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# Analytical Assessment of Iron Aluminide Alloys as Bearing Material for Rotor Dynamics

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***Abstract*— The deep groove ball bearing 3D model is developed and finite element analysis is carried out for the analysis about the effect of material properties to the different parameters such as natural frequency, stress and deformation. The stress parameters at the contact surfaces of ball bearing are considered and the evaluation of its strength is done. Relying on the analytical analysis natural frequency, equivalent stress, bearing deformation, contact frictional stress and contact pressure of different types of materials which are generally used in manufacturing of bearings are compared with the iron aluminide alloy. The conventional bearing materials like stainless steel, beryllium copper and chromium steel are considered for the analysis and their performance is compared. An angular velocity of 1000 RPM is applied to the inner race by keeping the outer race fixed. The natural frequencies at which all models of deep groove ball bearing deform are analyzed. The stress parameters at the same environmental conditions of all materials are compared and analyzed for a non-defective and defective deep groove ball bearing. The simulation results assess that the computational values were consistent. They all showed that model and above boundary conditions were correct and it will provide a scientific basis for design of bearing under complicated loads. For the present analysis the standard designed bearing 6210 is modeled and analyzed using ANSYS15 software. The result from the analysis suggests that iron aluminide alloy is a competitive and better bearing material over conventional bearing materials.**

***Keywords*— *Ball Bearings; Equivalent Stress; Contact stress; Contact pressure, Iron Aluminide alloy, ANSYS***

## INTRODUCTION

A very important component in mechanical transmissions is Ball bearing. It is used as supports for the rotating parts by depending on the rotator and the rolling contact with the internal and the external races. Through this; the transmission between force and motion can be realized [4]. The performance of the Ball Bearing is directly related to reliability of any mechanical system and it is also an easily failed part of the system. A statistical data says that nearly 30% of the mechanical faults occur due to the failure of ball bearings. Hence the ball bearing strength, contact stress and deformation have been the major issue of the engineering application studies. The major difficulty in studying the ball bearings is the contact between the ball, inner and outer races of ball bearing. The point contact which is seen in no load condition will change to an elliptical contact surface after loading. Shape, size, contact stress and the friction coefficient of the contact zone which are non-linear contact problems are not known and they are related to the size of the applied load condition [1].

The paper takes deep groove ball bearing as an example, and builds finite element three dimensional model by using Finite Element Analysis software ANSYS15 Workbench. Basing on the natural frequencies analyzed from modal analysis further structural analysis to analyze the parameters like equivalent stress, bearing deformation, contact frictional stress and contact pressure of different types of materials which are used in manufacturing of bearings.

The main objective of the work is to design a module of deep groove ball bearing via optimization of material properties to have high natural frequency and least stress parameters of module considering an angular velocity of 1000 RPM.

## I. IRON ALUMINIDE

*About Iron Aluminide*

First, Iron alloyed with aluminum forms ordered phases based on body-centered cubic derivative super lattices over a wide range of aluminum content (23-50 percent).These iron aluminides exhibit a positive temperature dependence of yield stress over the aluminum concentration range, irrespective of the ordering state. This is very attractive for high-temperature structural application.[5]

FeAl based materials are good candidates for use in medium to high temperature applications because of their excellent resistance to oxidation and sulfidation, good mechanical properties, low density, low cost and availability of raw materials. There is a large scope for research in producing massive parts of ultra-fine grained FeAl alloys.[6]

Intermetallic alloys based on FeAl are of interest as possible replacements for various stainless steels and heat-resistant Fe-Cr-Ni alloys because they have outstanding oxidation/corrosion resistance at high temperatures.[8] The powder-processed FeAl alloy Fe38Al. extruded at 950 or 1000ºC had excellent tensile strength and ductility, and high levels of energy absorption in impact tests.[10]



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## II. MODELLING OF BALL BEARING

### A. *Geometry of deep groove ball bearing*

The 3D finite element model of the 6210 type of the deep groove ball bearings is modeled [2]. In order to reduce the computational time, a modal analysis followed by a simple static analysis for bearing is carried out.

To ensure that all possible contact regions have sufficient mesh density suitable meshing is done. The geometrical parameters of deep groove ball bearing are listed in Table1.

