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A REVIEW ON THE MATERIALS USED FOR BEARING AND FAILURE BEHAVIOR

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Abstract

This paper highlights the metallic, polymeric and ceramic materials used to manufacture the bearings, the kind of failures experienced with those materials and their causes. The failure mechanism of bearings and influence of various elements on their properties are reviewed. It is identified from the study that the failure is mainly provoked by initiating the surface micro crack/flake and then subsequently propagating them to failure. Materials influencing wear resistance to control the material removal rate without much compromising the fracture toughness are discussed. The advanced composite materials used in bearings are also discussed. A review on nano composites is also done to turn out the research on bearing materials towards nano composites. The evolution of MMC, nano composites is investigated to come to a conclusion on stimulating a research work to make a better material for bearings at room temperature and cryogenic temperature. A suitable polymer material is suggested for carrying out the research at cryogenic temperature for low temperature application of bearings.

Keywords: Bearing Materials, Failure Causes, Research Exposure

1. INTRODUCTION

Materials are playing a vital role in deciding the behavior of the engineering structures under external stimulations such like loading, temperature and humidity etc. The mechanical, physical and chemical properties of the materials are decided by their microstructures/morphology in concern material. The metallic materials used in engineering applications are being slowly replaced by the composite materials because of the betterment in properties such as the specific strength and modulus. The morphology of the composite material is completely different from the metallic group since the composites exhibit the heterogeneous structure. The matrix/reinforcement interfacial properties of the composites are mainly deciding the damage behavior of the composites. As the composite material processing is difficult, it may give some defects in the interface of the matrix/reinforcement. The interfacial defects lead to the failure mechanisms like debonding, delamination, fiber pull-out etc. The potential of the reinforcement will be explored when the applied load is perfectly transferred from the matrix to reinforcement. The new emerging trend of material field is nano materials based on nano technology. The materials produced with the grain size of nano meter are called nano materials. The nano materials are giving greater properties (physical, chemical and mechanical) than the conventional metallic and composite materials.

The composite materials are classified as Polymer Matrix Composites (PMC), Metal Matrix Composites (MMC) and Ceramic Matrix Composites (CMC) based on the type of matrix material used. The properties of the composite materials can be further enhanced by the addition of nano fillers. The materials formed in such a manner are called nano composites. The nano fillers are nothing but the nano sized particles which are manufactured under complex experimental set up. The usage of the nano sized particles as filler in composite materials gives extraordinary improvement in mechanical properties especially fracture properties. The plastic deformation occurred in the composite materials are greatly improved by the addition of nano fillers. The fracture mechanisms are further getting complicated because of the improved plastic deformation during damage to failure. The nano fillers find its application with PMC, MMC and also CMC in research level. The expensiveness of the nano particles because of complicated processing has its own problem in getting implemented with many engineering applications.

A **bearing** is a machine element that constrains relative motion between moving parts to only the desired motion while reducing friction and handling stress. Resembling wheels, bearings literally enable devices to roll, which reduces the friction between the surface of the bearing and the surface it's rolling over. There are two different kinds of loading: radial and thrust. A radial load, as in a pulley, simply puts weight on the bearing in a manner that causes the bearing to roll or rotate as a result of tension. A thrust load is significantly different, and puts stress on the bearing in an entirely different way. The bearings experienced many types of failure during its service period. The types of failures and causes for those failures have been elaborately studied and analyzed. Mainly the materials used for the bearing until now are gathered with its compositions and properties. A platform to start a research work based on providing better advanced material for bearing to give its better performance under service conditions has been built.

2. BEARING MATERIALS

This part of the paper discuss about the various materials used for bearings along with their composition and properties. The materials reviewed are steels, ceramics and polymers.

2.1. Steels

Steels are generally used as bearing materials due to their versatile nature. The properties and use of different types of steels depend upon their composition and heat treatment processes. Composition plays a vital role in deciding the use of the bearing steels.

