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Thermal Analysis of Ceramic Ball Bearing and Conventional Ball Bearing Using Analytical and FEM



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ABSTRACT

The overall objective of this study was to evaluate and compare the thermal analysis and performance of ceramic ball bearing and conventional ball bearing. In this study a thermal analysis was conducted on ceramic ball bearing and conventional ball bearing.

A ball bearing is a type of rolling-element bearing that uses balls to maintain the separation between the moving parts of the bearing. The purpose of a ball bearing is to reduce rotational friction and support radial and axial loads. It achieves this by using at least two races to contain the balls and transmit the loads through the balls. Ball bearings tend to have lower load capacity for their size than other kinds of rolling-element bearings due to the smaller contact area between the balls and races. However, the bearing exhibit heat when they are in contact as they experience friction.

To analyze the heat transfer in a ceramic and conventional ball bearing and to study the heat dissipation by varying materials for bearings, temperature profile, and thermal gradient occurring in a bearing as a function of rotational speed. Thermal Analysis: The Finite Element Method (FEM) and Analytical was used to analyze the heat flow and other parameters in a bearing. Modelling of the system was done using CATIAV5. The analysis was done to study the heat dissipation in the bearing for various materials.

Production of many metals is aided by a production technique also referred to as thermal analysis. In this project thermal analysis between two bearings are carried out and the results are tabulated and compared. This project also helps in learning CATIAV5 and ANSYS software's. Bearing Materials - Ceramics, Chrome Steels &Stainless Steels

1. INTRODUCTION

A ball bearing is a type of rolling element bearing that uses balls to maintain the separation between the bearing races. The purpose of a ball bearing is to reduce rotational friction and support radial and axial loads. It achieves this by using at least two races to contain the balls and transmit the loads through the balls. In most applications, one race is stationary and the other is attached to the rotating assembly (e.g., a hub or shaft). As one of the bearing races rotates it causes the balls to rotate as well. Because the balls are rolling they have a much lower coefficient of friction than if two flat surfaces were sliding against each other. Ball bearings tend to have lower load capacity for their size than other kinds of rolling-element bearings due to the

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smaller contact area between the balls and races. However, they can tolerate some misalignment of the inner and outer races.

1.2 History and development of bearings:

A bearing is a machine element designed to fix, guide or hold moving parts and to reduce friction. Accordingly, bearings permit machine parts to rotate or move in a straight line relative to one another free of the friction created by rotational or linear motion. In most cases, one of the machine parts is fixed and the bearing acts as a support for the moving member. They are used in various applications including airplanes, automobiles, machine tools, precision instruments, household appliances, etc., none of which could operate effectively or efficiently without them. Bearings can be made of ceramic, sapphire or glass.

1.3 Common designs:

There are several common designs of ball bearing, each offering various trade-offs. They can be made from many different materials, including: stainless steel, chrome steel, and ceramic (silicon nitride (Si_3N_4)). A hybrid ball bearing is a bearing with ceramic balls and races of metal.

1.4 Angular contact:

An angular contact ball bearing uses axially asymmetric races. An axial load passes in a straight line through the bearing, whereas a radial load takes an oblique path that tends to want to separate the races axially. So the angle of contact on the inner race is the same as that on the outer race.

Angular contact bearings better support "combined loads" (loading in both the radial and axial directions) and the contact angle of the bearing should be matched to the relative proportions of each.

2. TYPES OF BEARINGS:

- BALL BEARINGS
- ROLLER BEARINGS
- THRUST BEARINGS

2.1 Materials and Methods:

Based on the literature review, the design and process parameters were selected. The steady state thermal solution was obtained. The static structural solutions were obtained. Figure 1 shows the flow chart for thermal and structural solutions.

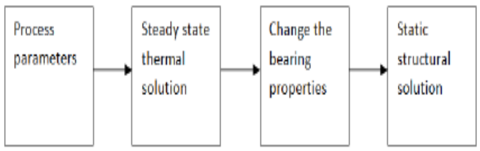

Figure 2.1 shows the flow chart for thermal and structural solutions.

3. Selection of the Bearing:

- A specific condition of the ball bearing was taken and the design calculation was done. The ball bearing was selected accordingly. A simply supported shaft, diameter 20mm, with a load of 10kN in the middle with the axial load of 3kN was taken. The speed of the shaft was taken as 440rpm. Bearing was selected for 1000 hours of rotation. The radial and axial load factor selection are given in Table .1

Table 1. Radial and axial load factor selection

$\frac{Pa}{Co}$	e	$\frac{Pa}{Pr} \leq e$		$\frac{Pa}{Pr} \geq e$	
		X	Y	X	Y
0.021	0.21	1.0	0.0	0.56	2.15
0.110	0.30	1.0	0.0	0.56	1.45
0.560	0.44	1.0	0.0	0.56	1.00

