N88-21486

TITANIUM CARBIDE COATINGS FOR AEROSPACE BALL BEARINGS

Hans J. Boving, Werner Haenni, Hans-E. Hintermann*

ABSTRACT

In conventional ball bearings, steel to steel contacts between the balls and the raceways are at the origin of microwelds which lead to material transfer, surface roughening, lubricant breakdown, and finally to a loss in the bearing performances.

To minimize the microwelding tendencies of the contacting partners it is necessary to modify their surface-materials; the solid to solid collisions themselves are difficult to avoid.

The use of titanium carbide-coated steel balls can bring spectacular improvements in the performances and lifetime of both oil-grease lubricated and oil-grease free bearings in a series of severe applications.

INTRODUCTION

In the age of space exploration many different kinds of bearings have been developped such as gas bearings, foil bearings, and magnetic bearings; each of these bearings excels in a specialized field of application. Ball bearings are not quite so limited and are encountered in a wide variety of applications. Recently, improved manufacturing techniques provide rolling bearings with increased accuracy and smoother surfaces; improved bearing-steel making processes provide higher quality steel, and improved fluid and dry lubrication techniques have served to considerably increase the bearing performances in most modern applications. Nevertheless, the useful lifetime of ball bearings remains strongly influenced by the roughness and tribological properties of the balls and races which are in rolling and sliding contact. Indeed, colliding surface peaks lead to cold weldings, material transfer, lubricant breakdown, and therefore to increased torque, noise and vibration levels.

Any surface modification of the contacting components which will result in smoother surfaces and/or in improved tribological properties will mean, for the ball bearing, not only a longer lifetime, but in some cases also increased performances.

This paper is concerned with the surface modification obtained by means of titanium carbide (TiC) coatings on AISI 440C steel balls. To avoid the direct steel to steel contact, it is in principle enough that the surface of

---

* Swiss Center for Electronics and Microtechnology, Inc., Neuchâtel, Switzerland

one of the two contacting components is modified: the balls or the races.

In order to provide the reader an overall view of bearing technology, which will provide him a better understanding of this paper, a series of mechanical, tribological and materials aspects are briefly described (ref. 1). Next, the deterioration of ball bearings for material-related reasons, and what can be done to avoid this type of deterioration, will be considered; e.g. surface modification by means of a TiC-deposit on the steel balls. Finally, the geometrical properties of TiC-coated steel balls will be examined and compared with uncoated steel balls.

The different components used in ball bearings are shown schematically in figure 1. Only the components taking an active part in the bearing operation are considered in this paper; these are the rings, the balls and the cage or ball retainer. In a ball bearing the following sliding and/or rolling contacts can take place: balls to races, balls to cage and cage to rings.

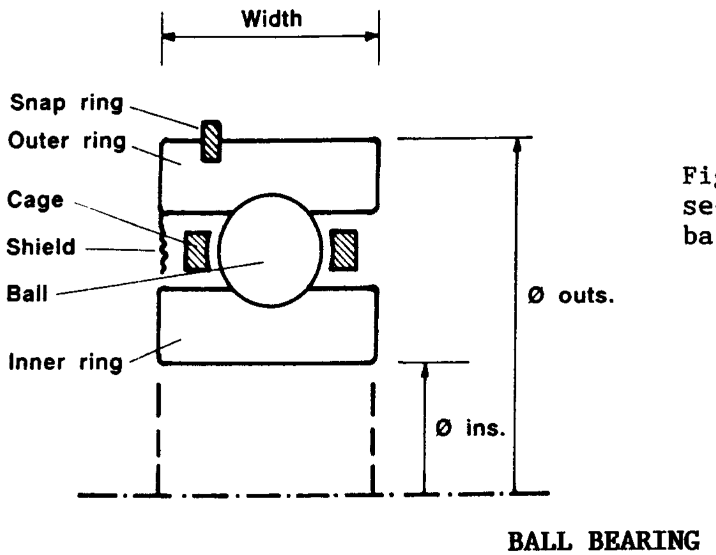

Figure 1. Schematic view of a section through a conventional ball bearing.