For High-Carbon Chrome Bearing Steel, the following materials, ASTM 51100, 52100, A 485-03 (Grade 1, 2, 3) are studied. The carbon content in these materials is similar and ranges from 0.85 to 1.10%. The Silicon content in ASTM 51100, 52100 varies from 0.15 to 0.35%, which is used for small and medium size bearings. The Silicon content in A 485-03 varies from 0.40 to 0.70%, which are used for large size bearings. Silicon is a de-oxidizing agent, which contributes to hardening of the ferritic phase in steels. This is the reason why A 485-03 has more Silicon content. The manganese content in ASTM 51100, 52100 varies from 0.20 to 0.40% and in A 485-03, it varies from 0.90 to 1.2%. Manganese, an austenite forming element is added to steels to increase strength, hardenability and toughness. Hence its composition increases as the bearing size increases. Chromium is added to steels to improve corrosion resistance. It also increases the response to heat treatment, thus improving the hardenability and strength. The percentage of chromium varies from0.90 to 1.6% in ASTM 51100 and 52100. In A 485-03, it varies from 0.9 to 1.6%. Phosphorus and Sulphur are generally added to improve machinability and corrosion resistance. The composition of these is similar in all the steels and is less than 0.025%. Molybdenum content is less than 0.1% in ASTM 51100, 52100, A 485-03 (Grade 1, 2). A 485-03 (Grade 3) is specially used for ultra large size bearings, where the working temperature are usually high due to increased area of contact. So, the molybdenum content is increased to 0.2-0.3%. Molybdenum improves high temperature strength and hardness, and also resists pitting corrosion.

In Carburizing Bearing Steels, the carbon content is comparatively lesser than High-Carbon Chrome Bearing Steel. In case of High-Carbon Chrome Bearing Steel, hardening process is carried out for the entire volume of the material, whereas in Carburizing Bearing Steel, the material is case hardened, mostly by flame hardening method. The generally used Carburizing Bearing Steels are 5120H, 4118H, 8620H, 4320H and 9310H. The Carbon and Silicon content in these steels varies from 0.17 to 0.23% and 0.15 to 0.35% respectively. 5120H, 4118H and 8620H are used for small bearings. These steels contain 0.55-0.95% Manganese, 0.25% Nickel, 0.3-0.7% Chromium, 0.1-0.3% Molybdenum, 0.025% of Phosphorous and 0.015% of Sulphur. 4320H is used for medium size bearings and contain same percentage of Carbon and Silicon. Manganese content varies from 0.4-0.7%. Nickel content is increased to 1.55-2.00% as it is responsible for higher strength and toughness at high temperatures. Molybdenum content varies from 0.2-0.3%. Phosphorous and Sulphur content are same. 9310H is used for large size bearings, where the

Carbon and Silicon content are same. Manganese content varies from 0.4-0.7%. Nickel content is comparatively higher than that of 4320H and it varies from 2.95-3.55% so as to provide higher strength at elevated temperatures. Chromium content is also increased and it varies from 1.00-1.45% as chromium increase the response to heat treatment, thus improving strength and hardenability. Phosphorous and Sulphur contents are same.

Even for bearings with countermeasures against High-Temperature, the upper limit of the operating temperature is maximum of about 400^{o}C because of constraints of lubricant. This kind of bearing may be used in certain cases at around 500 to 600^{o}C if the durable time, running speed and load are restricted. Materials used for high-temperature bearings should be at a level appropriate to the application purpose in terms of hardness, fatigue strength, structural change, and dimensional stability at the operating temperature. In particular, the hardness is important.

Ferrous materials generally selected for high-temperature applications include high speed steel (SKH 4) and AISI M50 of Cr-Mo-V steel. Where heat and corrosion resistances are required, martensitic stainless steel SUS 440C is used. These materials contain considerable amount of Tungsten, Vanadium and Cobalt. Tungsten has low coefficient of thermal expansion and high melting point. Hence it reduces the chance of failure at higher operating temperatures. Vanadium increases strength of the steel. With Vanadium content of 1 to 2%, hardness of about 40 HRC can be obtained. Cobalt increases the resistance to softening at higher temperatures. Their hardness at high temperature is shown in the following figure.

The following graph shows the hardness of different materials at higher temperatures. High speed steel (SKH4) and Cr-Mo-V steel (M50) have shown extraordinary resistance to changes in property even at 600^{o}C where SUS440C has shown this property till 500^{o}C. They are exhibiting great thermal resistance. The constituents of those materials can be further analyzed to form a composite which will withstand and retain its properties at higher temperatures.