TABLE I. GEOMETRICAL PARAMETERS OF BALL BEARING

| PARAMETER | DIMENSIONAL VALUE | UNITS |
|---|---|---|
| Ball diameter(D) | 12.7 | mm |
| Bore diameter(d) | 50 | mm |
| Inner raceway diameter(di) | 57.21 | mm |
| Outer raceway diameter(do) | 82.79 | mm |
| Outside diameter(da) | 90 | mm |
| Width(b) | 20 | mm |
| No. of balls | 9 | |

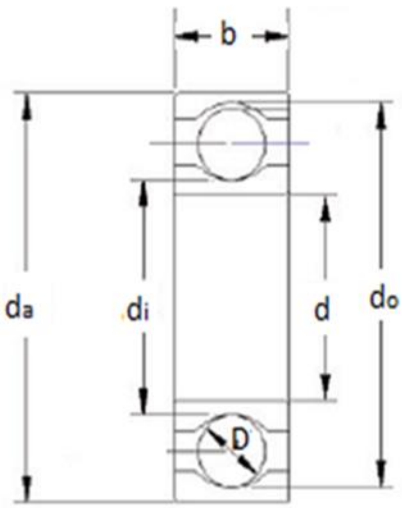


Fig.1.Geometry of ball bearing[3]

The geometry of deep groove ball bearings is modeled and different materials that are conventionally used are considered for the analysis along with Iron Aluminide alloy. The materials and their properties are listed in Table2.

TABLE II. TYPES MATERIALS AND THEIR PROPERTIES

| MATERIAL PROPETY | STAINLE-SS STEEL | BERYLLIU-M COPPER | CHROMI-UM STEEL | IRON ALUMINIDE [7] |
|---|---|---|---|---|
| Young's modulus (MPa) | 193000 | 131000 | 203300 | 244000 |
| Density (kg/m3) | 7750 | 8774 | 7800 | 6100 |
| Poission's ratio | 0.31 | 0.285 | 0.3 | 0.3 |

### B. *Modeling*

The finite element mechanics models of rolling element bearings include important design details such as accurate roller and race crownings, internal radial and axial clearances, contact angle, roller length, bearing width, length and diameter of raceway for ball bearings, and so on. They are, however, not included in many theoretical bearing models.[9] Many types of 3-D modelling software are available; each one having their strengths and weaknesses. In this work the solid modeling was done using Ansys Design Modeler tool. Ansys well known as analysis software can also be used for modelling mechanical components competitively [3]. By modelling in Ansys gives excellent 3-D model comparatively and importing errors are reduced. Though Ansys design modeler is competitive and better in certain limitations. The 6210 designed ball bearing is modelled for different situations such as no-defect, defect in inner race and defect in outer race.

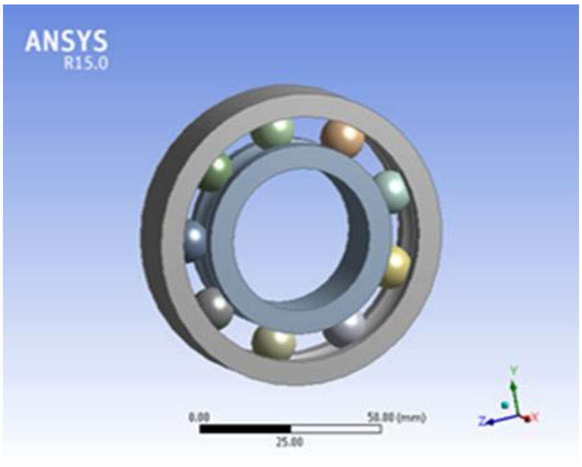


Fig .2.Geometry of ball bearing without defect

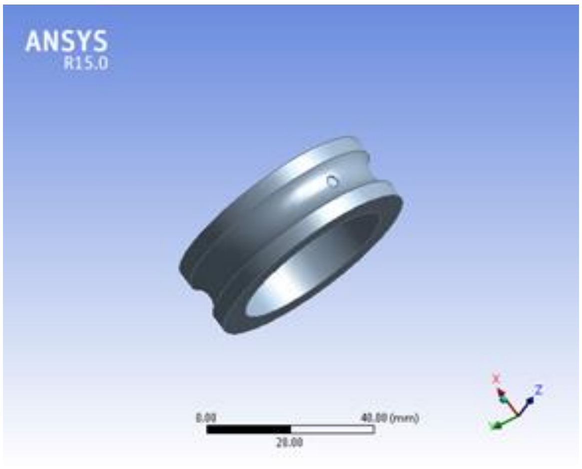


Fig .3.Inner race with defect


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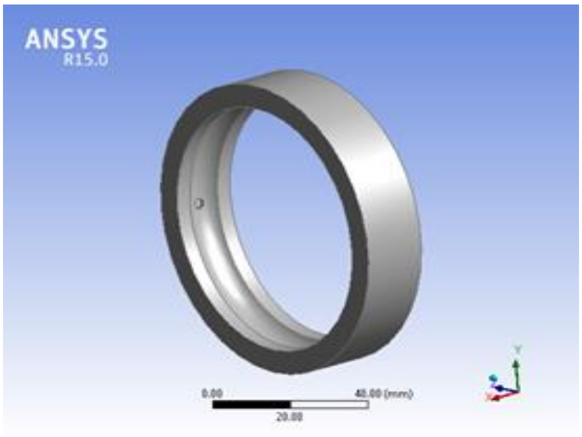