- r = 5 kN
- Pa = 3 kN
- Life of the Bearing in millions of revolution.
- $L10 = \dfrac{60 \times 1440 \times 1000}{10^6}$
  = 86.4
- Equivalent load on the bearing is given by,
- Pe = X. Pr + Y. Pa
- The X value and Y value were determined from the chart. The factor, Co was obtained

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from the bearing catalogue. Co =5 kN;
referring the bearing catalogue at d = 20mm

$$\frac{Pa}{Co} = \frac{3}{5} = 0.6$$

- From the above table e = 0.45 by interpolation.

$$\frac{Pa}{Pr} = \frac{3}{5} = 0.6 < e$$

- From the above table X = 1 and Y = 0
- Equivalent radial load, Pe = X. Pr + Y. Pa

$$P_e = (1 \times 0.1 \times 5) + (0 \times 3)$$

$$P_e = 0.5 \text{ kN}$$

Basic dynamic load rating, $C = P_e (L10)^{\frac{1}{3}}$

$$C = 0.5\,(86.4)^{\frac{1}{3}} = 11.05 \text{ kN}$$

3.1. Heat Generation in the Bearing:

The major source of heat generation is the machining process and the friction between the balls and the races. The major portion of the heat is taken away by the coolant and the chips. In ball bearings heat is generated by three sources. First is the load related heat generation, second source is the viscous shear of lubricants between the solid bodies, known as viscous heat dissipation. The third source of heat is known as spin related heat generation. Considering this, analytical formulation for heat generation in a bearing was developed. The heat generated in a bearing is given as

Hf= 1x10-4 . n. M

where, Hfis the heat generation due to friction in Watts, n is the rotational speed (rpm), M is the total frictional torque (N mm). Rotational speeds of 50,100 ,150,200,250,300,350,400,450,500,550 were taken and the total frictional torque as 100 N-mm. The internal heat generation can be calculated by using the formula, Internal Heat Generation = Hf/ V. The volume of the Ball bearing was calculated as 56.54 mm3. The values were tabulated and the internal heat generation was calculated. The internal heat generation for different speeds is shown

Table 2. Internal Heat Generation for different speeds

Speed (rpm)	Heat Generation (W)	Volume of bearing (mm^3)	Internal Heat Generation (W/mm^3)
50	0.5253	56.54	0.009258932
100	1.047	56.54	0.018517863
150	1.5705	56.54	0.027776795
200	2.094	56.54	0.037035727
250	2.6175	56.54	0.046294659
300	3.141	56.54	0.05555359
350	3.6645	56.54	0.064812522
400	4.188	56.54	0.074071454
450	4.7115	56.54	0.083330386
500	5.235	56.54	0.092589317
550	5.7585	56.54	0.101848249

3,2. Modelling in CATIA V5:

- The bearing consists of ceramic balls of mass 0.067kg. The outer and inner diameter are D = 42 mm, d = 20 mm respectively, B = 12mm, ao = 150 and Z = 9 balls. The bearing operates under dynamic load rating of C = 9.95kN and static load rating of C0 = 5 kN and at a rotational speed of 50-**550rpm.**

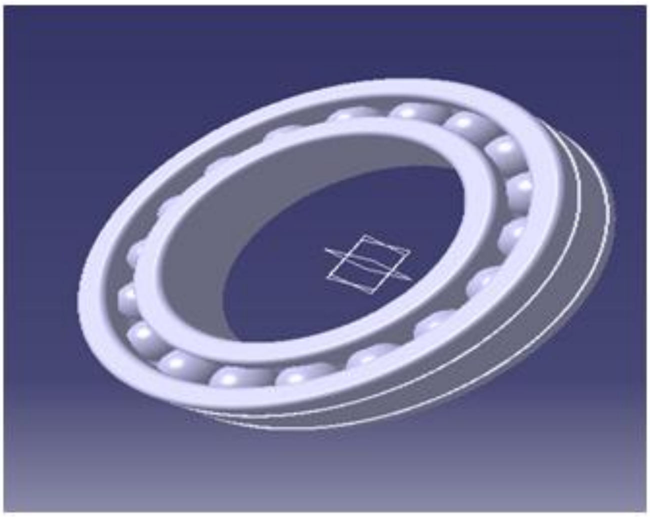

Fig 3.1. PARTS OF BEARING

3.3 MATERIAL PROPERTIES OF CERAMIC($A1_2 0_3$):

- The properties of ceramic are given as follows.
- density = 3200 kgm-3
- coefficient of thermal expansion = 2.9E-06 C-1 ,

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- Thermal Conductive = 36 (W/mK) at 20° C
- Young's modulus = 320E9 Pa,
- Poisson's ratio = 0.27

3.4. MATERIAL PROPERTIES OF CHROME STEELS:

- The properties of CHROME STEELS are given as follows.
- density = 8,050 kg/m^3
- coefficient of thermal expansion = 9.6 x 10^{-6} m/m-deg C
- Thermal Conductive = 61 (W/mK) at 20° C
- Young's modulus = 180 GPa
- Poisson's ratio = 0.27-0.30

