Comparative Analysis for Titanium alloy and Silicon Nitride (Si3N4) of Thermal Analysis for Deep Groove Ball Bearing

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Abstract. In this paper, the analysis of the directional heat flux and total heat flux for the bearing balls of Titanium alloy and Silicon Nitride has been demonstrated across a temperature range between 150 to 250 degree celcius. The obtained data allowed comparing the values of total heat flux and various directional heat flux. By comparing directional and total flux of heat in materials it enables the choice of the best-suited material creating bearings with regard to the performance needed. The use of the findings of the current comparison is to ensure efficiency and durability in particular operations. The data presented in the paper helped to analyze the patterns of heat distribution and see the differences between the materials and results a better material for ball bearing. Titanium alloy has excellent mechanical properties like mechanical strength and corrosion resistance. Silicon Nitride is characterized by thermal stability and high thermal resistance and also has excellent wear properties. Thus, using the results of the analysis allows choosing the material for bearing production for high-velocity and high-load operation based on a profound comparison to select the right material. The choice of right material will allow for a more efficient and durable bearing in an industrial setting.

Keyword-: Ball bearing, Titanium alloy, Silicon Nitride, Robust, Mechanical Strength Thermal Analysis, Heat Flux, Materials.

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1 Introduction

The Mechanical deep groove bearings are fundamental elements of machines that allow smooth rotatory motion and reduced friction during rotation. Basically, In ball bearings thermal properties play a big role in influencing the bearings' workability and durability, especially under very challenging and harsh conditions [1, 2]. Bearing condition monitoring is a big part of the maintenance of any machine that rotates regularly. They ensure that any potential fault with the bearings are detected earlier and repaired in good time to prevent economic loss [3-5]. Diverse analysis schedules are generally communicated for the components that are used during industrial tasks such as structural loads [6]. Furthermore, material selection for ball bearing construction also significantly influences the thermal performance, Titanium alloy and Silicon Nitride have been prominently considered due to their unique characteristics [7-9]. Suitable due to its high mechanical strength, physical properties, material properties, and lower density in thermal engineering Titanium alloy shows excellent performance [10]. On other hand, Silicon Nitride also stand out as the best materials to withstand high temperatures physically due to having excellent load-wearing properties [11-13]. Therefore, this paper aims to compare findings and thermal analysis between Titanium alloy and Silicon Nitride in the ball bearing with deep groove [14]. This paper reports the thermal behavior of the materials such as heat flux and directional heat flux measurement produced via experimenting and active analysis methods [15-17]. Temperature insights and heat flux patterns of the materials present in the paper to reveal the differences between the materials for visual support and interpretation of the materials to understand their thermal properties [18]. This study and these findings can be used to select materials adequately and improve design efficiency to obtain enhanced deep groove ball bearings' thermal performance and reliability for industrial applications [19]. Discuss on the friction, early ball bearing friction is two times more slide friction, and it should cause lesser consideration when bearing with original contact pressure of a plain bearings [20]. Friction qualities of a bearing are contingent on operational load, velocity, and lubrication viscosity age, with a small proportionate on the ratio of cleaning of the support bearin [21-24]. As mentioned in a bearing journal, it is hardly to regulate a bearing here but still using into industry under bearing bearing [25-26]. The bearings learning also varied from the fact-finding about all topics with many others observations to the perspective of the technical engineer, because the bearing allocated by genetic engineering as the case requires [27-29]. The load-carrying developer, therefore, is faced by the problem of designing a system of components which constitute the direct effect: which will fit in a given envelope, support a load of stated characteristics, and, eventually, have a life satisfactory when operated under a stated condition [30-34]. Through analyzing this paper, the selection of suitable materials based on the understanding of the thermal behavior and heat flux of Titanium alloy and Silicon Nitride becomes easier to improve the bearing efficiency and durability at high speed and high load for various purposes in the industry segment [35-36].

2 CAD Modelling and Meshing

The deep groove ball bearing is the most often used type of bearing in the industry and its market share is about 80 % of all industrial rolling element bearings sell in this sector. The computational method is used to create the model. For the 3D CAD model the parameters are diameter of the bearing from inside is 70 mm, diameter of the bearing from outside is 110 mm, diameter of rolling balls 9.525 mm and there are 12 number of balls as shown in figure.