To assure a successful bearing application it is necessary to consider in detail aspects of different nature.

Mechanical Aspects

The mechanical design engineers are concerned with the bearing dimensions (Ø outs., Ø ins., width: figure 1) because of optimum interface conditions with the corresponding mechanism. From tables provided by the bearing producers, they can read the static and dynamic load bearing capacities, which have to be compatible with the actual preloads and the loads seen in duty. Operating temperatures have to be examined carefully to evaluate their influence on the bearing loads through differential thermal expansions and gradients. In addition they will have to check if the bearing stiffness and elasticity correspond to what is required by the precision level of the mechanism.

Tribological Aspects

It is a well known fact that there is a rolling and sliding contact between the balls and the races. Although the rolling to sliding proportions are variable and influenced by the bearing geometry and load, it must be stated that the tribological properties of these components are important. Therefore for each specific bearing application, the design engineer has to make a decision as to what lubricant type is to be used (solid or fluid); this decision is influenced by the expected lubricant lifetime, by the static and dynamic torque values, and by the wear rates of the bearing components.

Materials Aspects

Conventional bearings are most often made of steel (balls and rings). Over 90% of the bearings produced are of 52100 steel; the remaining are made of special purpose steels such as T15 high speed steel or AISI 440C stainless steel. For most aerospace applications the stainless steel is used. The cage material can be metallic or organic depending on the bearing application and the lubricant type. The radial and axial loads seen by the bearings are transmitted by the actual ball to race contacts. Figure 2 shows a schematic view of a ball to race contact in the case of a conventional, lubricated bearing.

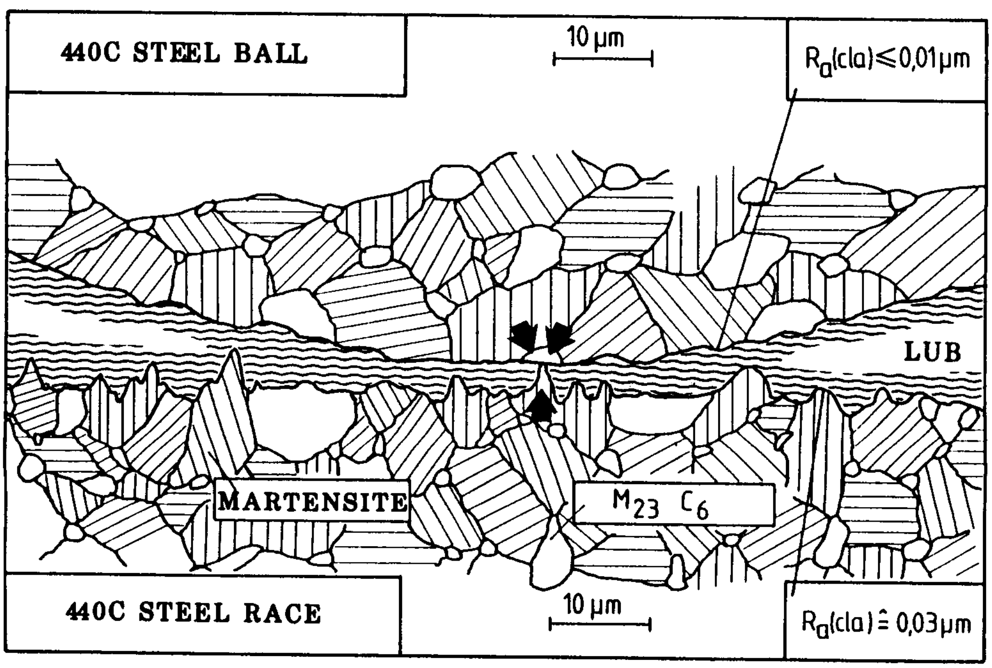

Figure 2. Typical presentation of a lubricated ball to race contact. The steel microstructure is on scale; the surface roughness and curvature scales are arbitrary. The race is approx. 3 times rougher than the ball. Despite the lubricant film, metal-to-metal contacts (microwelds) occur.

