



REVIEW ON GRAPHITE PLUGGED BRONZE BUSHINGS

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Abstract: The purpose of lubricating contacting surfaces is to lower wear and friction by adding a layer of low shear strength or separating the surfaces with a fluid coating. While adhering a lubricating solid to a worn surface can be done in a variety of ways, the end effect is always the same: in practically dry conditions, a low friction medium is deposited to minimize wear and friction between two relatively moving surfaces. Graphite is mechanically pressed under extreme pressure into a bearing's grooves to form graphite filled bearings. High loads may be handled by this material, and the graphite acts as self-lubricant. This kind of bearing offers a self-lubricating, maintenance-free bearing solution and operates well in high temperatures. This study seeks to present an extensive review of the mechanisms, performance, drawbacks, and possibilities for productivity and environmental sustainability of graphite-plugged bronze bushings used in machining.

Keywords: Graphite, bronze, solid lubricant, friction, wear

1. INTRODUCTION

Self-lubricating materials have been increasingly popular for bearing applications for several years, due to economic, environmental, and even technological grounds. This allows for the exclusion of external lubricants like oil or grease and simplifies the design [1]. With increasing shortages of materials and energy, there will be an increasing demand for longer product lifespans, more wear resistance, and lower friction through lubrication. From the standpoint of performance and reliability, the latter is an undesired phenomenon. The term "tribological materials" refers to materials that are intended to reduce wear and friction. In addition, these materials need to meet requirements for damping, thermal expansion, strength, stiffness, and fatigue life. Achieving a balance between these conflicting objectives and minimizing friction from bulk materials used to build tribological components becomes practically impossible from a practical design perspective [2]. To achieve the self-lubricating characteristic, the wear resistance metal back combined with solid lubricants can continually offer a lubricating source during the bearing operation. This material is suitable for a range of operating circumstances due to its low friction factor and the metal's ability to withstand large loads and impacts. This review paper aims to provide an overview of graphite plugged bronze bushings and the graphite that is used as a solid lubricant and their applications in extreme conditions.

2. SOLID LUBRICANT

In these and many more conditions, solid lubricants—defined as any solid material intended to reduce friction

and wear between two moving surfaces—are utilized. Solid lubricants are divided into various categories. The two most prevalent kinds are inorganic (which includes MoS₂ and graphite, soft metals, metal oxides, nitrides, and hBN-based lubricants) and organic (which includes polymer-based materials like polyimide and polytetrafluoroethylene). Lubricants that are inorganic and organic can be classified according to their operating temperatures. Liquid lubricants or greases are not suitable for lubricating bearings used in vacuum, extremely high temperatures, or high radiation environments [3]. To put it simply, the specific lubricating needs of extreme operating environments, like corrosive atmospheres and temperatures ranging from -200 to 850C, require a substantial amount of solid substance [3]. Because of their low shear strength and ease of adhesion to the friction surface, solid lubricants can coat the surface of the friction pairs with a steady, continuous lubricant. As a result, friction and wear on the friction pairs are decreased [4]. Like solid lubricants, self-lubricating materials are essential for bearing applications. High temperature performance is achieved due to their self-lubricating characteristics, which reduce the requirement for grease or other lubricants. Graphically (graphite/metal) alloys leverage graphite's unique characteristics, resembling a set of cards having layers that are simple to remove. The crystal system of graphite is hexagonal (Fig.1). Strong bonds hold the carbon atoms in sheets together. The weak connections between the sheets cause graphite to have a decreased shearing strength under friction stress. This helps create a lubricating covering and makes smearing graphite easier. So it can be used as a solid lubricant and become one of the foundations of solid lubrication [6]. Self-lubricating composites can be made using a variety of processes, including machining [7], powder metallurgy [8 - 10] and semi-solid casting [11]. The self-lubricating

qualities and dry sliding characteristics of composites made of metal have been the subject of many investigations to now. The solid lubricant and backing metal are equally as crucial to the creation of composites as the manufacturing method.