3.5. MATERIAL PROPERTIES OF STAINLESS STEELS:

- The properties of STAINLESS STEELS are given as follows.
- density = 7.85 g/ cm³
- coefficient of thermal expansion = 13.0 x 10^{-6} m/m-deg C
- Thermal Conductive = 16.63 (W/mK) at 20° C
- Young's modulus = 200 GPa
- Poisson's ratio = 0.30–0.31

4. Ansys Results:

Model imported into Ansys:

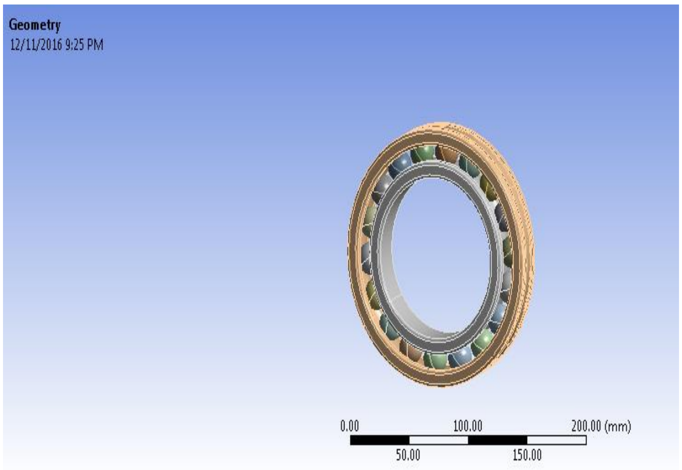

Fig 4.1. Model is imported into Ansys in the format of *.Stp

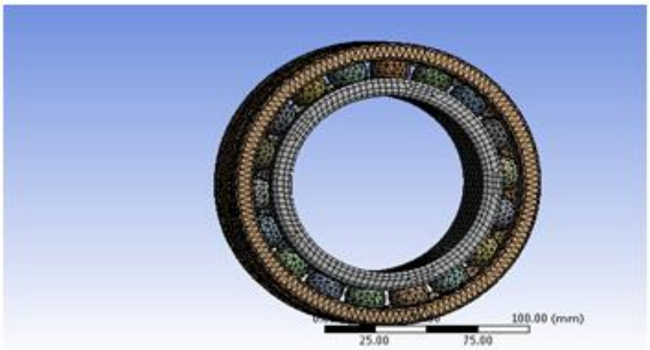

Fig 4.2 Solid Mesh model

CASE 1:

Using Material as CERAMIC($A1_20_3$) and speed range of 50, 250 & 550 RPM. Thermal Analysis is carried out on ball bearing:

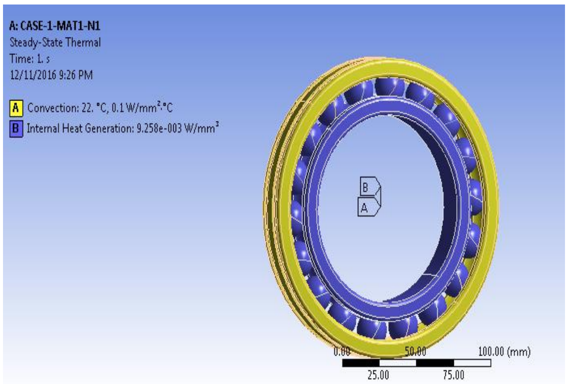

Fig 4.3 Input load Heat Generation and Convection load shown

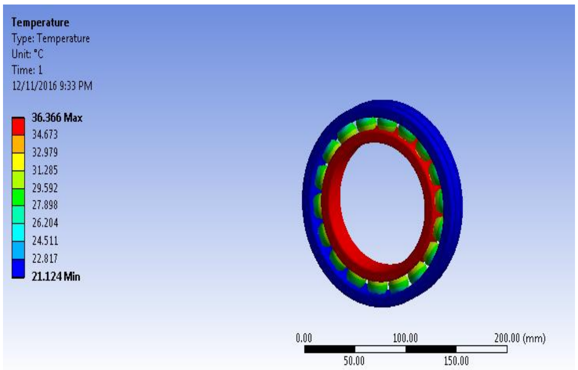

Fig 4.4 Tempture distrubition of ball bearing for speed of 50 RPM

Tempture distrubition of ball bearing for speed of 50 RPM and Heat Gearation of 0.00925 **W/mm^3**
21.12 to 36.36 ^{0} C