Fig .4.Outer race with defect

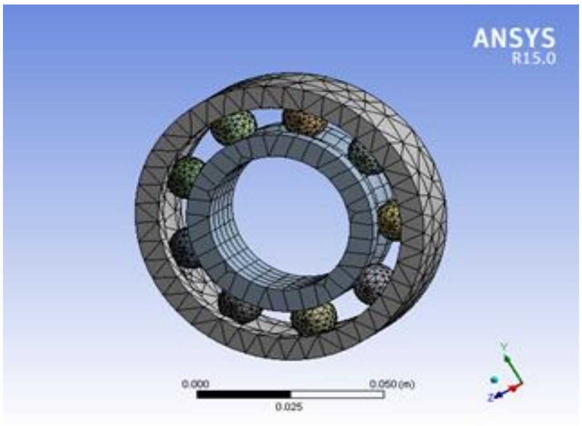


Fig .5.Meshed model

## III. ANALYSIS

Basic theme of Finite Element Analysis is to make calculations at only limited (Finite) number of points and then interpolate the results for entire object.

It is a numerical method which uses mathematical representation of actual problem and gives approximate results.ANSYS provides an effective way to explore the performance of products or processes in a virtual environment. With this technique, users can iterate various situations to optimize the product long before the manufacturing is started. This enables a reduction in the level of risk, and in the cost of ineffective designs. The multifaceted nature of ANSYS also provides a means to ensure that users are able to see the effect of a design on the whole behavior of the product, be it electromagnetic, thermal, mechanical etc. ANSYS has the capability to solve complex engineering problems by mathematically simulating the exact behavior of the structures.

Solving a structural problem by FEA involves following steps:

- Define and understand the problem
- Preparation of mathematical models
- Solving the models
- Analysis of Results

## IV. RESULTS AND DISCUSSIONS

The static analysis is performed by imparting an angular velocity ranging from 100 to 1000 rpm to inner race while the outer race is fixed. The maximum equivalent stress, contact frictional stress, contact pressure and bearing deformation of the deep groove ball bearing are analyzed. The contact parameters are analyzed by setting a frictional contact between the balls and the inner and outer races. The coefficient of friction at contact regions is set as 0.2. The analysis is done initially for a non-defective bearing for all the considered materials. Then a circular defect is introduced with help of Boolean operations while modeling in inner race and outer race as well. The effect of material properties is observed to be varying in the solution parameters. For the healthy bearing, the stress values from the analysis resulted that iron aluminide alloy is better than conventional bearing materials such as stainless steel, chromium steel and beryllium copper. Then defective bearing models are analyzed which also suggested that iron aluminide alloy material stress intensity is low comparatively.