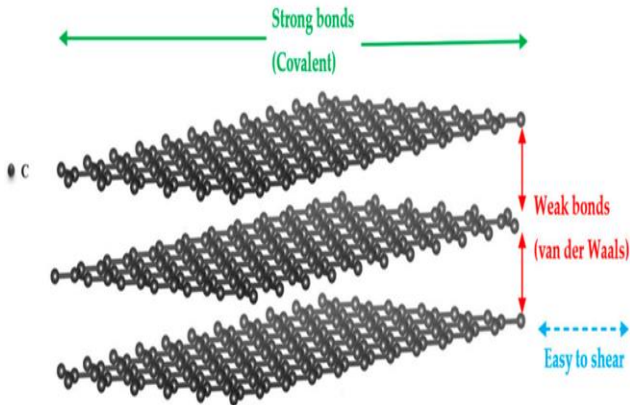


Fig. 1: Crystalline Structure of Graphite [5].

Though numerous recent research concentrate on utilizing nickel (Ni) [9, 12], aluminium alloys [6], steel [7, 13], and molybdenum disulfide [9] as backing metals (matrix), the other studies are more interested in solid lubricants, such as polytetrafluoroethylene [7, 13], graphite [12, 6, 10, 8], and aluminium dioxide plus silver [14]. However, very few scientific investigations were published on self-lubricating composites; these studies focused mostly on the use of solid lubricants made of graphite and bronze as backing metals [8, 15]. The dry sliding behavior of graphite composites based on bronze in the case of Fe-based contacts is not well understood. As previously mentioned, traditional casting and powder metallurgy methods can be used to create composites based on bronze. By using traditional casting, a nonhomogeneous structure is created because of huge variances in the densities of Cu and graphite (about 8.96 and 2.25 gr/cm³, respectively) and solidification temperatures (1083°C and 3,550°C, respectively) [16]. Nonetheless, other variables need to be managed, including high temperature sintering, mixing, and powder manufacture and this approach waste excessive amounts of energy [15]. Another method for creating bronze-graphite composites is to mechanically drill holes in the bronze and then insert graphite mass into the holes which is an oilless bearing. The types of oilless bearings:

1. Graphite plugged bronze plates
2. Graphite plugged bronze washers.
3. Graphite plugged bronze bushings.



(a)



(b)

Fig. 2: oilless bearings: (a): graphite plugged bronze bushings. (b): graphite plugged bronze plates

2.1. Lubricants Based on Carbon (Graphite)

Graphite is a solid laminar lubricant that is only made of carbon atoms. These atoms arrange themselves into a hexagonal lattice, with covalent bonds tying the layers together loosely. Graphite's remarkable lubricating properties are attributed to its hexagonal structure, which arranges parallel basal planes that are slightly out of alignment. Because basal planes glide over one another so easily, lubrication relies on this property, which makes solid lubricants with low friction coefficients useful [5]. Figure 1 illustrates a schematic picture of graphite's atomic structure. Graphite absorbs air, oxygen, moisture, and hydrocarbon vapours to achieve low-shear strength as a solid lubricant. However, this need restricts its application in vacuum settings or at high altitudes [17]. Graphite's coefficient of friction (CoF) has been tested several times. One study found that graphite has a CoF of approximately 0.1 at temperatures below 100 °C [18]. In the range of 100 °C to 425 °C, the coefficient increases to approximately 0.4. In a second investigation, it was discovered by Peace et al. [19] that graphite maintains lubricity up to 600 °C, even in oxidizing conditions. It can also function as a lubricant at temperatures as high as 1100 °C to 1200 °C.