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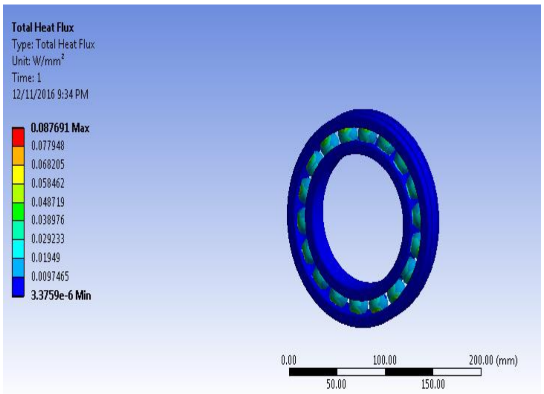

Fig 4.5 Heat Flux distribution of ball bearing for speed of 50 RPM

Heat Flux distrubition of ball bearing for speed of 50 RPM and Heat Gearation of 0.00925 **W/mm³ is in range of 3.37 E-6 to 0.0876 W/mm²**

CASE-1.2: Speed with 150 RPM and Heat generation with 0.0277**W/mm³**

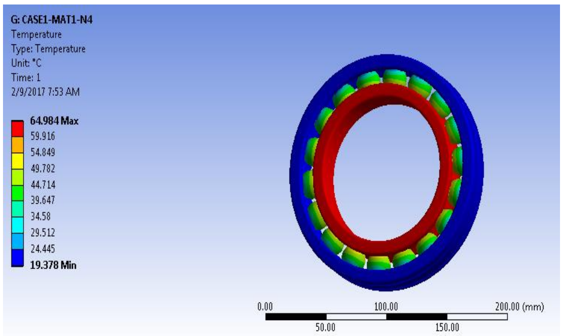

Fig 4.6 Temputure distribution of ball bearing for speed of 250 RPM

Temputure distrubition of ball bearing for speed of 250 RPM and Heat Gearation of 0.0277**W/mm³19.37 to 64.98 ⁰ C**

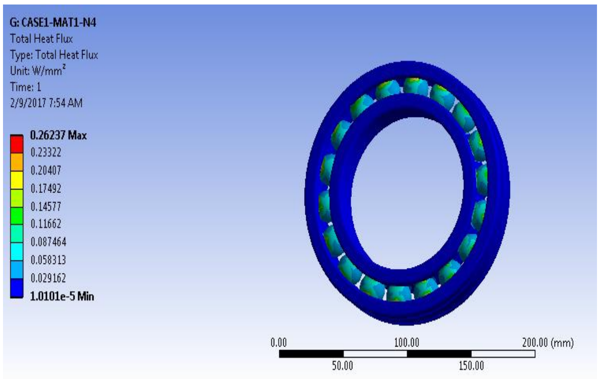

Fig 4.7 Heat Flux distribution of ball bearing for speed of 150 RPM

Heat Flux distrubition of ball bearing for speed of 150 RPM and Heat Gearation of 0.0277**W/mm³ is in range of 1.01 E-5 to 0.2623 W/mm²**

CASE-1.3: Speed with 250 RPM and Heat generation with 0.04629**W/mm³**

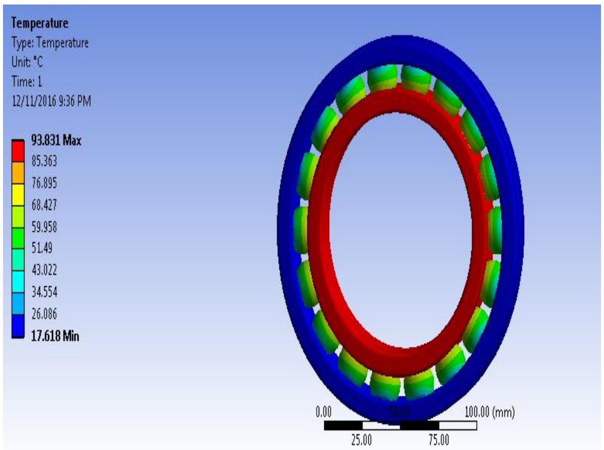

Fig 4.8 Temputure distribution of ball bearing for speed of 250 RPM

Temputure distrubition of ball bearing for speed of 250 RPM and Heat Gearation of 0.04629**W/mm³17.61 to 93.831 ⁰ C**

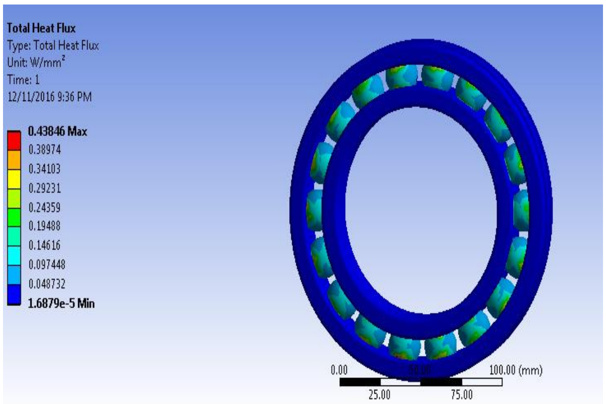

Fig 4.9 Heat Flux distribution of ball bearing for speed of 250 RPM

Heat Flux distrubition of ball bearing for speed of 250 RPM and Heat Gearation of 0.04629 **W/mm³ is in range of 1.68 E-6 to 0.4384 W/mm²**