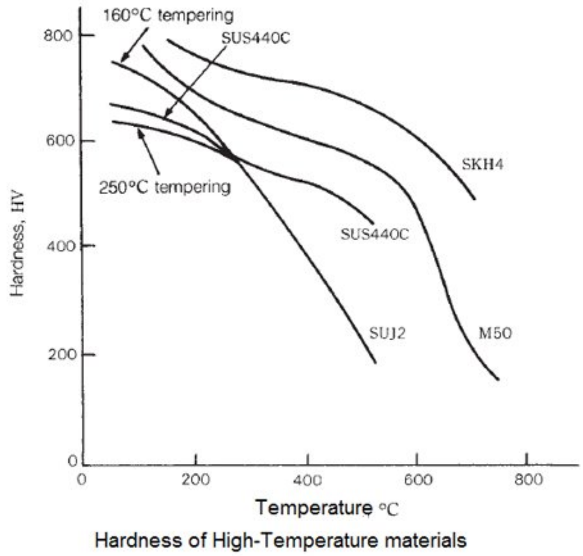

Figure.2.1. Hardness of high temperature resisting material.

The properties and composition of different types of steels used in bearings are provided in the annexure.

2.2 Ceramics

Ceramics are superior to metal materials in corrosion, heat and wear resistance, but are limited in application because they are generally fragile. But engineering ceramics that have overcome this problem of fragility are highlighted as materials to replace metals in various fields. Some of the ceramic materials used in making bearings are Silicon nitride (Si_2N_4), Silicon carbonate (Sic), Alumina (Al_2O_3) and partly stabilized Zirconia (ZrO_2) . In practice, the angular contact ball bearing with silicon nitride balls is applied to the head spindle of machine tools. The heat generation characteristics and machine rigidity allows this material to offer functions which have not been available with other materials

Engineering ceramics are of low density for weight reduction and high- speed rotation, have high hardness and small frictional coefficient and superiority in wear resistance, small coefficient of thermal expansion and satisfactory dimensional stability, superior heat resistance and less strength degradation at high temperatures, excellent corrosion resistance, superior elastic insulation and Non-Magnetic.

Some applications which take advantage of these characteristics include bearings for rotary units to handle molten metals, and non-lubricated bearings in clean environment. It is essential to know various properties of ceramic material to successfully use ceramics as bearing material for matching the operating conditions. Silicon nitride has high strength over a wide temperature range, high fracture strength and hardness. On the other hand, Silicon carbide has low density, high strength, low thermal conductivity and superior chemical inertness. Though suffering from problems of workability and cost, improvement in material design and manufacturing technology will further accelerate application of ceramic bearings in high temperature environments, corrosive and in vacuum environment. The different ceramic bearing materials along with their properties are provided in the annexure.

2.3 Polymers as Bearing Material

Polymer bearings can be made from a variety of materials and material combinations. The materials selected depend on the application. Polymers have significantly different properties than steel. One of the most unique properties is that they are corrosion and chemical resistant.

The polymers used to make bearings have a low coefficient of friction and are highly resistant to wear and fatigue. These self-lubricating bearings can run dry and require no lubrication. However, the loads and maximum speeds that a polymer bearing can accommodate are much lower than for conventional all-steel bearings. The high specific strength – (strength to weight ratio) is a valuable property of polymer bearings, especially in applications where weight is an important design consideration. High dimensional stability throughout the lifespan is achieved by the low creep tendency of the polymers used. Polymers have corrosion resistant, chemical resistant, self-lubricating (no lubricant required) property, are light weight (80% less than steel), low coefficient of friction, are quiet running, have good damping properties, are electrical insulator and have low lifecycle costs

Polymers may be used independently, but they are usually combined with functional fillers to form a composite material. Composites can be customized to have specific properties. In this way composites can be designed to be bearing materials. For example, fillers can be used to improve such properties as low friction, low wear, etc. The different polymer bearing materials along with their properties are given in the annexure.

3. BEARING FAILURES: TYPES AND CAUSES

Generally, a rolling bearing cannot rotate forever. Unless operating conditions are ideal and the fatigue load limit is not reached, sooner or later material fatigue will occur. The period until the first sigh of fatigue appears is a function of the number of revolutions performed by the bearing and the magnitude of the load. Fatigue is the result of shear stresses cyclically appearing immediately below the load carrying surface. After a time these stresses cause cracks which gradually extend upto the surface. As the rolling elements pass over the cracks fragments of material break away and this is known as flaking or spalling.

The flaking progressively increases in extent and eventually makes the bearing unserviceable. The life of bearing is defined as the number of revolutions the bearing can perform before incipient flaking occurs. The types of damage may be classified as primary and secondary damages. The primary damages can be further classified into wear, indentations, smearing, surface distress, corrosion, electric current damage. And the secondary damages are classified as Flaking and cracks.