3. GRAPHITE PLUGGED BRONZE BUSHINGS

One kind of bearing composed of graphite and bronze is the bronze bushing with a graphite plug. Graphite plugged bronze bushings are manufactured with machined holes and/or grooves into which graphite is inserted. They are frequently employed in many applications due to their desirable feature of providing continuous lubrication in harsh environments where oil or grease is difficult to reach [20]. The graphite plugs act as solid lubricants, and the bronze material gives the bushing strength and durability. Under extreme pressure, graphite is mechanically pressed into the grooves and holes. When the bronze bushing is moving relative to one another, the graphite plugs that are embedded within it release lubricating particles which form a film of lubricant between the shaft and bushing. By decreasing friction between the bushing and the shaft or other moving elements, this self-lubricating feature minimizes wear and increases the bushing's lifespan. This eliminates the need for manual lubrication, making these bushings ideal for applications where regular maintenance is difficult or where traditional lubrication methods are impractical. Bronze bushings with plugs made of graphite are available in various alloys and can be specially made to meet specific industrial requirements. They are known for having superior friction, wear, and seizure resistance. These bushings are used in many different sectors and applications, including agricultural machinery, industrial mixers, oil and gas, and even applications involving seawater.

3.1 Reasons for choosing graphite-plugged bronze bushings.

3.1.1 Total self-lubricating: No oil or grease is necessary:

Bushings can be used in cases where oiling is difficult, costly, or not possible due to the self-lubricating characteristics. Even at low speeds and with high loads, excellent lubrication is accomplished.

3.1.2. Excellent Wear Resistance:

When oil film development is challenging, such as in high load, low velocity, reciprocating, oscillating, and intermittent motions, excellent wear resistance is achieved.

3.1.3. Low Friction Coefficient: Typically 0.04 to 0.2:

Friction is reduced by self-lubrication using solid lubricants that are carefully placed in.

3.1.4. Extended Operational Temperature Range: -415°F to 1,100°F:

Excellent performance is demonstrated in both hot and cold temperatures.

3.1.5. Corrosion and Chemical Resistance:

Water and caustic chemicals have little effect on performance.

3.1.6. Cost Competitive:

When compared to similar self-lubricating goods, the superior service life results in lower maintenance, replacement, and end-item downtime costs.

4. PREVIOUS STUDIES RELATED TO SELF-LUBRICATING BUSHINGS.

It is evident from reading the literature that significant research has been done on estimating the wear and friction of the bronze matrix combined with graphite in the form of whiskers and particles [21–24]. Frictional elements composed entirely of bronze often experience severe adhesive and abrasive wear under high stress situations [25]. On the other hand, the addition of graphite particles into the metallic matrix greatly aids in lubricating the sliding contact and mitigating wear [21 – 24]. The wear graphite debris was found to be able to be preserved by an experiment with texture creation on the copper-graphite composite surface, which further allowed for lowering friction because the transfer layer was simple to produce [26]. The mechanism of mechanical damage in graphite filled bronze composite is rarely studied due to its extreme conditions, which makes it a special instance. This type of solid bronze body minimizes wear and friction because it is drilled readily and filled with solid graphite plugs. In 1999 (J. A. Jones et al) [27] who worked in the US Army Corps of Engineers presented

actual use cases for self-lubricating bushings. According to the Corps' experience, the majority of bearings with lubrication plugs exhibit poor performance in small-movement applications, which nearly exclusively comprise the intended hydropower applications. A poor experience with 30 upgraded machines from 1992 onward was also recorded by J. C. Jones [28] in 2001. He claimed that swelling of lubricant plugs reduced bearing clearance and increased friction and that increased friction with lubricant-plugged bronze bearings and delaminated lining in polymer-lined bearings resulted in a loss of servomotor capacity. The methods for lubricating with grease were put back in place in some instances. Jan Ukonsaari et al. have reported on the performance of numerous bearing types in dry conditions when exposed to different oscillating motion patterns [29]. Eight bearing types in all were tested using a specialized test rig under two distinct motion patterns. Among the eight varieties of bearings were:

Oiles JM3: Oiles 500 JM3 SL4: tin Bronze, Graphite and lead lubricating plugs.

Oiles JM7: Oiles 500 JM7 SL4: aluminum Bronze, lubricant plugs with graphite and lead.

Surface characteristics related to friction and wear are found to be suitable for wicket gate guide vane applications. Only four types were thoroughly investigated in this study, and two of those types are thought to be more appropriate.