CASE-1.4: Speed with 350 RPM and Heat generation with 0.0648**W/mm³**

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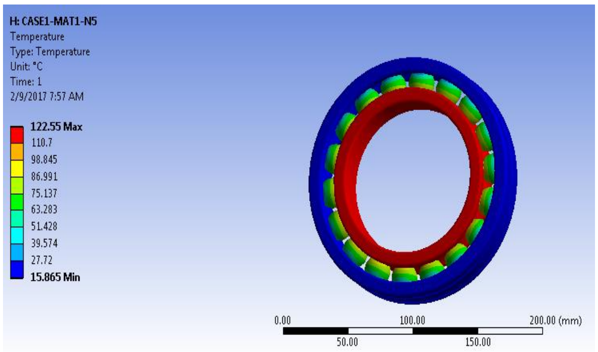

Fig 4.10 Temputure distrubition of ball bearing for speed of 350 RPM

Temputure distrubition of ball bearing for speed of 350 RPM and Heat Gearation of 0.0648**W/mm^{3}15.865 to 122.55 ^{0} C**

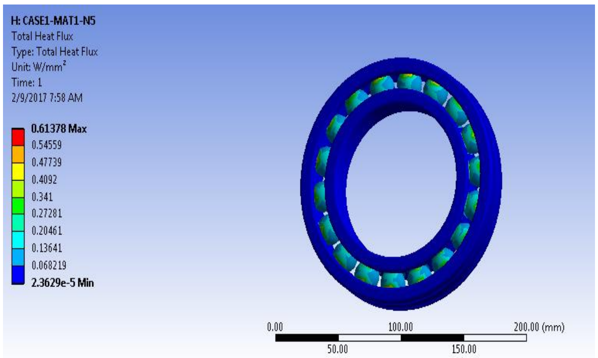

Fig 4.11 Heat Flux distrubition of ball bearing for speed of 350 RPM

Heat Flux distrubition of ball bearing for speed of 350 RPM and Heat Gearation of 0.0648**W/mm^3 is in range of 2.36E-5 to 0 0.6137 W/mm^2**

CASE1. 5: Speed with 550 RPM and Heat generation with 0.10184**W/mm^3**

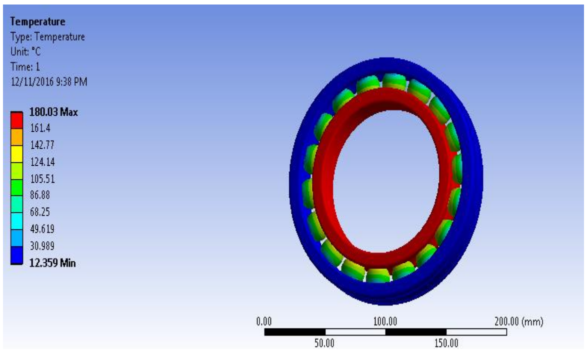

Fig 4.12 Temputure distrubition of ball bearing for speed of 550 RPM

Temputure distrubition of ball bearing for speed of 550 RPM and Heat Gearation of 0.10184**W/mm^3**
12.35 to 180.03 ^{0} C

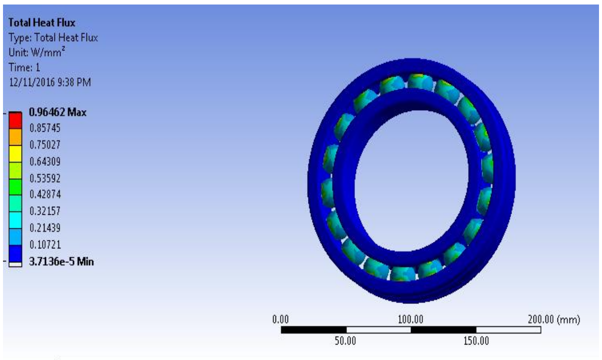

Fig 4.13 Heat Flux distrubition of ball bearing for speed of 550 RPM

Heat Flux distrubition of ball bearing for speed of 550 RPM and Heat Gearation of 0.10184 **W/mm^3 is in range of 3.71 E-6 to 0.9646 W/mm^2**

Table 4.1 : Result table for max Temp and max Heat flux

S.NO.	MATERIALS	MAX TEMP (oC)	MAX HEAT FLUX (W/MM2)
1	A1203 N1	36.366	0.0876
2	A1203 N2	64.984	0.2623
3	A1203 N3	93.831	0.4384
4	A1203 N4	122.55	0.6137
5	A1203 N5	180.03	0.9646
6	CR ST N1	30.604	0.0871
7	CR ST N2	47.743	0.2607
8	CR ST N3	65.02	0.4356
9	CR ST N4	82.22	0.6098
10	CR ST N5	116.65	0.9584
11	SS N1	36.366	0.0876
12	SS N2	47.949	0.2607
13	SS N3	65.364	0.4356
14	SS N4	82.704	0.6099
15	SS N5	117.4	0.9583