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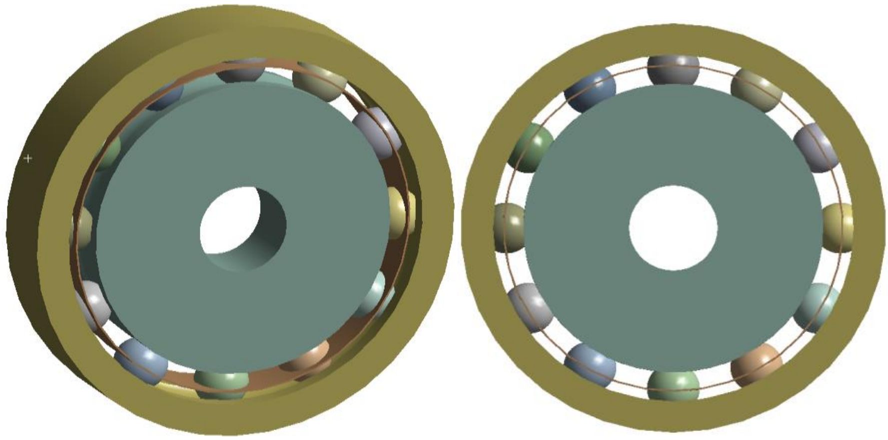

Fig. 1: CAD model representation in three dimensions of a deep groove ball bearing

Meshing is the after process, when we done with CAD modelling. This procedure involves importing the CAD model into the ANSYS workbench for further analysis then it is divided into small pieces and these small pieces are called mesh. The quality of the mesh is assessed to fulfill the criteria and after quality check it is exported to to analysis. The mesh is created for this paper shown in figure 2.

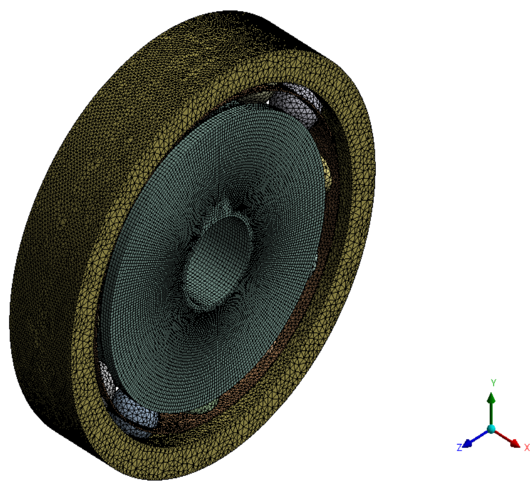

Fig. 2: CAD model representation in three dimensions of a deep groove ball bearing

3 Methodology

This paper provides a holistic process to find the thermal response of silicon Nitride and the Titanium alloy high-performance deep groove ball bearings and compare them. This process involves mathematical calculations for the frictional torque and heat generation in the presence of viscous effects. The equations are developed based on the loading and material properties of the bearing. It also includes finite analysis element which necessitates developing a detailed 3D CAD model of the high-performance deep groove ball bearing, defining precise material properties, meshing for accuracy, applying professional boundary conditions and solving the system using ANSYS Workbench. The results, i.e., temperature distribution and thermal stresses, are then processed to compare the performance of the two materials and identify the most effective bearing material for high performance based on efficiency and longevity.

3.1 Mathematical analysis of deep groove bearing:

3.1.1 Frictional torque measured by using following relation:

$T_v = 0.8 \times f_v.(\mu_v.n)^{2/3} \times (r_i + r_b)^3$
$T_l = \mu_l \times f_l \times (F_n + F_t)(r_i + r_b)$
Where:
T_v= Frictional torque viscous effect of the lubricants
T_l = torques generated by friction when a weight is applied
f_v = Rolling coefficient of friction
n = Speed in rpm
r_i = Inside ring radius (m)
r_b = Ball or roller radius (m)
μ_l = Friction coefficient due to loading
f_l = Coefficient related to loading direction
F_n = Contact force as a result of outside loading (N)
F_t = Preload caused by heat (N)
$F_t = k_t.\varepsilon_t^{1.5}$
k_t = Value for the ball bearing's radial elastic contact coefficient
ε_t= Total radial interference change
μ_v = Lubricant viscosity (Pas)
$\mu_v = \mu_{vi}.e^{-\beta.(T_{oil}-T_i)}$
μ_{vi} = initial viscosity
β = Temperature- viscosity coefficient
e = Eccentricity of the rolling support
T_{oil} = Oil temperature
T_i = Initial temperature

3.1.2 The total frictional heat generation:

$Q_f = \frac{2\pi n T_v \; or \; T_l}{60}$
Q_f = Total frictional heat generation

3.2 Algorithm used for Analysis of finite element

The finite element analysis tool is the mathematical idealization of a real system. It is a computational method that decomposes geometry into elements and associates each one with a series of equations, which are then solved simultaneously to evaluate the behavior of the entire system. It is useful for complicated geometry, loading, and material property problems where an exact analytical solution is difficult to obtain.

