Assign the **Materials**to PIN and DISC
   The pin material is Aluminium Alloy (A380), the Young’s modulus 50.034Gpa & poisons ratio is 0.3. This material properties data was taken from the reference. The disc material is generally steel i.e. Young’s Modulus is 210Gpa and poisons ratio 0.3.

c. Define the **coordinate system** –**Global Coordinate System**

d. Define the **Connections.** The Connection are here two types (1). Contacts & (2) Joints.
   1. **Contacts**
      - The friction contact is made between pin and disk. The friction was varying in this analysis based on the loading conditions and type material of the pin.
   2. **Joints**
      - A disc was rotate in z – direction with velocity of 4.71m/s.

e. Create the **Mesh** for Model.

f. Astatic **Structural analysis** was performed. The are two types boundary condition are used (rotation of disc and external force on surface of the pin in Z-direction). The force was varying on surface of the pin from 30 to 90N.

g. **Solve** the contact problem using **Solution** option. The following parameters are outputs for this analysis.
   - ✓ Total Deformation
   - ✓ Strain Energy
   - ✓ Equivalent elastic Strain
   - ✓ Equivalent Stress

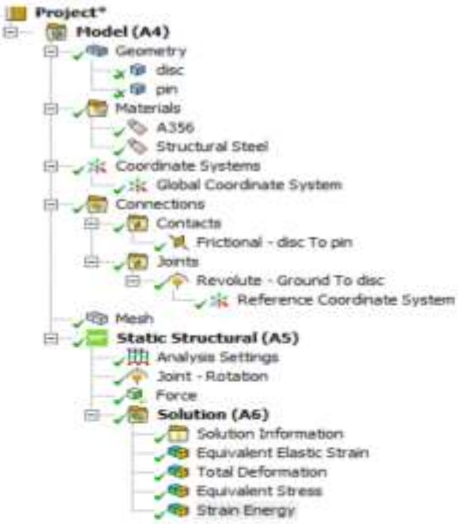

Fig1.2 The Detailed project structure of the pin on disk analysis

The table 1.1 represents the analysis results of A380 Material determined from ANSYS WORKBENCH. Fig 1.3 the friction between the contacts & revolute joint,Fig 1.4 the meshing & revolution of the disc &Fig 1.5 Force on pin in Z-direction & total Deformation on Pin – On- Disc (30N).For the pin on disc pin material Aluminium Alloy (A380), the load is increases the total deformation, equivalent stress, and strain energy are increased shown in Fig 6.1 to Fig 6.3. At the loads of 30N & 60N the deformation was same for 90N it was little bit increased.

Table 1.1 Results of A380 w.r.t varying Load

Load (N)	Total Deformation (mm)	Equivalent Stress	Strain Energy
30	0.0057544	2.0869e6	1.1312e-6
60	0.0057544	4.19e6	4.53e-6
90	0.0057545	6.26e6	1.018e-5