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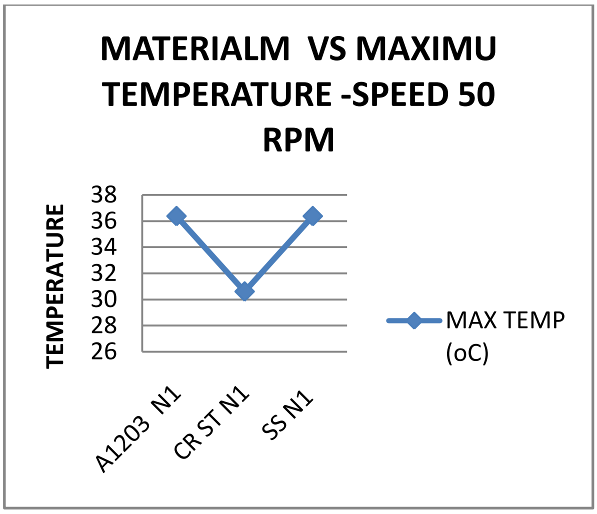

are plotted Fig: 4.1 At speed 50 rpm material VS Temperature

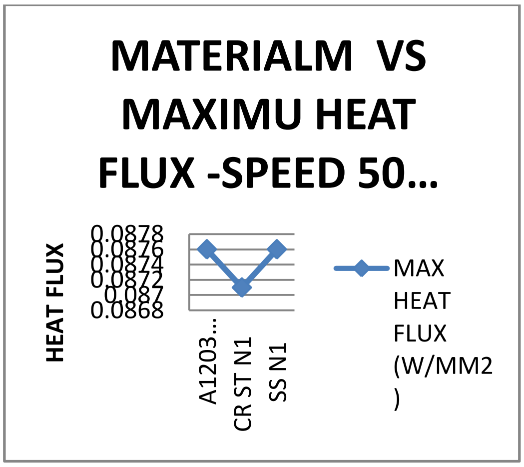

Fig: 4.2 At speed 50 rpm material VS Heat flux are plotted

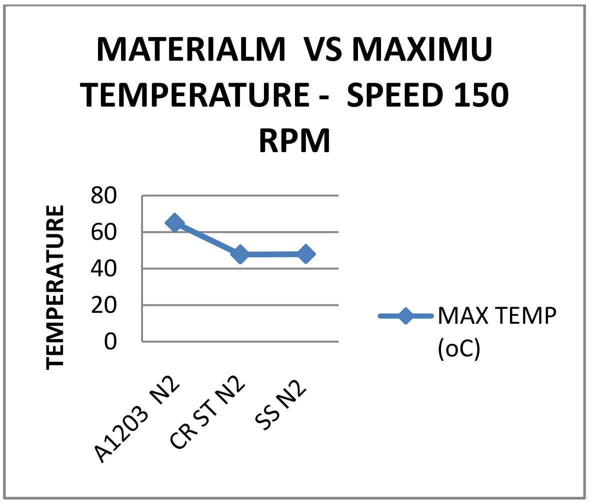

Fig: 4.3 At speed 150 rpm material VS Temperature are plotted

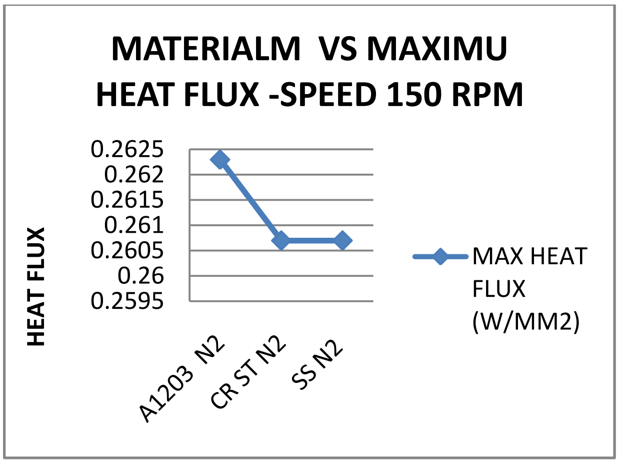

Fig: 4.4 At speed 150 rpm material VS Heat flux are plotted