### *A. Modal Analysis*

*Mode shapes of iron aluminide alloy bearing geometry*

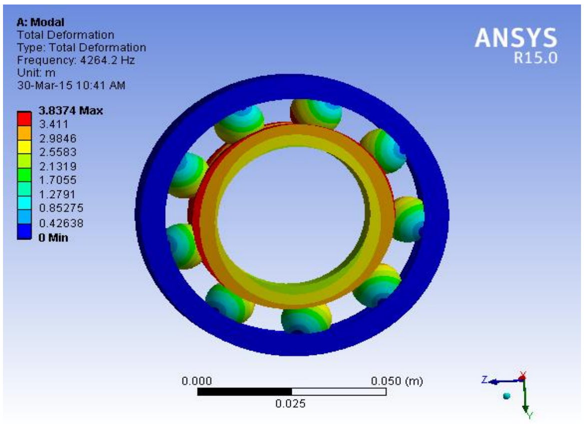


Fig .6.No defect

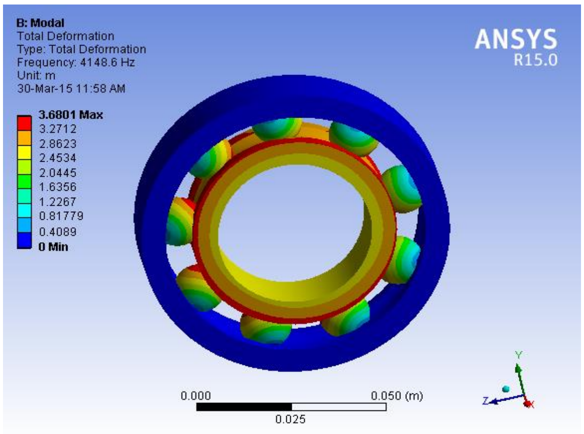


Fig .7.Inner race with defect


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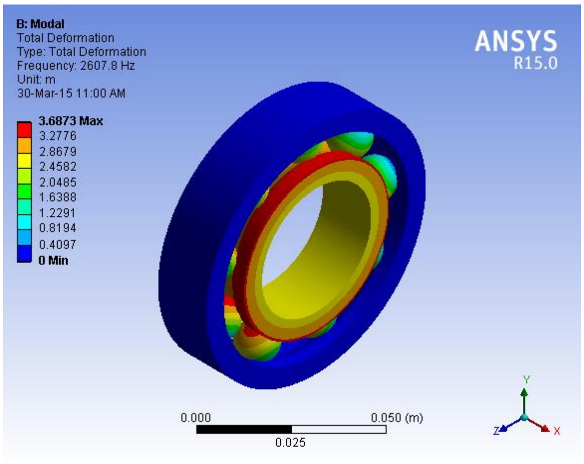


Fig .8.Outer race with defect

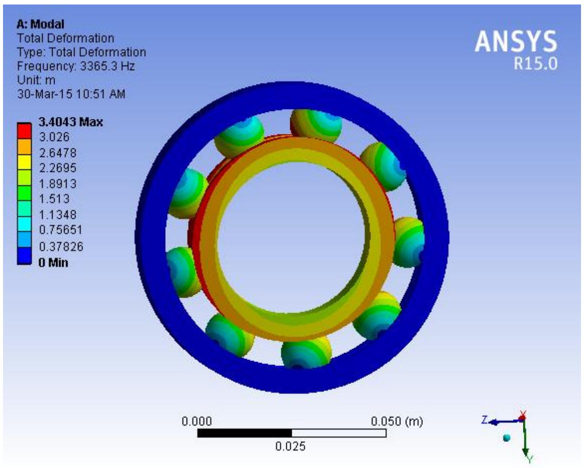


Fig .9.No defect

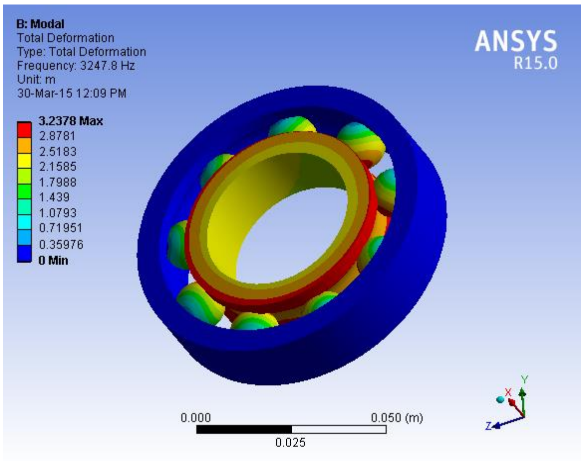


Fig .10. Inner race with defect

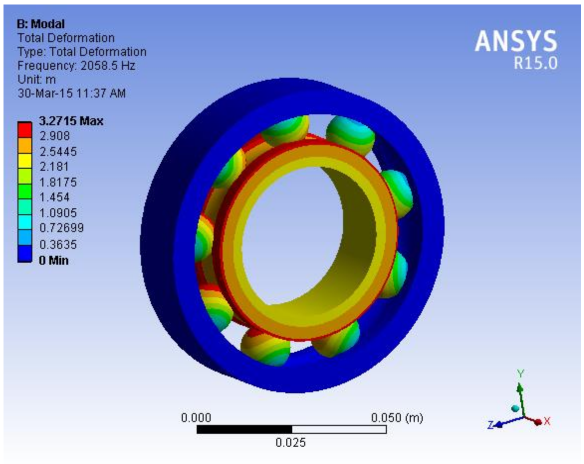


Fig .11.Outer race with defect

TABLE III. RESULTS OF MODAL ANALYSIS.

| Name of Material | Frequency(Hz) | | |
|---|---|---|---|
| | No defect | Inner race defect | Outer race defect |
| Stainless steel | 3365.3 | 3247.8 | 2058.5 |
| Chromium steel | 3442.1 | 3321.2 | 2105.9 |
| Beryllium copper | 3244.8 | 2556.2 | 1592.4 |
| Iron Aluminide alloy | 4264.2 | 4148.6 | 2607.8 |