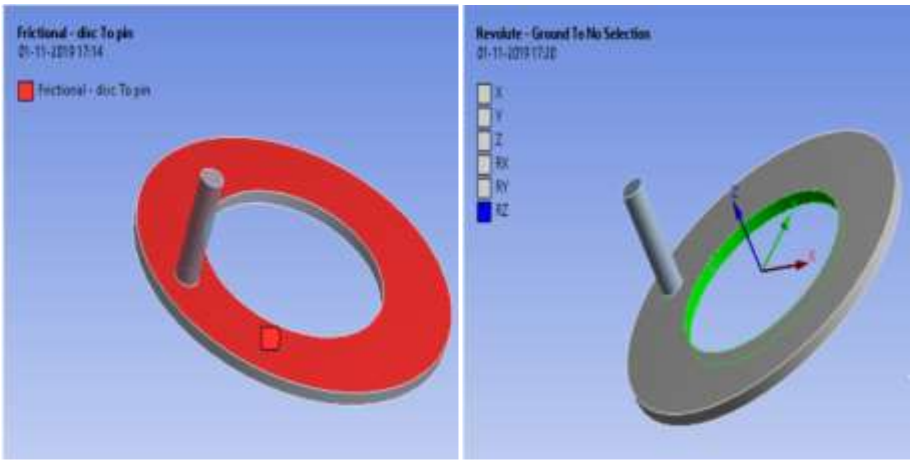

Fig 1.3 the friction between the contacts & revolute joint

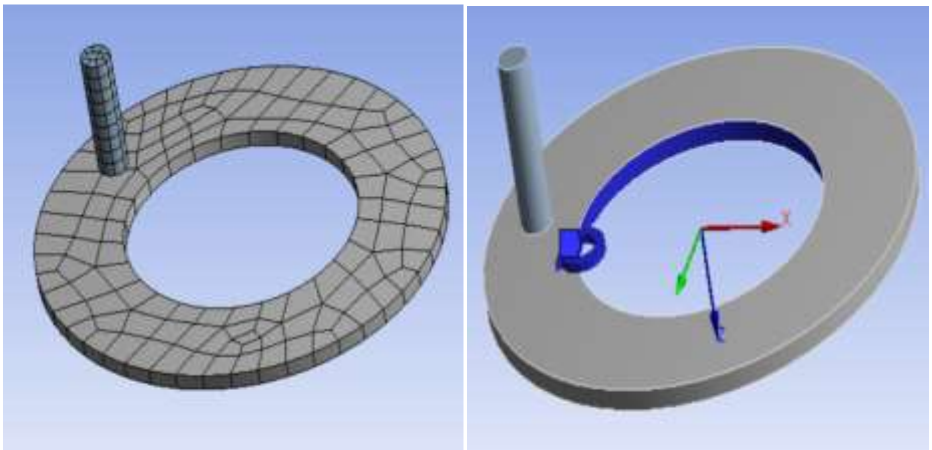

Fig 1.4 the meshing & revolution of the disc

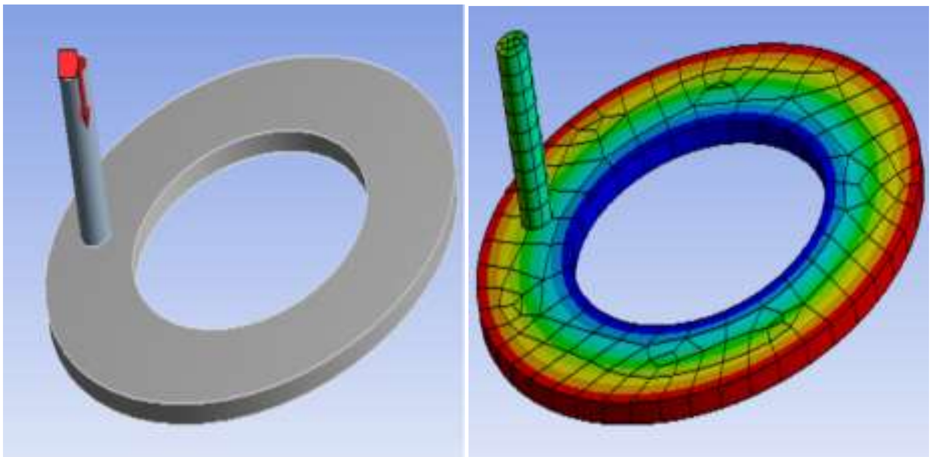

Fig 1.5 Force on pin in Z-direction & total Deformation on Pin – On- Disc (30N)