The purpose of the lubricant (solid or fluid) is to separate the contacting components and to ease their respective movement. Unfortunately peak to peak collisions do occur due to surface irregularities, to insufficient lubricant film thickness, to lubricant breakdown or to exaggerated momentary or continuous bearing loads. Whatever the reason of such peak to peak collisions, as shown in figure 2, their results are usually similar: microwelding between the steel ball and steel race surfaces. Due to the uninterrupted movement of the bearing the microweld has a very short lifetime and upon rupture there will be material transfer accompanied by a surface roughening. At the rupture site a hot spot is created which in its turn can cause damage to the lubricant by molecule cracking (ref. 2). The deterioration rate of the ball bearing is therefore strongly influenced by the frequency and intensities of the microwelds.

A good understanding of the exact reasons of bearing deterioration is of course very helpful when the useful lifetime has to be extended. It is difficult to completely avoid peak to peak collisions between the contacting surfaces. To minimize the microweld tendencies, one has therefore to work with the material choice. In other words the surface-materials have to be modified.

Modified Contacting Surfaces

The surface modification can basically be achieved in 2 different ways:

a) by using bulk materials of different nature. If the balls and/or races are made of ceramic materials like Si_3N_4 or SiC, their contacts will not lead to cold weldings as with steel to steel. The elastic properties of the ceramic materials are very different from those of steel; therefore the geometry of ceramic bearing components has to be adapted accordingly. Several authors have published papers on ceramic bearings and their performances (ref. 3,4).

b) by applying appropriate coatings on the surface of the contacting steel components. This solution has the advantage that the basic elastic properties of the steel bearing are not modified since the steel is still determining the load bearing capacity of the bearing; the geometry of the different components does not have to be modified.
Dictated by the application, the engineer has a choice of organic and inorganic coatings, which are available on an industrial or development basis. Examples of coatings are: PTFE, Pb, Ag, TiC, BN, MoS_2, WSe_2, etc...

Figure 3 shows schematically a ball to race contact, when a TiC-coated ball is used. The race roughness is unchanged; TiC-coated balls, on the contrary, can be polished to an exceptionally smooth surface which is estimated at about 5 times better than the race surface. When peak to peak collisions do occur, there is no microwelding since TiC and steel have an insignificant welding tendency.