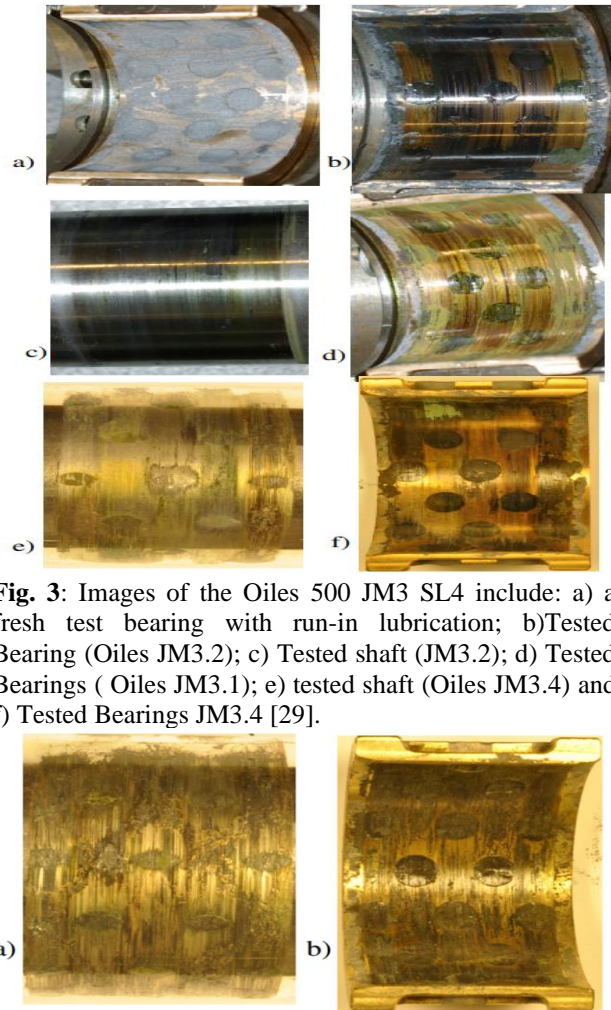


Fig. 3: Images of the Oiles 500 JM3 SL4 include: a) a fresh test bearing with run-in lubrication; b) Tested Bearing (Oiles JM3.2); c) Tested shaft (JM3.2); d) Tested Bearings (Oiles JM3.1); e) tested shaft (Oiles JM3.4) and f) Tested Bearings JM3.4 [29].

Fig. 4: Photographs of tested Oiles JM7.4 a) shaft, and b) bearing [29].

(Jun Jiang et al.)[20] used numerous topographic characterizations and computational analysis to study the wear characteristics and contacting stress of graphite filled bronze sliding plates from the field experiment. The findings showed that localized fatigue and erosion were present together with abrasive and adhesive wear, which dominated the contacting surface of the graphite-plugged bronze plate. (Zhao et al.)[30] used aluminium bronze, aluminium bronze-based inlay solid self-lubricating bearing (ISSLB), tin bronze, and tin bronze-based ISSLB materials to perform friction and wear experiments on 45# carbon steel under varying loads (Fig. 5). Under the same load, the wear and friction characteristics of the new self-lubricating bearing material and the old copper alloy were contrasted. The study looked at the effects of wear parameters and friction caused by C-MoS2 composite solid lubricant. While bronze-based ISSLB materials perform better than aluminium bronze-based ISSLB materials in terms of wear and friction, copper-based ISSLB materials show exceptional wear resistance.