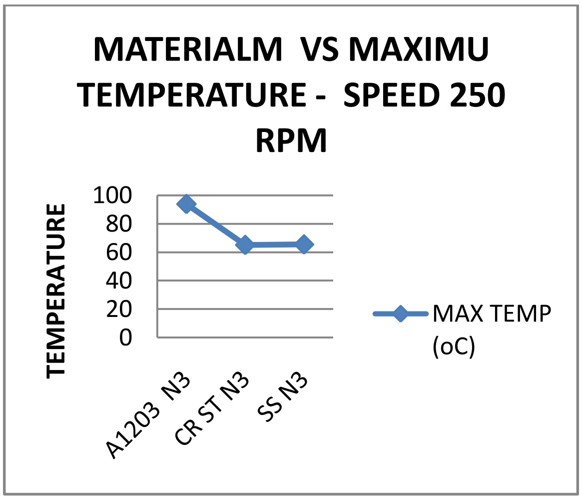

Fig: 4.5 At speed 250 rpm material VS Temperature are plotted

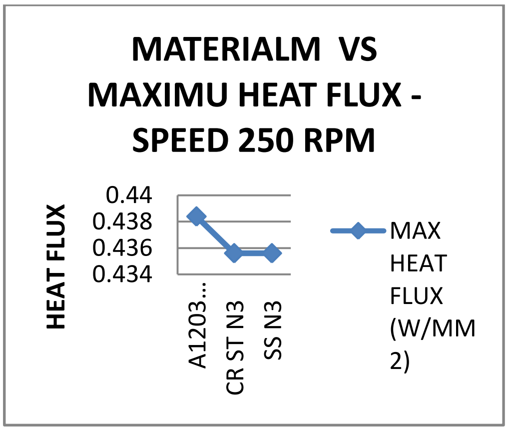

Fig: 4.6 At speed 250 rpm material VS Heat flux are plotted

Fig: 4.7 At speed 350 rpm material VS Temperature are plotted

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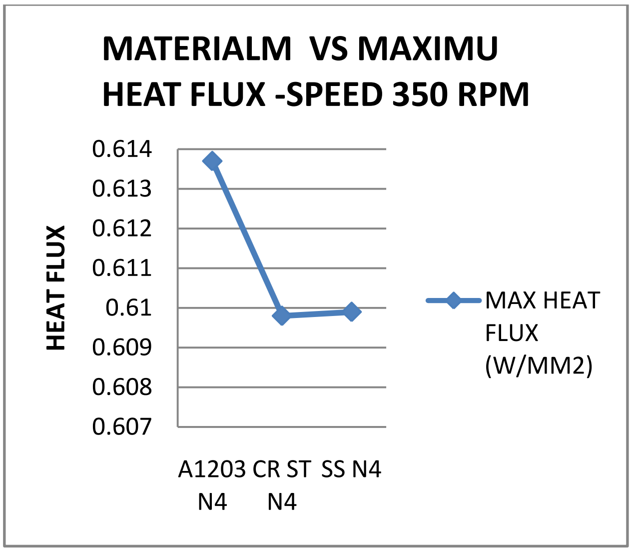
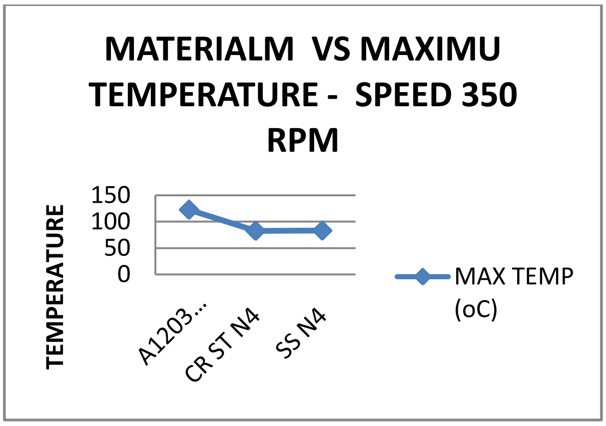