## A. *Structural analysis*

*Contours Shapes Of Iron Aluminide Alloy*

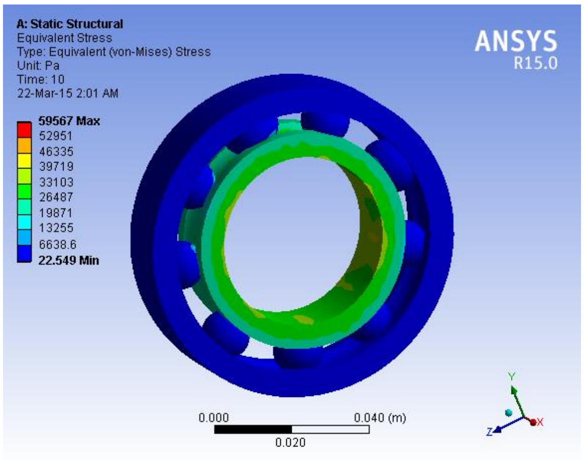


Fig .12. Equivalent Stress


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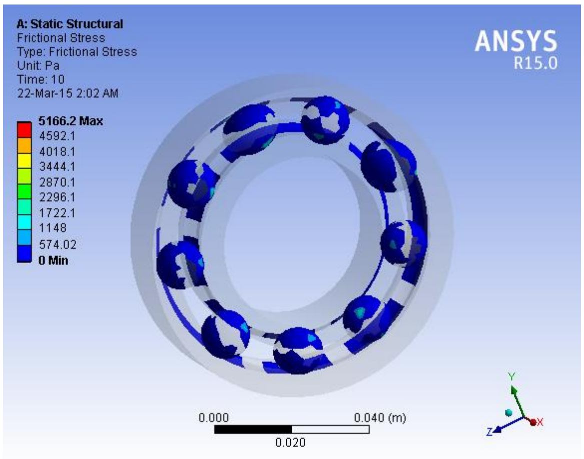