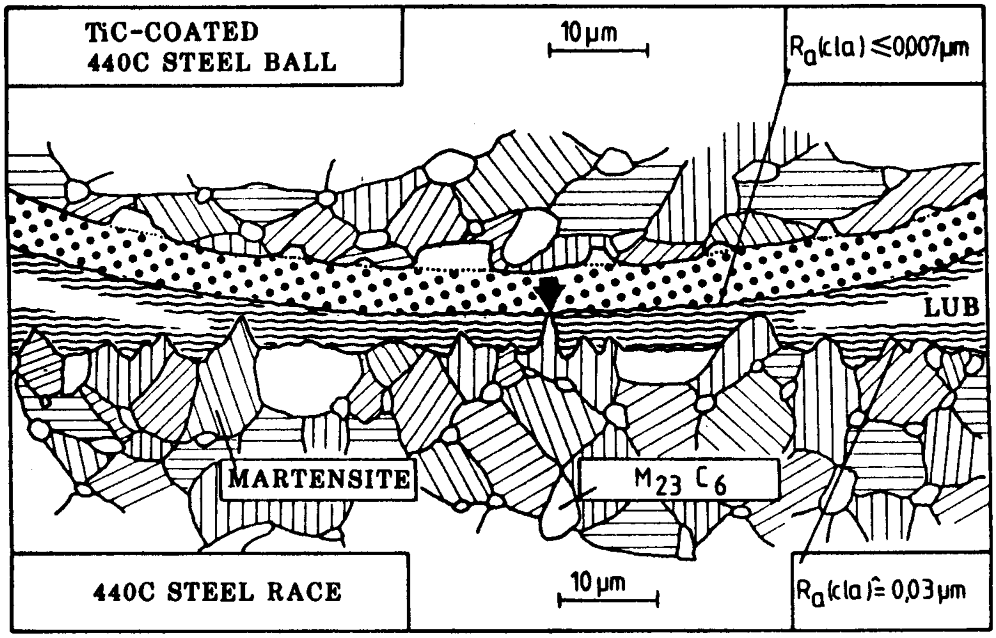

Figure 3: Typical presentation of a lubricated TiC-coated ball to race contact. The steel microstructure and the coating thickness are on scale; the surface roughness and curvature scales are arbitrary. The race is approx. 5 times rougher than the ball. Despite the lubricant film, solid-solid contacts (no microwelds!) occur.

TiC-COATED BALLS

The TiC-coated 440C steel balls are of precision GRADE 3 (according to AFBMA*), which is the highest precision grade used to specify metallic balls for ball bearings. GRADE 3 precision specifications concern the characteristics of both individual balls and ball lots. At this point the main interest lies with the degree of precision which is reached with the individual balls. It has indeed been observed that balls coming from one polishing lot are perfectly identical; no physico-mechanical instrument would be able to find noteworthy differences between two balls of one polishing lot.

Ten TiC-coated balls (3/32" diam.) are hereafter compared with 2 lots of ten uncoated GRADE 3 440C steel balls coming from 2 different producers; it will be seen that even within GRADE 3, important differences in quality exist between TiC-coated and uncoated balls.

---

* Anti-Friction Bearing Manufactures Association, Inc., Arlington, Va

Ball diameter and sphericity

The instrumentation which is currently used for the measurement of the ball diameter and sphericity allows verification that the balls of the 3 examined series indeed satisfy the GRADE 3 specifications. It is, however, difficult to observe notable differences between the coated and uncoated ball series. Therefore, these two aspects are not pursued any further.

Ball surface roughness

The surface roughness of the races and the balls has a strong influence on the useful lifetime of the ball bearing. Therefore, this geometrical characteristic will be given more attention.

The AFBMA standards specify the roughness of the balls; the roughness of the races, however, is not specified. In high precision bearings the race roughness is seldom below R_a = 0.025 μm (or cla = 1 millionth of one inch), which corresponds to the roughness allowed for GRADE 10 balls. Figure 4 shows the results of the R_a (cla) surface roughness measurements performed on 10 balls from each of the 3 series; the extreme and the average values are shown on the graph. It can be seen that although all 3 sets of data correspond to GRADE 3 precision, the TiC-coated balls have a much smoother surface and, in addition, their roughness values present a definitely smaller dispersion.