3.1. PRIMARY DAMAGES

Wear occurs in bearings as a result of the ingress of foreign particles into the bearing or when the lubrication is unsatisfactory. Wear is causes due to different factors such as abrasive particles, inadequate lubrication, and vibration. Wear due to abrasive particles may be due to lack of cleanliness, ineffective seals and the lubricant contaminated by worn particles from cages. It forms small indentations around the raceways and rolling elements. The surfaces will dull and worn. Frequent exposure to vibration while stationary may also cause wear.

Raceways and rolling elements may become dented if the mounting pressure is applied to the wrong ring, so that it passes through the rolling elements, or if the bearing is subjected to abnormal loading while not running. Foreign particles in the bearing also cause indentations. Indentations are formed in the raceways of both rings with equal spacing between the rolling elements.

When two inadequately lubricated surfaces slide against each other under load, material is transferred from one surface to the other. This is known as smearing and the surfaces concerned become scored, with a “torn” appearance. When smearing occurs, the material is generally heated to such temperatures that rehardening takes place. This produces localized stress concentrations that may cause cracking or flaking. The different types of smearing include smearing of roller ends and guide flanges, raceways smearing at intervals corresponding to the roller spacing, smearing of external surfaces and smearing in thrust ball bearings. Smearing of roller ends have scored and discolored ends and flange faces. Raceway smearing forms transverse smear streaks- spaced at intervals equal to the distance between the rollers. Smearing in thrust ball bearings causes diagonal smear streaks in the raceways. Smearing of external surfaces leads to formation of scored and discolored ring bore.

If the lubricant film between raceways and rolling elements become too thin, the peaks of the surface asperities will momentarily come into contact with each other. Small cracks then form in the surfaces and these are known as surface distress. These cracks are different from the fatigue cracks that originate beneath the surface and lead to flaking. The surface distress cracks are microscopically small and increase very gradually to such a size that they interfere with the smooth running of the bearing. These cracks may, however, hasten the formation of sub-surface fatigue cracks and thus shorten the life of the bearing.

Initially the damage is not visible to the naked eye. A more advanced stage is marked by small, shallow craters with crystalline fracture surfaces. This is caused due to inadequate or improper lubrication.

Rust will form if water or corrosive agents reach the inside of the bearing in such quantities that the lubricant cannot provide protection for the steel surfaces. This process will soon lead to deep seated rust. Another type of corrosion is fretting corrosion. Metallic bearings have tendency to fail due to corrosion. The different types of corrosion are Deep seated corrosion and Fretting corrosion. Presence of water moisture or corrosive substances in the bearing over a long period of time causes Deep seated corrosion whereas fretting corrosion occurs due to lose fitting of shafts, housing etc.

When an electric current passes through a bearing, i.e. proceeds from one ring to the other via the rolling elements, damage will occur. At the contact surfaces the process is similar to electric arc welding. The material is heated to temperatures ranging from tempering to melting levels. This leads to the appearance of discolored areas, varying in size, where the materials has been tempered, re-hardened or melted. Small craters also form where the metal has melted. The passage of electric current frequently leads to the formation of fluting in bearing raceways. Rollers are also subject to fluting, while there is only dark discoloration of balls. The main causes are passage of electric current through rotating and non-rotating bearing.

3.2 SECONDARY DAMAGE

Flaking occurs as a result of normal fatigue, i.e. the bearing has reached the end of its normal life span. However, this is not the commonest cause of bearing failure. The flaking detected in bearings can generally be attributed to other factors. Flaking is a secondary type of failure which may accompany any of the primary failures. Flaking may be caused by preloading, axial compression, indentations, smearing, deep seated rusts or by fluting. The site of flake formation depends on the site of primary failure, i.e. it may be at the most heavily loaded zone in case of preloading or at the start of the load zone in case of smearing.

All types of causes in bearing lead to the production of micro cracks may form in bearing rings and mainly on the surfaces, worn out due to the repeatedly applied load. The type of defects is called as intrusion/extrusion. They will form micro cracks on time. The micro cracks will be propagating to cause failure due to crack propagation. This kind of problems mainly arises due to fatigue loading. Cracks can be formed due to rough treatment of the bearing material. It may be due to heavy blowing with hammer or hardened chisels. Cracks can also be developed when there is excessive drive-up on the tapered seating or sleeve. In this case the bearing ring cracks right through and loses its grip on the shaft. Sometimes, cracks are also formed due to smearing and fretting corrosion. Cracks are transverse in inner rings and generally longitudinal in outer rings in case of fretting corrosion.