Fig .13.Frictional Stress

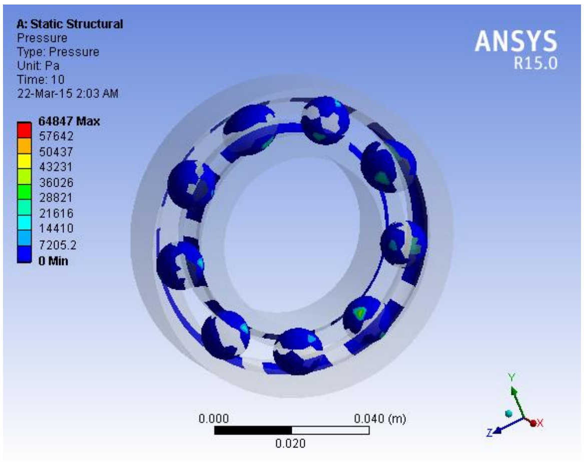


Fig .14.Contact Pressure

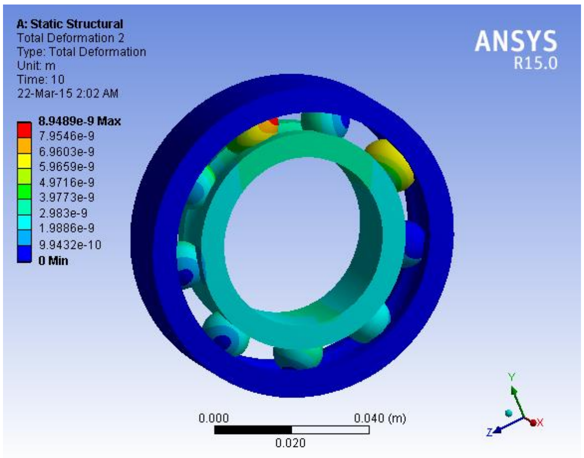


Fig .15.Bearing Deformation

*Contours Shapes of Stainless Steel*

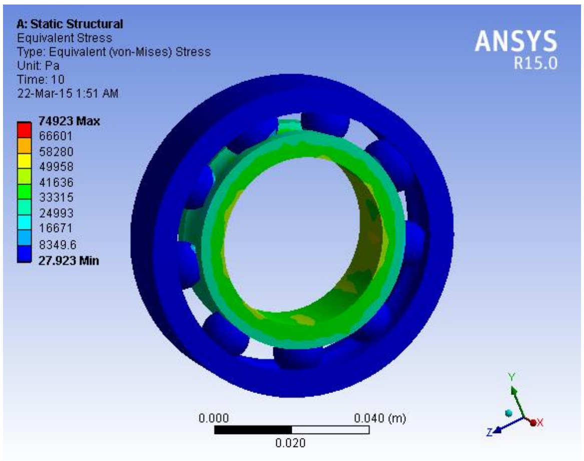


Fig .16.Equivalent Stress

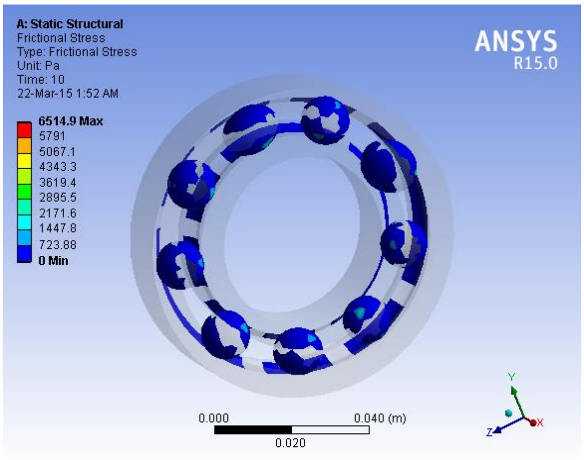


Fig .17.Frictional Stress

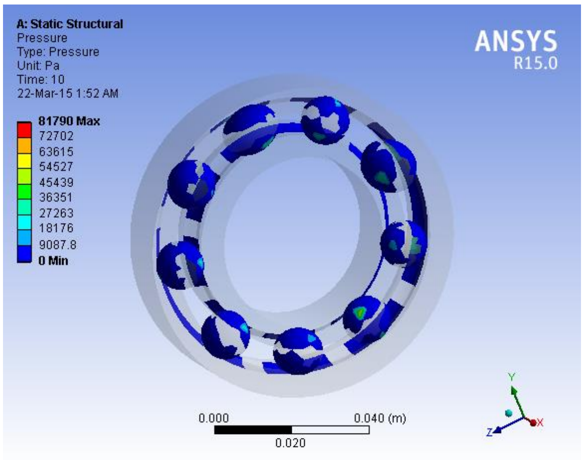


Fig .18. Contact Pressure


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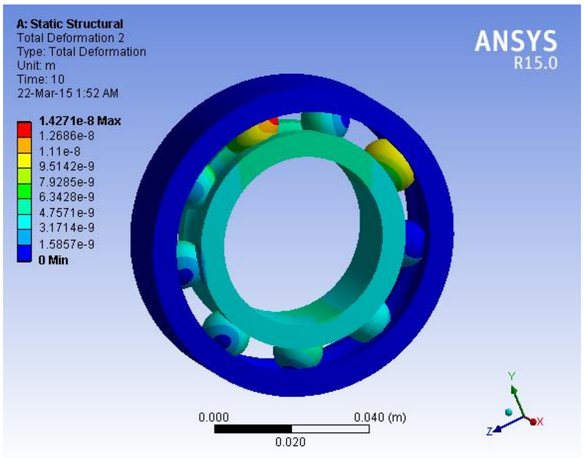