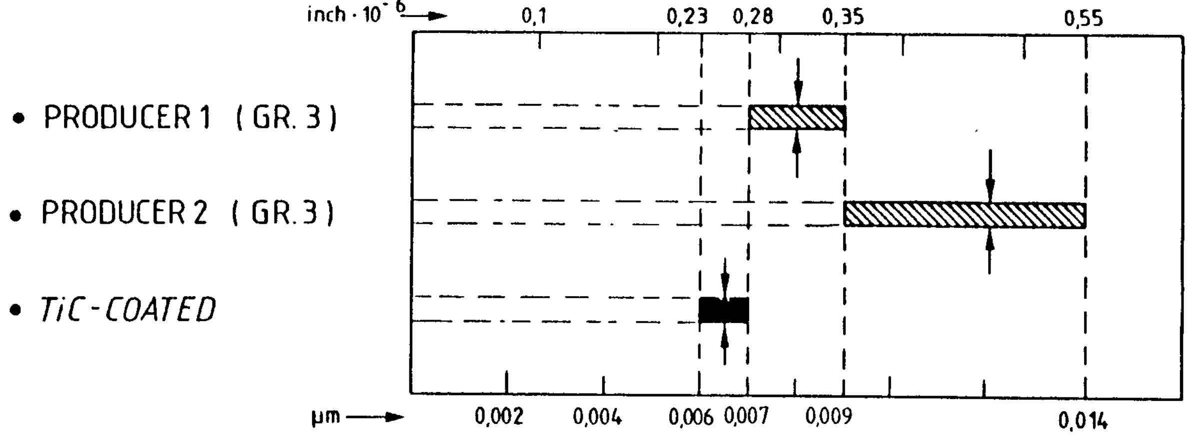

Figure 4: Comparison of the surface roughnesses (arithmetical average: R_a in μm or cla in millionth of an inch) of 3 series of ten 440C steel balls each - diameter 2.381 mm (3/32") - precision GRADE 3 (AFBMA); producer 1 and 2 correspond to uncoated balls. The arrows indicate for each series the average of the measurements on 10 different balls (the maximum allowable surface roughness corresponding to GRADE 3 is Ra = 0.014 μm).

APPLICATIONS

Due to the space environment and to contamination problems, it is often impossible to use conventional oil/grease-lubrication in ball bearings onboard spacecraft. In these and other bearing applications under hostile environments, the use of TiC-coated balls can assure the requested bearing lifetime and performance. Space-related examples where TiC-coatings are used have been described in the literature: METEOSAT (ref. 5) and the SPACE TELESCOPE (ref. 6). Briscoe mentions in a review on lubricants for space, that TiC-coatings are frequently used to prevent fretting damage on highly loaded contacts in hold down and release mechanisms and latches on deployables (ref. 7).

It has been shown that especially in permanently oil/grease - lubricated bearings, the use of TiC-coatings increases notably the bearing performances. This is very much the case with bearings for spin axis gyro applications (ref. 8).

CONCLUSIONS

- CVD TiC-coated 440C steel balls can be lapped/polished to extremely high precision (better than GRADE 3 according to AFBMA).
- In oil/grease-lubricated bearings the use of TiC-coated steel balls presents two basic advantages:
  - . the very low surface roughness of the coated balls; this leads to very low bearing vibration and noise levels
  - . the TiC-modified surface avoids microwelds at the metal-to-metal contacts between balls and races; a consequence of this is that the lubricant remains in good condition.
- In oil/grease-free bearings the use of TiC-coated steel balls enables operation in extreme environments such as vacuum, elevated and cryogenic temperatures, etc. As a function of the requested duty cycle, the TiC-coated balls can be used as such or combined with a solid lubricant (e.g. MoS_2).

REFERENCES

1. Harris, T.A.: Rolling Bearing Analysis. John Wiley and Sons, Inc., 1984.

2. Baxter, B.H.: Chemical Processes Occuring in the Regions of Rubbing Contact in S 166 Bearings for Satellite Type Recorder Use, Proc. Int. Ball Bearings Conf., Charles Stark Draper Laboratory, 1973.

3. Hanson, R.A.: The Effect of Advanced Materials Technologies on Wear in Instrument Bearings. Proc. 1987 Ball Bearing Symposium, DoD/Instrument Bearing Working Group, Charles Stark Draper Laboratory, 1987.

4. Hamburg, G., Cowley, P., Valori, R.: Operation of an All-Ceramic Mainshaft Roller Bearing in a J-402 Gas Turbine Engine. Lub. Eng., 37 (7) 1981, 407-15.

5. Jouan, J.: ESA METEOSAT Radiometer Focalising Mechanism. Proc. 11th Aerospace Mechanisms Symp., NASA Conf. Publ. 2038, NASA GSFC, 1977, 13-22.

6. Veit, A., Chandler, D.P.: SPACE TELESCOPE Solar Array Primary Deployment Mechanism. Proc. First European Space Mechanisms and Tribology Symp., ESA SP-196, 1983, 27-34.

7. Briscoe, M.M.: Some Considerations on Lubricants for Use in Spacecraft, Proc. of Int. Symp. on Spacecraft Materials in Space Environments, ESA SP-178, 1982, 27-34.

8. Brown McKee, F.: Gyro Spin Axis Bearing Performance using Titanium Carbide Coated Balls. Proc. 1987 Ball Bearing Symposium, DoD/Instrument Bearing Working Group, Charles Stark Draper Laboratory, 1987