4. A VIEW ON NANO COMPOSITES

A few of the research work which carried out in nano composites are summarized as follows. The addition of ZnO with Epoxy [1], nano silicate with Nylon6 [2], Poly propylene with nano $CaCO_3$ [9], Multi walled carbon nano tube with Epoxy [12], Carboxyl terminated butadiene acrylonytrile (CTBN-liquid rubber) with epoxy [14], Carbon Nano Fibers (CNF) with epoxy [16] are improved the fracture toughness under different mode of loading of PMC considerably. The yield strength, tensile strength and young's modulus are enhanced by the addition of organoclay with poly propylene [3], Multi wall carbon nano tube with epoxy [12], (CTBN-liquid rubber) with epoxy [14], which are observed from the literature review. The nano graphene platelet with epoxy [4], multi walled carbon nano tube with epoxy [5] have influenced the fatigue properties in positive way. The ternary composites which are made with nano fillers like Al_2O_3 with glass fiber reinforced epoxy PMC [8] are developed the tensile, shear and bearing strength, Basalt fabric and (graphite and nano SiO_2 individually and combindly) with epoxy [10] are greatly increased the wear resistance of the material. The other ternary composites Nano Poly vinyl alcohol with carbon fabric in epoxy polymer [15], Rigid-silica nano particles and soft liquid rubber in epoxy [13] also have enhanced the tensile properties, fatigue and fracture properties effectively. The research work is also being done in nano particle reinforced in metal matrix composites and ceramic matrix composites. The nano sized alumina particle in magnesium [18] which improved wear resistance and tensile properties, nano sized Ni reinforced in Al_2O_3 [19] which improved fracture toughness are few reviewed literatures which showed the effect of nano particle in MMC and CMC.

5. EXPOSURE FOR RESEARCH WORK

The complete analysis of the materials used for bearings and their failure modes with causes gives a clear indication that there is still a research gap in developing better materials to enhance the properties and to improve the life of the bearings. As conventional metallic, polymers and ceramics have served their purposes with flaws, and advanced materials is needed to be developed. A review on literatures published in nano composites revealed that there is a tremendous improvement in most of the properties when the nano fillers are reinforced with polymers, metal matrix composites and with polymer matrix composites. There is no sufficient literature work on developing a better material for bearing. The failure analysis of bearing revealed that most of the failure have occurred by creating flakes and subsequently cracks on the surface of the races. This is mainly due to minute removal of material from the surface because of friction, loads on bearings, etc. Whatever may be the reason, the failure is provoked by initiating surface micro crack/flakes and then subsequently propagating them to failure which is mainly due to wear rate. So it is important to improve the wear resistance of the material to control the material removal rate. It is also expected to improve the fracture toughness to some extent to withstand subsequent crack growth. As we know wear resistance and fracture toughness are inverse properties, if any one increases, the other would decrease. The material of MMC reinforced with nano fillers are opted for developing a material for this problem, since the metallic materials are used mostly than polymer and ceramics for bearing materials. It has been observed from the study that the presence of V and Cr content is also influencing the high temperature resisting property. It can be taken to the nano scale as reinforcement and further analysis can be done. The collected material data expressed that the nickel content in alloy steels increases the fracture toughness, and in some cases, Manganese has been observed to influence fracture toughness as well as hardness. Manganese has also been used as substitute for nickel in some cases. Silicon nitride in ceramic group influences fracture, toughness and hardness as well as high temperature strength. The nano sized aluminium oxide particles in magnesium [18] improved the wear resistance and tensile properties. The nano sized Nickel reinforcement in Al_2O_3 [19] has improved the fracture toughness. Research work can be proposed on reinforcing Si_2N_2 with Al_2O_3 matrix, which can be expected to give improved fracture strength, along with improved hardness and tensile strength to some extent. Similarly reinforcement can be changed as Nickel, Manganese and other influencing elements and the properties can be evaluated.

The bearing materials are mostly having the upper operating temperature as 400°C. It is because of the constraint of having the lubricant used in bearing with a stable form after that temperature. So, another question can also be framed like is there any possibility to form a material which can self lubricate? So that it can be used in high temperature application (more than 400°C). As of now, for self lubricating bearing with limited temperature range of 400°C, Polymer matrix with MoS_2 composite is developed and used.