Fig .19.Bearing Deformation

*NO DEFECT*

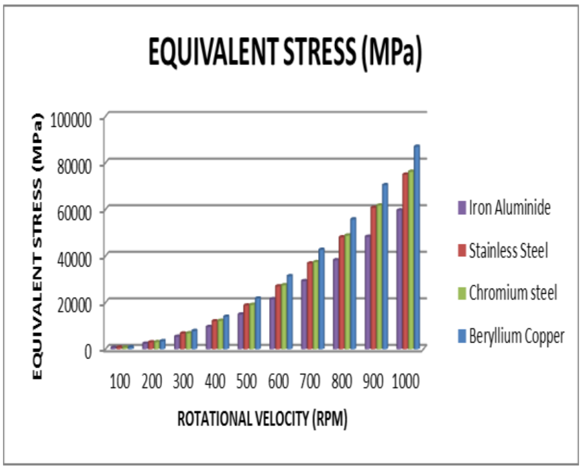


Fig .20.Equivalent Stress

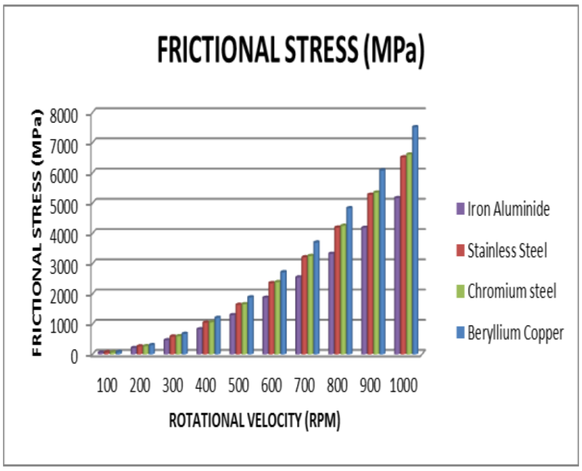


Fig .21.Frictional Stress

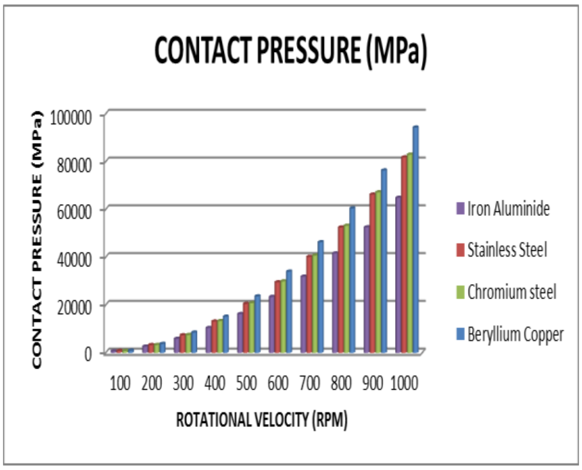


Fig .22.Contact pressure

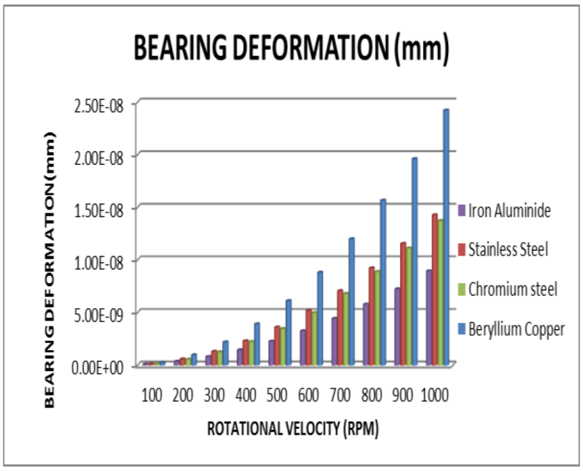


Fig .23.Bearing deformation

*INNER RACE DEFECT*

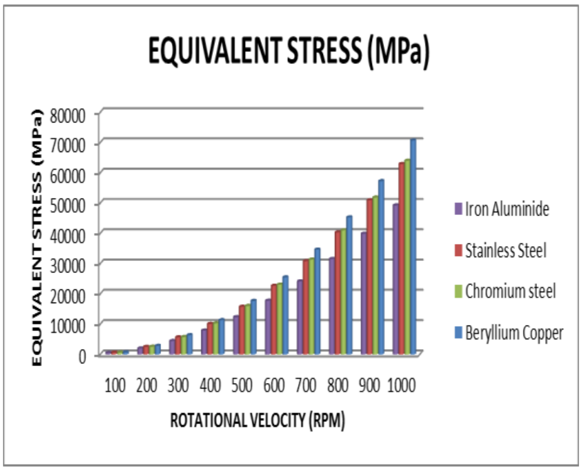


Fig .24.Equivalent stress


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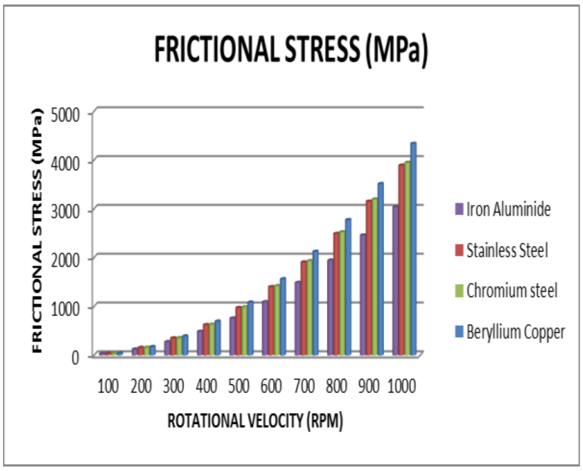