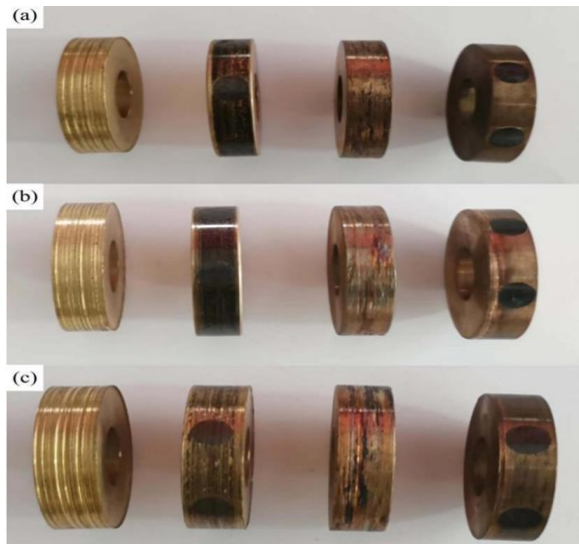
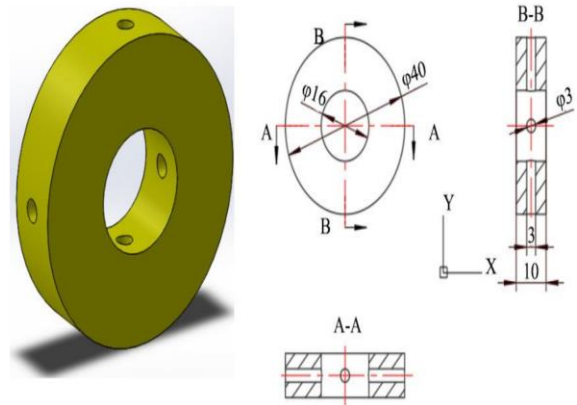


Fig. 5: Sample images taken at three different loads: 100 N, 300 N, and 500 N [30].

The effect of graphite-MoS2 composite solid lubricant on the tribological characteristics of copper-based bearing materials in dry conditions was examined by (Chen et al.)[31]. The graphite-MoS2 combination has been incorporated in the matrix of ZQA19-4 aluminium bronze and ZQSn6-3 tin bronze, respectively (figure 6). The results demonstrate that self-lubricating bearing materials with integrated copper have lower friction coefficients and wear rates than conventional copper-based bearing materials. In addition, the wear performance of tin bronze inlaid self-lubricating bearing material is better than that of aluminium bronze inlaid self-lubricating bearing material.



(a) Three-dimensional diagram (b) Two-dimensional diagram

Fig. 6: The diagram of sample geometry [31].

Graphite is used as a solid lubricant to study the tribological characteristics of tin bronze and 45 steel with varying filled pore structure sizes [4]. Using an orthogonal equivalent test on a grease-filled MMW-1A tester, the effects of filling pore diameter, depth, and area distribution rate on wear characteristics and friction were examined. Three factors were discovered to have the biggest effects on test results: filling pore diameter > area distribution rate > and filling pore depth. The optimal filling pore size under working conditions is 3 mm, 12%, and 0.5 mm.

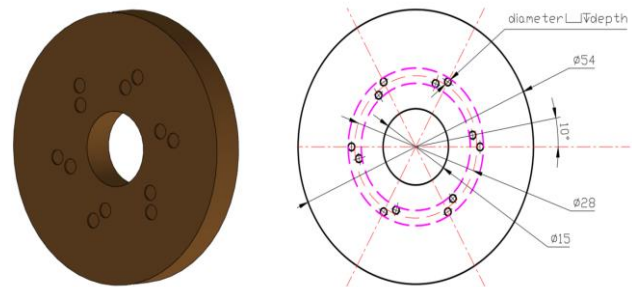


Fig. 7: Filling pore structure: (a) 3D diagram, (b) 2D diagram [4]

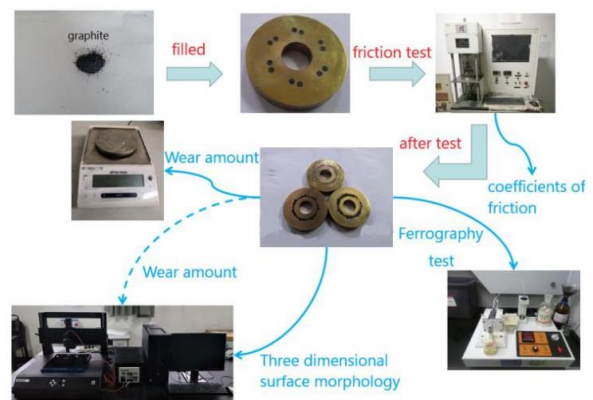


Fig. 8: Friction and wear test scheme [4].