It is also suggested to carry out the research work in improving the wear resistance and fracture toughness of the bearing material. This is because the material removal in the surface (inner race) of the bearing during the service and subsequent crack initiation and propagation are mainly identified as the failure mechanism. It is also proposed to analyze the adaptability of property enhancement of the bearing materials at lower temperatures (Cryogenic temperatures). It is identified that the presence of Ni, Cr, and W and Silicon nitride has improved the wear resistance; Ni, silicon nitride also improved the fracture toughness because of their presence. Any of these elements and compound (silicon nitride) can be taken to the nano scale and can be used as reinforcement to form a composite material to improve the wear resistance and the fracture toughness. Since the material is also going to be tested for low temperature applications, it is suitable to choose polymer matrix instead of metal matrix. The reason is that the presence of these Ni or Cr or W or silicon nitride in nano scale with metal matrix would definitely improve the hardness of the material. If the same material is taken to the low temperature the brittleness of the material can be further increased which would suppress the fracture toughness of the material. But in case of Polymers this effect can be avoided to some extent. The following table shows the glass transition and melting point of some important polymers.

Table 1: Glass transition & Melting Temperatures of polymers

MATERIAL	GLASS TRANSITION TEMPERATURE [^{o}C (^{o}F)]	MELTING TEMPERATURE [^{o}C (^{o}F)]
Polyethylene (low density)	-110 (-165)	115 (240)
Polytetrafluoroethylene	-97 (-140)	327 (620)
Polyethylene (high density)	-90 (-130)	137 (279)
Polypropylene	-18 (0)	175 (347)
Nylon 6,6	57 (135)	265 (510)
Polyethyleneterephthalate (PET)	69 (155)	265 (510)
Polyvinyl chloride	87 (190)	212 (415)
Polystyrene	100 (212)	240 (465)
Polycarbonate	150 (300)	265 (510)

Among these polymers, Polyethylene has very low viscosity and very low glass transition temperature (-110°C) (temperature at which the polymer will be transformed from rubbery nature to rigid glassy nature). It is also witnessed that Polyethylene has been used as bearing material with the remarks of high creep, softening and tough material. When taking the polyethylene to cryogenic atmosphere, the transition of ductile to brittle (rubbery to glassy) would happen only below -100°C. So Polyethylene can be analyzed to give better toughness along with wear resistance when reinforced with above said elements/compound at room temperature as well as cryogenic temperature.

6. SUMMARY

The effort on preparing platform to carry out the research in materials used for bearing is done. The data of properties, composition of the materials used for bearing as of now is provided. The failure types and their causes are analyzed. A review on nano composite is also done. The research exposure on bearing material is expressed.

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ANNEXURE

TABLE 1: Applicable National Standards and Chemical Composition of High-Carbon Chrome Bearing Steel

<table>
<tr><th rowspan="2">MATERIAL</th><th colspan="6">Chemical Composition (%)</th><th rowspan="2">APPLICATION</th></tr>
<tr><th>C</th><th>Si</th><th>Mn</th><th>Cr</th><th>Mo</th><th>Others</th></tr>
<tr><td>51100(ASTM)</td><td>0.98to1.10</td><td rowspan="3">0.15to0.35</td><td rowspan="2">.25to.45</td><td>0.90to1.20</td><td rowspan="2">≤0.10</td><td>*1</td><td>Not generally Used</td></tr>
<tr><td>A 295-89 52100</td><td>0.93to1.05</td><td rowspan="2">1.35to1.60</td><td>P≤0.025
S≤0.015</td><td rowspan="3">Typical Steel type for small and medium size bearings</td></tr>
<tr><td>100C6 (NF)</td><td rowspan="2">0.95to1.10</td><td>0.20to0.40</td><td>≤0.08</td><td>P≤0.030
S≤0.025</td></tr>
<tr><td>535A99 (BS)</td><td>0.10to0.35</td><td>0.40to0.70</td><td>1.20to1.60</td><td>–</td><td>*1</td></tr>
<tr><td>A 485-03 Grade 1</td><td>0.90to1.05</td><td>0.45to0.75</td><td>0.90to1.20</td><td>0.90to1.20</td><td rowspan="2">≤0.10</td><td rowspan="3">P≤0.025
S≤0.015</td><td rowspan="2">For large size bearings</td></tr>
<tr><td>A 485-03 Grade 2</td><td>0.85to1.00</td><td>0.50to0.80</td><td>1.40to1.70</td><td>1.40to1.80</td></tr>
<tr><td>A 485-03 Grade 3</td><td>0.95to1.10</td><td>0.15to0.35</td><td>0.65to0.90</td><td>1.10to1.50</td><td>0.20to0.30</td><td>For ultra large size Bearings</td></tr>
</table>