Fig .25.Frictional Stress

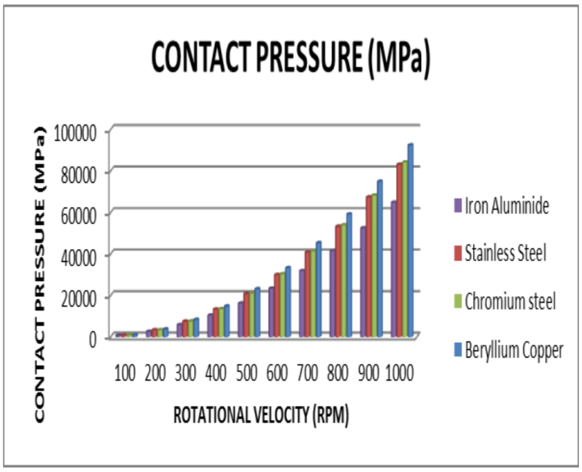


Fig .26.Contact Pressure

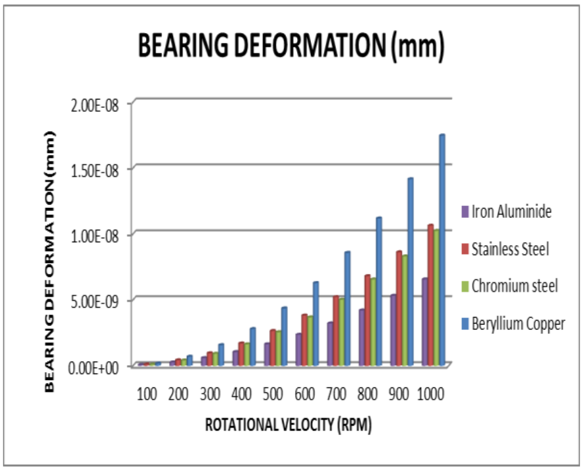


Fig .27.Bearing Deformation

*OUTER RACE DEFECT*

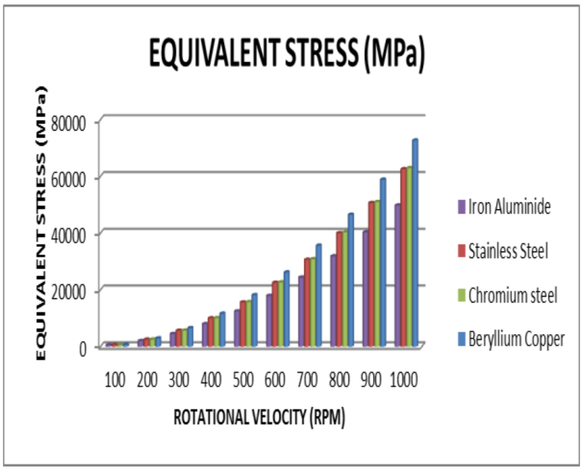


Fig .28.Equivalent stress

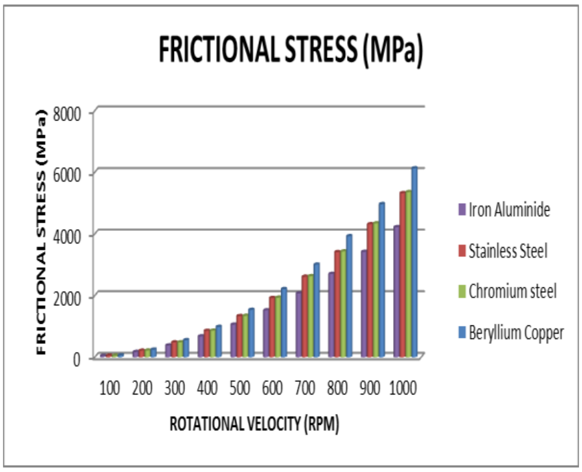


Fig .29. Frictional Stress

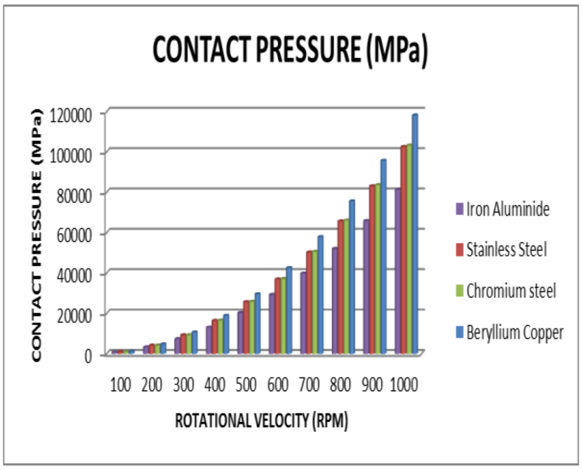


Fig .30.Contact Pressure


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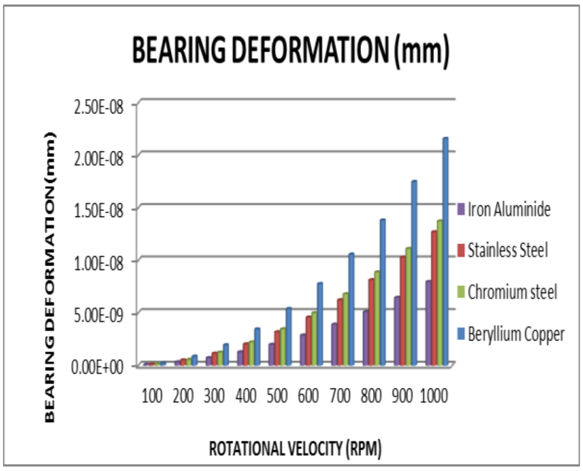


Fig .31.Bearing Deformation

## V. CONCLUSION

From this analysis, it is observed that the equivalent stress, contact frictional stress and contact pressure for different materials are observed to be under safe design limits. As the comparison of the different material results suggest that Iron aluminide alloy is a better material and can be proposed as a competitive bearing material for the Rotor dynamic applications. Also it is observed that the natural frequency is higher for Iron Aluminide material vowing to its higher material stiffness compared to other materials considered for the analysis. The natural frequency of vibration decreases with defects in the bearing inner and outer races.

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