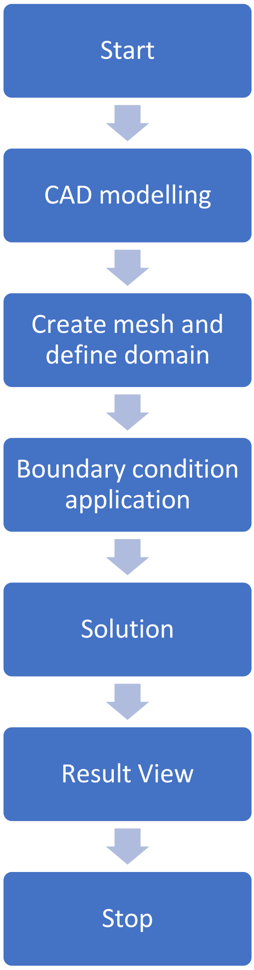

Fig. 3: Flow chart for Finite element analysis

The algorithm used for analysis of finite elements contain three steps:
1. Prior to Processing
2. Processor Solution
3. After Processing

In first step prior to processing, the design or 3D model is created in CAD by direct generation and import it to Ansys workbench to further assessments. After this process material is defined by its constants. For accurate result the material constant should be correct. At last stage of preprocessing it is broken in small parts called the mesh. Mesh is designed to generate results with high precision.

In the second step of the algorithm solution processor, this step is to solve the problem by collection of information provided by the problems. In this phase of processing the computation is used to soles the instantaneous equations created from finite element. Point to remember is that the outcome will only get when all the problem is defined in the proper method.

The third step of the algorithm is pre-processing or after processing, in this step the analysis of the yielded outcomes is occurred across the entire design of the model and the outcome is saved for further case. This After processor has the abilities to range the graphical views and tabular lists to more to more intricate data processing like combine load case and others.

3.3 Material properties

The standard ball bearings materials taken for outside and inside of balls are silicon nitride and titanium alloy. Here the paper discuss about the materials characteristics such as materials structural and thermal behaviour in the form of fundamentals like Young's modulus, Poission ration, density, conductivity specific heat with their particular units to ease the assessment of the paper. Here the materials characteristics below in the tabular form.

Table 1: Silicon Nitride Characteristics with their values

S. No.	Fundamentals	Values
1	YM (E)	3.1e+11Pa
2	PR (nu)	0.26
3	Density	3200 Kg/m^3
4	TC (V)	320 w/m.^{o}C
5	Specific heat	481 J/kg.^{o}C

In this table, paper discuss about the material's characteristics such as structural and thermal behaviour of the material in the form of fundamentals to ease the assessment of the paper. The characteristics for Silicon Nitride are Young's modulus = 3.1e+11 Pa, Poission ratio = 0.26, density = 3200 Kg/m^3, conductivity = 320 w/m. ^{o}C, and specific heat = 481 J/kg ^{o}C .

Table 2: Titanium alloy Characteristics with their values

S. No.	fundamentals	Values
1	YM (E)	1.19e+11 Pa
2	PR (nu)	0.312
3	Density	4429 Kg/m^3
4	TC (V)	7100 w/m.^{o}C
5	Specific heat	553 J/kg.^{o}C

In this table, paper discuss about the material's characteristics such as structural and thermal behaviour of the material in the form of fundamentals to ease the assessment of the paper. The characteristics for Titanium alloy are Young's modulus = 1.19e+11 Pa, Poission ratio = 0.312, density = 4429 Kg/m^3, conductivity = 7100 w/m.^{o}C, and specific heat = 553 J/kg.^{o}C .

Note: In both the above tables following terms are used YM = Young's modulus, PR = Poisson's Ratio, TC = Thermal Conductivity

4 Simulation Outcomes and Findings

From the analysis of this paper, primary aim of this work is to conduct thermal assessment on the ball bearing for the distinct steels used in this paper to increase the strength and thermal efficiency, so the 3D CAD design of the ball bearing with an outside diameter of 110mm, inside diameter of 70 mm, with 12 balls and rolling balls of 9.525 mm diameter created by ansys layout has to perform the thermal assessment for the Titanium alloy and Silicon nitride (Si3N4). After performing of thermal analysis on all above-mentioned materials some results have been obtained in the shape of diagram and graphical representation are discussed in this chapter.

In this paper the temperature distribution while thermal assessment, the temperature that is applied to the inside part of the bearing is varies between 150 to 250 degrees. In this range 150 mark shows the minimum and 250 shows the maximal amount of temperature applied on the bearing. To improve the thermal conductivity of the materials this thermal assessment is occurred on materials. Following the completion of the thermal assessment of the bearings of distinct materials outcomes such as flux of heat and temperature distribution have been compared and represent in below table.