Notes *1 : P≤0.025, S≤0.025 Remarks ASTM: Standard of American Society of Testing Materials, NF: French Standard, BS: British Standard

TABLE 2: ASTM standards and chemical composition of carburizing bearing steel

<table>
<tr><th rowspan="2">ASTM A 534-90</th><th colspan="7">Chemical Composition (%)</th><th rowspan="2">Application</th></tr>
<tr><th>C</th><th>Si</th><th>Mn</th><th>Ni</th><th>Cr</th><th>Mo</th><th>Others</th></tr>
<tr><td>5120H</td><td rowspan="4">0.17to0.23</td><td rowspan="5">0.15to0.35</td><td rowspan="2">0.60to1.00</td><td rowspan="2">–</td><td>0.60to1.00</td><td>–</td><td rowspan="5">P≤0.025
S≤0.015</td><td rowspan="3">For small size bearings</td></tr>
<tr><td>4118H</td><td>0.30to0.70</td><td>0.08to0.15</td></tr>
<tr><td>8620H</td><td>0.60to0.95</td><td>0.35to0.75</td><td>0.35to0.65</td><td>0.15to0.25</td></tr>
<tr><td>4320H</td><td rowspan="2">0.40to0.70</td><td>1.55to2.00</td><td>0.35to0.65</td><td>0.20to0.30</td><td>For medium bearings</td></tr>
<tr><td>9310H</td><td>0.07to0.13</td><td>2.95to3.55</td><td>1.00to1.45</td><td>0.08to0.15</td><td>For large bearings</td></tr>
</table>

TABLE 3: High-Temperature bearing materials

Steel Type	Chemical Composition (%)									Remarks
	C	Si	Mn	Ni	Cr	Mo	W	V	Co	
SUJ2	1.02	0.25	≤0.5	-	1.45	-	-	-	-	General use
SKH4	0.78	≤0.4	≤0.4	-	4.15	-	18.0	1.25	10.0	High Temperature use
M50	0.81	≤0.25	≤0.35	≤0.10	4.0	4.25	≤0.25	1.0	≤0.25	
SUS 440C	1.08	≤1.0	≤1.0	≤0.60	17.0	≤0.75	-	—	-	Corrosion resistance/high temperature

Remarks Figures without ≤ mark indicate median of tolerance

TABLE 4: Physical and mechanical properties of bearing materials

Material	Heat Treatment	Density g/ cm^3	Young's modulus MPa	Yield Point MPa	Tensile Strength MPa	Elongation %	Hardness HB	Remarks
SUJ2	Quenching, tempering	7.83	208000	1370	1570 to 1960	0.5 max.	650 to 740	High carbon chrome bearing steel No.2
SUJ2	Spheroiding, annealing	7.86		420	647	27	180	
SCr420	Quenching, low temp tempering	7.83		882	1225	15	370	Chrome steel
SAE4320 (SNCM420)				902	1009	16	*293 to 375	Nickel chrome molybdenum steel
SNCM815		7.89		-	1080	12 Min	311 to 375	
SUS440C		7.68	200000	1860	1960	-	*580	Martensitic stainless steel
SPCC	Annealing	7.86	206000	-	275	32 Min	-	Cold rolled steel plate
S25C				323	431	33	120	Carbon steel for machine structure

CAC301 (HB,C1)	–	8.5	103000	–	431	20 Min	–	High-Tension brass

Note * Though Rockwell C scale is generally used, Brinell hardness is shown for comparison

TABLE 5: Properties of engineering ceramics and metal material

Material	Density g/cm^3	Hardness HV	Young's Modulus GPa	Flexural strength MPa	Fracture toughness MPa
Silicon nitride (Si_2N_4)	3.1 to 3.3	1500 to 2000	250 to 330	700 to 1000	5.2 to 7.0
Silicon carbide (SiC)	3.1 to 3.2	1800 to 2500	310 to 450	500 to 900	3.0 to 5.0
Alumina (Al_2O_3)	3.6 to 3.9	1900 to 2700	300 to 390	300 to 500	3.8 to 4.5
Partly-stabilized Zirconia (ZrO_2)	5.8 to 6.1	1300 to 1500	150 to 210	900 to 1200	8.5 to 10.0
Bearing steel	7.8	700	208	–	14 to 18