Moreover, because graphite is present, the solid bronze is resistant to extreme marine conditions like acid raid and distilled or seawater [32]. Surface texture is one of the primary methods of surface engineering for achieving the desired tribological properties. The goal of surface texturing technology is to create microstructure arrays on a surface with a desired size, shape, and arrangement without altering the material to obtain special characteristics. Square, round, triangular, and elliptical structures are examples of common texture types [33]. Several studies have examined the impact of surface texture type. A study found that adding texture to the surface of a copper-graphite composite reduced friction by preserving worn graphite debris and making the transfer layer easier to create [34]. The surface texture of journal bearings is seen in Figure (9). The following are typical texture attributes: convex body height, texture spacing, pit diameter, depth, depth-to-diameter ratio, groove width, and substrate surface roughness.



Fig. 9: Surface textures of plain bearings [35].

The mechanical and tribological performance is determined by the strength of the interface between the surrounding metal and the graphite plug. Graphite, however, has a relatively weak chemical affinity for copper. Graphite can separate from the matrix under highly stressed shearing conditions, leading to worsened wear of the bronze matrix [36]. Regarding the mechanical characteristics at the interface between bronze plugs and graphite, stress is commonly believed to build up at this point between the heterogeneous phases, which negatively impacts the material's resistance to fatigue and wear [20]. Therefore, one of the primary fields of concern should be the stress situation between the bronze matrix and graphite plug, which is closely related to the interfacial shearing and compressive stresses during the friction process [37].

5. DESIGN OF GRAPHITE PLUGGED BRONZE BUSHINGS.

Between 30 and 35% of the surface area should be covered by the generally accepted standard solid lubricant. The proportion may differ depending on the application. To help with the design of bronze bushings with filled graphite, the National Bronze Manufacture in Michigan has created a quick reference guide as shown in Table (1).

Table 1. Calculation of lubrication coverage and plug size


Calculation of Lubricant Coverage and Plug Size
Percentage of Graphite or Solid Lube Coverage


Drill Size	10 %	15%	20%	25%	30%	35%	40%	45%	50%
3/16	8.95	13.43	17.9	22.38	26.85	31.33	36.81	40.28	44.5
1/4	3.03	7.54	10.05	12.57	15.08	17.6	20.11	22.63	25
5/16	3.22	4.83	6.44	8.05	9.66	11.27	12.88	14.49	16.1
3/8	3.23	3.35	4.47	5.59	6.7	7.82	8.94	10.06	11.1
7/16	1.64	2.46	3.28	4.1	4.92	5.75	6.57	7.39	8.2
1/2	1.28	1.89	2.51	3.14	3.77	4.4	5.03	5.66	6.28

1. Choose the appropriate drill or plug size.
2. Locate the desired solid lubricant coverage. Use factor number opposite drill or plug size.
3. Multiply bushing ID x bushing length. Multiply factor number to obtain the number of holes or plugs.

Example: 2" ID x 2-1/2 OD x 2" Length

1. 1/4 plug diameter
2. 35% coverage from chart 17.6
3. 2 x 2" length x 17.6 + 70 drilled holes or plugs.





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6. CONCLUSION

Based on experimental results and applications of graphite plugged bronze bushing, we conclude that the following factors should be taken into account when constructing a self-lubricating graphite bronze bushing:

- Wear and friction: The bushing needs to be made with as little wear and friction as possible. Although self-lubrication is provided by the graphite in the bushing, the mating surface and operating circumstances should also be considered in the design.
- Load capacity: The bushing needs to be able to support the loads applied to it without breaking down or deforming. This is dependent upon the bushing's geometry and material qualities.
- Temperature and surroundings: The bushing must be able to function in the specified temperature range and surrounding circumstances without degrading or breaking. Temperature-related effects on the graphite in the bushing should be taken into account in the design, along with other environmental considerations.

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