1.8 Analysis of Composite- A380+ 1%B4C&A380+ 2%B4C

A pin in pin on disc is made of composite material (A380+ 1%B_4C &A380+ 2%B_4C) of their properties are young's modules (E= 64.26 & 68.06Gpa) and poisons ($\vartheta = 0.3$) ratio. That values are taken from the literature review. The dimensions of the pin (10mm *40mm). And the velocity of the disc is 4.71m/s and the material of the disc is steel (E=210Gpa and poisons$\vartheta = 0.3$). The load was applied on the surface of the pin it was varying from 30N, 60N and 90N (the corresponding coefficient of frictions are 0.519, 0.00865 & 0.45). The rotating disc inner and outer diameters are 80mm and 140mm. The stress analysis was performed for this composite material (A380+ 1%B_4C) using a powerful finite element analysis software ANSYS WORKBENCH. Table 1.2 & 1.3 represents the results of (A380+ 1%B_4C& A380+ 2%B_4C) w.r.t varying Load. Fig 1.6 shows the Von – Misses Stress of pin on disc (A380+ 1%B_4C) & (A380+ 2%B_4C) Load of 90N.

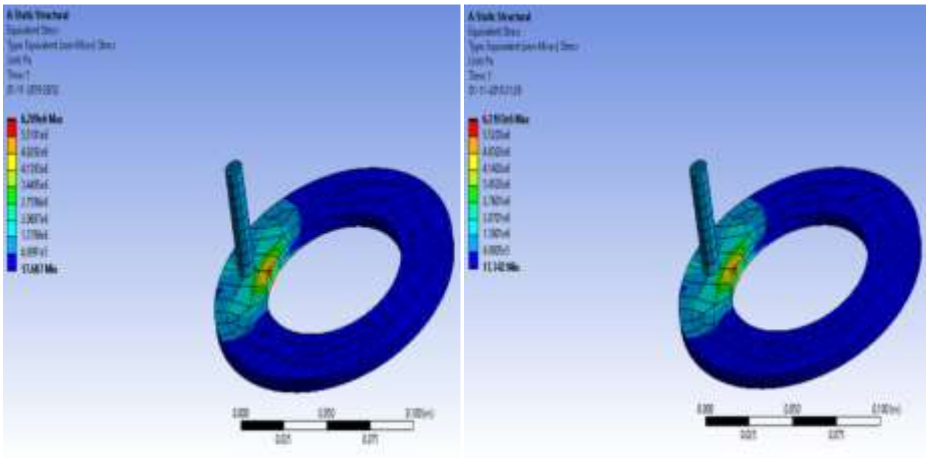

Fig 1.6 Von – Misses Stress of pin on disc (A380+ 1%B_4C)& (A380+ 2%B_4C) Load of 90N

Table 1.2 Results of (A380+ 1%B_4C) w.r.t varying Load

Load (N)	Elastic Strain	Deformation	Equivalent Stress	Strain Energy
30	1.9115e-6	0.0057544	2.069e6	1.1245e-6
60	3.823e-6	0.0057544	4.148e6	4.5129e-6
90	5.7345e-6	0.0057545	6.209e6	1.0124e-5

Table 1.3 Results of (A380+ 2%B_4C) w.r.t varying Load

Load (N)	Elastic Strain	Deformation	Equivalent Stress	Strain Energy
30	1.9115e-6	0.0057544	2.0692e6	1.1245e-6
60	3.823e-6	0.0057544	4.1483e6	4.5129e-6
90	5.7345e-6	0.0057545	6.2103e6	1.0128e-5

1.9 Results and Discussions

Stress analysis on rotating pin on disc was determined for the three composite materials. For each composite material, the load on surface of the pin was varying 30N, 60N &90N and the von- misses stress, total deformation of the pin on disc, total strain & strain energy was found.

Initially the mathematical modeling and developed theory on pin on disc was discussed. Generally the wear analysis i.e. wean on pin on disc was found in the past research, in this thesis an attempt was made to determine the stress on pin on disc by considering three composite materials. Did not found stress analysis research on pin on disc using finite element method from the literature survey. The three composite, material properties are taken from the literature (for A380-E=55.064Gpa $\&\vartheta = 0.3, \text{for A3801\%B4C} - \text{E} = 64.26\text{Gpa } \&\vartheta = 0.3, \text{for A3802\%B4C} - \text{E} = 68.06\text{Gpa } \&\vartheta = 0.3$).