TABLE 6: Characteristics of representative polymers

Plastics	Elastic modulus (GPa)	Strengt h (GPa)	Density (g/cm^3)	Specific elastic modulus $\times 10^4$mm	Specific strength $\times 10^4$mm	Melting point ^oC	Glass transition Temp. ^oC	Thermal deformation Temp. ^oC (^{2})	Continuous Operating Temp. ^oC	Remarks
Polyethylene										
HDPE	0.11	0.03	0.96	12.6	3.3	132	-20	75/50	-	High creep and toughness, softening
UHMWPE	50.5	0.025	0.94	53.2	2.7	136	-20	75/50	-	
Polyamide										
Nylon 6	2.5	0.07	1.13	221.2	6.2	215	50	150/57	80to120	High water absorption and toughness
Nylon 66	3.0	0.08	1.14	263.2	7.0	264	60	180/60	80to120	

Nylon 11	1.25	0.04	1.04	120.2	3.8	180	-	150/55	Lower than Nylon 66	Low water absorption
Polytetra fluoroethylen e PTFE	0.40	0.028	2.16	18.5	1.3	327	115	120/-	260	High creep, sintering low friction and adhesion, inert, stable at 290 ^{o}C
Polybuthylen e terephthalate PBT	2.7	0.06	1.31	206.1	4.6	225	30	230/215	155	
Polyacetal POM										
Homo-polymer	3.2	0.07	1.42	225.3	4.9	175	-13	170/120	-	High hardness and toughness, low water absorption
Co-polymer	2.9	0.06	1.41	205.7	4.3	165	-	155/110	104	
Polyehter sulfon PES	2.46	0.086	1.37	179.6	6.3	-	225	210/203	180	Usable upto 200 ^{o}C chemically stable
Polysulfon PSF	2.5	0.07	1.24	201.6	5.6	-	190	181/175	150	
Polyallylate (Aromatic polyester)	1.3	0.07	1.35	96.3	5.2	350	-	293	300	Inert, high hardness, used as filler for PTFE, stable upto 320 ^{o}C
	3.0	0.075	1.40	214.3	5.4	350	-	293	260 to 300	
Polyphenylen e sulfide PPS (GF 40%)	4.2	0.14	1.64	256.1	8.5	275	94	>260	220	Hot cured at 360 ^{o}C

Polyether ether ketone PEEK	1.7	0.093	1.30	130.8	7.2	335	144	152	240	
Poly-meta-phenylene Isophthalic amide	10(fiber)	0.7	1.38	724.6	50.7	375	>230	280	220	Fire retardant, heat resistance fiber
	7.7(mold)	0.18	1.33	579	13.5	415 Decomposition				
Polypromellitic imide	3 (film)	0.17	1.43	203	7.0	Heat De-composition	417 (De-composition)	360/250	300	No change in inert gas upto 350°C
	2.5to3.2 (mold)	0.1							260	Usable upto 300°C for bearing. Sintering no fusion
Polyamide imide PAI	4.7	0.2	1.41	333.3	14.2	-	280	260	210	Usable upto 290°C as adhesive or enamel improved polyimide of melting forming
Polyether imide PI	3.6	0.107	1.27	240.9	-	-	215	210/200	170	Improved polyimide of melting forming
Polyamino bis-maleimide	-	0.35	1.6	-	21.9	-	-	330	260	

Note

If there is a slash mark "/" in the thermal deformation temperature column, then the value to the left of the "/" applies to 451 kPa, if there, the value relates to 1.82 MPa.

Table 7: Base Polymers with Fillers and Reinforcements

BASE POLYMERS	MAX, USEFUL TEMP. (^oC)	FILLERS AND REINFORCEMENTS	
Thermoplasts			
Polyethylene (high m.w.)	80	Asbestos	Improve mechanical properties
Acetal (home- &co-polymer)	125	Glass	
Polyamides (nylon 6,6,6)	130	Carbon	
PTFE	280	Textile fibres	
Polyphenylene oxide	200	Mica	
Polyamide	300	Oxides	
Thermosetting resins			
Epoxides	200	MoS_2	Reduce friction
Polyesters	130	Graphite	
Phenolics	200	PTFE (particles or fibre)	
Silicones	300		
		Bronze	Improve conductivity
		Silver	