Fig: 4.8 At speed 350 rpm material VS Heat flux are plotted



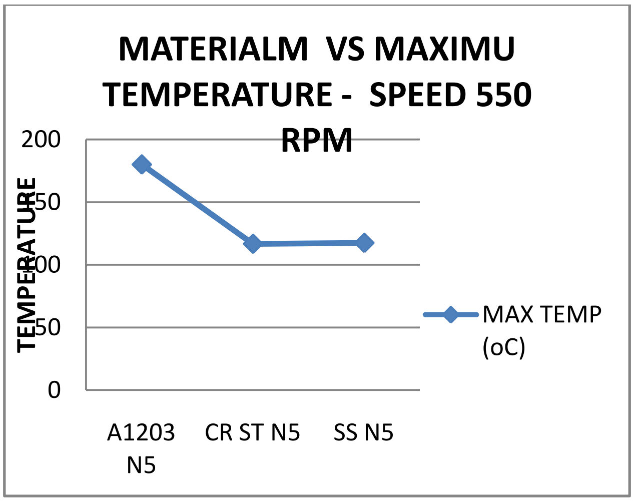


Fig: 4.9 t speed 550 rpm material VS Temperature are plotted

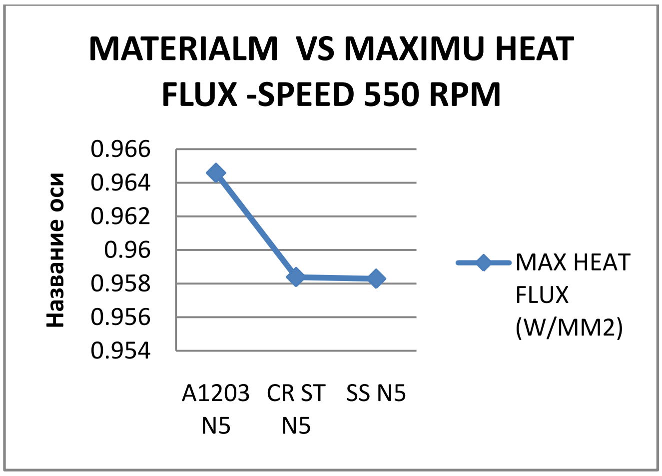


Fig: 4.10 At speed 550 rpm material VS Heat flux are plotted

CONCLUSION:

The heat generation rate & temperature profile of the bearing were measured. The simulation was performed, and the temperature increases with heat generation. The effects of temperature for different bearing speeds are analyzed and the rotational speeds have major effect on the temperature which tends to increase with the increase of speeds. By varying various materials like Al2O3, Cr steel, Steel are calculated .From the results table best suit material order are Al2O3, Cr Steel , SS and. Stage speeds of 50,150, 250, 350 & 550 RPM are studied and heat generation is calculated accordingly.

The flash temperature and friction heat of the hybrid and steel bearings were theoretically analyzed. The hybrid ceramic bearings produce less heat and lower temperatures for high-speed conditions.

A thermal model is developed to study the heat generation rate, temperature distribution, deformation and thermal stress occurred in the bearing system at various stages with rotational speed as parameter and preload load applied to a feed system .

Based on the characteristics of dynamic behavior of the bearing system, the thermal stress simulation is conducted, and it is observed from the simulation that the temperature in the bearing increases with increase

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in heat generation developed by bearing and also it is found that bearing inner ring temperature is higher than the outer ring temperature due to centrifugal forces that make inner ring contact forces and their corresponding heat generation rate higher than those of the outer ring. Further the increase of rotation speed the inner ring centrifugal displacement value increases greatly, this increase in inner ring centrifugal displacement causes larger contact deformation and stress. Furthermore, the effect of the inner ring centrifugal displacement is larger on inner raceway than on outer raceway.

The temperature distribution model is a wide covering one because it includes the thermal transfer between ball and races and also the heat generated both by the viscous friction in lubricant film and the boundary fiction on the asperity contact.

By result table, temperature and heat flux distribution plot . Cr Steel is best result found for various speed of bearing. By using this as per speed of bearings, we can use bearing with combination of speed vs material.

REFERENCE:

1. Anbazhagan AMS, AnandMD. Design and crack analysis of pressure vessel saddles using finite element method. In- dianJournalofScienceandTechnology.2016Jun;9(21):1– 12.
2. Krishnamani S, MohanrajT. Thermal analysis of ceramic coated aluminum alloy piston using finite element meth- od. Indian Journal of Science and Technology. 2016 Jun; 9(22):1–5.
3. AlfaresMA,Abdallah,ElsharkawyA.Effectsofaxial pre- loading of angular contact ball bearings on the dynamics of a grinding machine spindle system. Journal ofMaterials ProcessingTechnology.2003;136:48–59.
4. JedrzejewskiJ,KwasnyW.Modelingofangularcontactball bearings and axial displacements for high-speed spindles. ManufacturingTechnology.2010;59:377–82.
5. Bao-min W, Xue-Song M, Chi-bing H. Effect of inner ring centrifugal displacement on the dynamic characteristics of high-speed angular contact ball bearing. International Conference on Mechatronics and Automation;2010.
6. GaoJ, Zhang R. Contact simulation of thrust ball bearing basedonANSYS.AdvancedMaterialsResearch.2010;154– 155:1629–33.
7. Jin C, Wu B, HuY. Heat generation modelling of ball bear- ing based on internal load distribution. TribologyInterna- tional.2011.
8. Guo B, Han YQ, Lei WJ. Finite element analysis ofhybrid ceramic ball bearing contact. Key Kngineering Materials. 2011; 474-476:2064-70.
9. Wang C, YulW, Ren C. An accurate method for calculat- ingthecontactsubsurfacestressfieldofhybridceramicball bearing.SolidStatePhenomena.2011;175:215–18
10. Yu DM, ShangbCP, Wang D, Gao ZH. Bearing loadsstudy forhigh-speedmotorizedspindle.KeyEngineeringMateri- als. 2011;480–481:1511–15.

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