The total deformation is constant for A380, A380 +1% B_4C & A380+2% B_4C of composite materials. Equivalent Stress values and Strain Energy values are high for A380 Compare to other two materials for respective loading conditions. Fig 1.7 Total

Deformation & Von – Misses Stress of A380, A380+1%B4C & A380+2%B4C (90N) & Fig 1.8 Strain Energy of A380, A380+1%B4C & A380+2%B4C (30 & 90N).

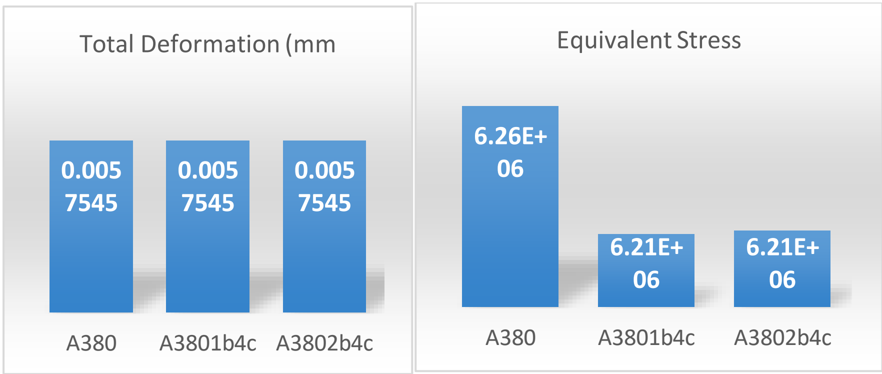

Fig 1.7 Total Deformation & Von – Misses Stress of A380, A380+1%B4C & A380+2%B4C (90N)

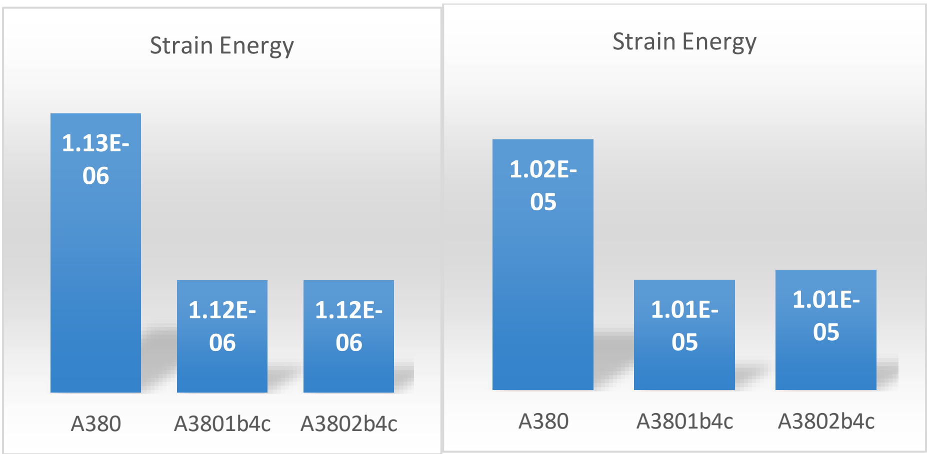

Fig 1.8 Strain Energy of A380, A380+1%B4C & A380+2%B4C (30 & 90N)

1.10 Conclusions

- The total Deformation Stress and strains are found for A380, A380 +1% B_4C & A380+2% B_4C composite materials using ANSYS WORK BENCH
- For A380 Composite exhibit good results compare to other two materials. For improving the results A380 is reinforced with some other ceramics or inorganic compounds like Sic, ZrO2 varying different weight percentages.

1.11 Future Scope

- ✓ A literature gap was observed that development of stress analysis analytical theory on pin on disc for vary loading conditions and different sliding distances of disc is also very important.
- ✓ For getting good results different MMC are plays vital role.

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