After performing thermal analysis on ball bearing with deep groove for Titanium alloy and Silicon Nitride (Si3N4) the heat distribution contour has been obtained, the maximum temperature of 250 °C has been observed at inner portion of the bearing as shown in table. Following the completion of thermal analysis on ball bearing with deep groove for Titanium alloy and Silicon Nitride (Si3N4) the total thermal flux contour has been obtained, for Titanium alloy the maximum thermal flux is 3.69E+05 watt per meter square, and for Silicon Nitride the maximum thermal flux is 1.99E+06 watt per meter square has been observed. For the similar materials Titanium alloy and Silicon Nitride the directional thermal flux contour has been obtained, the maximal directional thermal flux for Titanium alloy is 1.93E+05 watt per meter square, and for Silicon Nitride the maximal directional thermal flux is 9.30E+05 watt per meter square as shown in table.

Table 3: Comparative results of thermal analysis for different materials

Materials	Temperature distribution [°C]	Total thermal flux [watt per meter square]	Directional thermal flux [watt per meter square]
Silicon Nitride	250	1.99E+06	9.30E+05
Titanium alloy	250	3.69E+05	1.93E+05

Basically this table provides the comparative data of the deep groove ball bearing's directional and total heat flux for Titanium alloy and Silicon Nitride at max. temp. of 250 degree C. For Silicon Nitride the maximum thermal flux is 1.99E+06 watt per meter square, and for Titanium alloy the maximum thermal flux is 3.68E+05 watt per meter square has been observed. For the similar materials Titanium alloy and Silicon Nitride the directional thermal flux contour has been obtained, the maximal directional thermal flux for Silicon Nitride is 9.30E+05 watt per meter square, and for Titanium alloy the maximal directional thermal flux is 1.92E+05 watt per meter square.

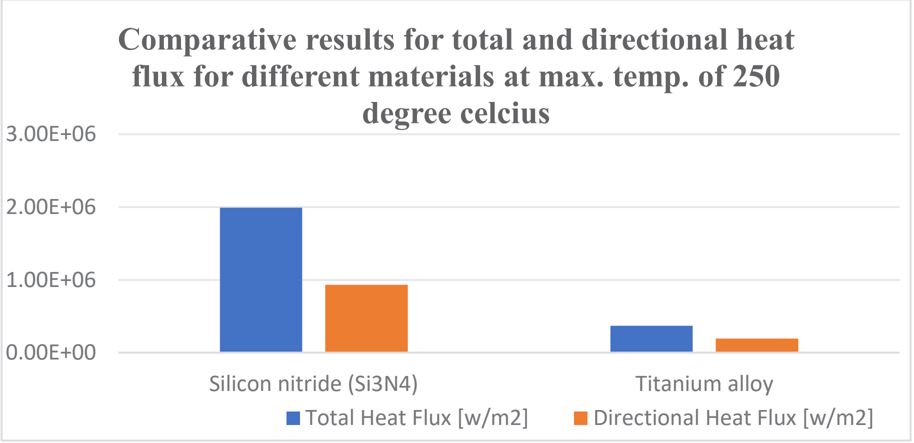

Fig. 4: Comparison of the ball bearing's directional and total heat flux for various materials at max. temp. of 250 °C.

From the result analysis of ball bearing's different materials, it has been observed that the overall thermal flux in deep groove for Silicon Nitride (Si3N4) produces greater outcomes as compared with Titanium alloy shown in figure 4 with the bar graph representation. When the assessment is based on individuals flux performances here also Silicon Nitride performs well. It has been observed that the total thermal flux in Silicon Nitride (Si3N4) is 440.37% more than Titanium alloy and after observing the directional thermal flux in Silicon Nitride and Titanium alloy, the directional thermal flux of Silicon Nitride is 383.75% more than Titanium alloy.

5 Conclusion

This analysis on two different material assist the selection of suitable materials based on the understanding of the thermal behavior and heat flux of Titanium alloy and Silicon Nitride and this improves the bearings efficiency and durability for various purposes. There are following conclusion having been observed from the above analysis.

- After performing thermal analysis on thermal assessment for temperature range of 150 ^{o}C to 250 ^{o}C on ball bearing with deep groove for Silicon Nitride (Si3N4) , the total and directional flux of heat is 1.99E+06 w/m^2 and 9.30E+05 w/m^2 respectively.
- Following the completion of thermal assessment for temperature range of 150 ^{o}C to 250 ^{o}C on ball bearing with deep groove for Titanium alloy, the total and directional flux of heat is 3.68E+05 w/m^2 and 1.92E+05 w/m^2 respectively.
- Following the completion of thermal assessment for temperature range of 150 ^{o}C to 250 ^{o}C on ball bearing with deep groove for Silicon Nitride (Si3N4) , the total and directional flux of heat is 1.99E+06 w/m^2 and 9.30E+05 w/m^2 that is 440.37% and 383.75% respectively more than Titanium alloy.

From the result analysis it has been observed that ball bearing with deep groove has the thermal assessment in for Silicon Nitride (Si3N4) produces greater outcomes as compared with Titanium alloy.

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