

# Research Progresses and Suggestions of Manufacturing Technologies of Engine Bearing Bushes

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**Abstract:** Bearing bush is a key part of diesel engine, and its performance directly influences the life of whole machine. Several manufacturing technologies of bearing bush such as centrifugal casting, sintering, electroplating and magnetron sputtering have been overviewed. Their bond strength, porosity, production efficient, layer thickness, frictional coefficient and corresponding materials analyzed and compared. Results show that the porosity and oxidation of sintering and centrifugal casting are higher than that of other two methods. However, the production efficiency and coating thickness are better than that of electroplating and magnetron sputtering. Based on above comparisons and discussions, the improvements of all manufacturing technologies are suggested and supersonic cold spraying is suggested. It is proved that cold spraying technology is the best choice in the future with the developing of low frictional materials.

## 1. Introduction

Bearing bush is a kind of journal bearing which widely used in automotive engineering, aerospace and many industrial applications. Roller bearings replaced by plain bearings are becoming popular because its life, manufacture cost, structure, vibration and wear are higher than that of plain bearings [1]. The yaw roller bearings are replaced by plain bearings due to the smaller structure and lower cost in the wind power system. In Pratt & Whitney Group, plain bearings had been used in aero-engine gear box [2]. With the development of advanced materials and manufacturing technologies, the low starting torque of plain bearings will be obtained, and roller bearings can be widely replaced in the future.



Bearing bushes must meet several requirements such as compliance, structure strength, low CoF, high bond strength and long service life [3]. In this paper, four common manufacturing technologies like centrifugal casting, sintering, electroplating and magnetron sputtering of plain bearing and their bond strength, porosity, production efficient, layer thickness, frictional coefficient and corresponding materials are introduced and compared. Based on the above summaries, the improvement suggestions of centrifugal casting, sintering, electroplating and magnetron sputtering are given. In addition, new manufacturing technology of the cold spraying is introduced. Through analyzing the mechanical properties and manufacturing efficiency, it proves that cold spraying can be applied for producing bearing bushes.

## 2. Manufacturing Technologies of Bearing Bush

The review ranges are narrowed to the engine bearing bushes because they are the most widely used plain bearings. The structures of engine bearing bushes usually are double layers and three layers which structure shown as figure 1 and figure 2. The double layers consist of a layer of steel back and a layer of alloy. The bearing of three layers consists of steel back, a transition layer and a antifriction layer. The common material of transition layer is nickel which can enhance the bond strength of back steel and antifriction layer [4]. The materials of top layer are usually the copper or aluminium alloys which have low CoF (Coefficient of Frictional) and the capacity of bearing heavy load.

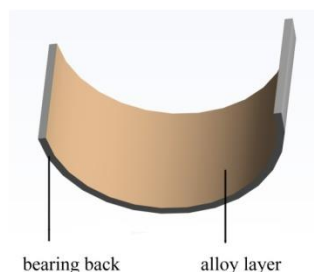


**Figure 1.** Bimetallic bearing bush

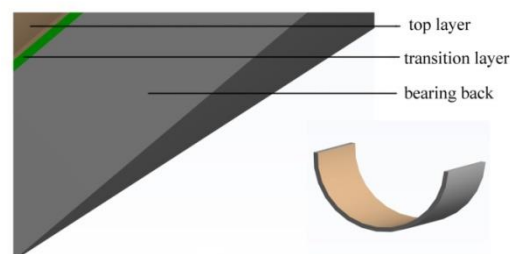


**Figure 2.** Triple metal bearing bush

### 2.1. Properties centrifugal casting

The centrifugal casting technology is shown as figure 3. With the centrifugal force, the molten liquids of alloy metals are bonded on the surface of bearing back steel. The properties of bearing bush had been studied and many excellent results obtained. The porosity was about 2.4%, and the CoF was more than 1 of aluminium bronze bearing bush made by centrifugal casting which indentified by the study of Alam [5]. The traditional material such as Pb has the problem of environment pollution. Some green materials had been studied to improve the frictional properties of bearing bush. The material of  $\text{Cu}_6\text{Sb}_{11}\text{Sn}_{83}$  and its proper coating thickness was from 0.05 to 0.15 mm which CoF was from 0.03 to 0.04 [6]. To improve mechanical properties of bearing, the additive materials had been studied. It was proved that with the additive of WC, anti-wear performance of bearing bush made by centrifugal

casting was improved [7]. Samadi had studied the temperature and thickness which influenced  $\text{Al}_2\text{Cu}$  layer hardness and density. It is shown that the properties of 10 mm coating thickness were better than that of 16 mm [8]. The bond strength of babbitt alloy and bearing back was from 40 MPa to 60 MPa which shown by Diouf [9].

## 2.2. Properties of sintering

Sintering is the most popular technology to produce bearing bushes. The principle of sintering of bearing bush is shown in figure 4. Bearing alloys are melted in the furnace, and the bearing back is preheated. The bearing back and liquid alloy are ground together by a water cooling roller. Cao has studied the mechanical properties of  $\text{Ti}_6\text{Al}_4\text{V}$  which made by sintering, and its porosity is 3.5% [10]. Mironov had shown the mechanical properties of bearing bush which was made of low alloyed materials. The CoF was 0.26 and its porosity was about 15% [11].

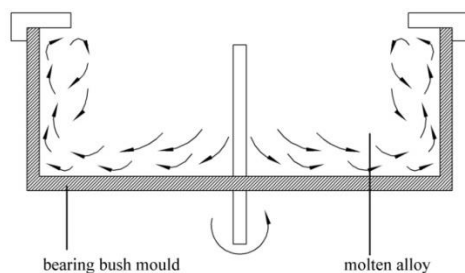


**Figure 3.** The principle of centrifugal casting

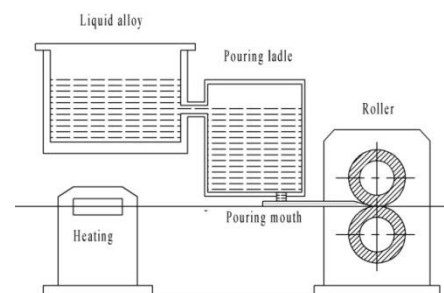


**Figure 4.** The principle of sintering

Dourandish had studied 3Y-TZP/Cr composite bilayers produced by sintering. The results shown that the bond strength was 41 MPa, and its porosity was from 10 % to 16 % [12]. In order to improve the mechanical properties of Cu alloys, some materials like W, Ta, Mo, Ag had been added [13, 14]. The composite alloys were studied by researchers also.  $\text{Sn}_{4.0}\text{Ag}_{0.5}\text{Cu}_{1.0}\text{Ni}$  alloy was produced and its microstructure properties were studied [15]. The layer thickness of bearing bush can be produced more than 1 mm, and its produce efficiency was high. However, the oxidation and high porosity can not be avoided [16].

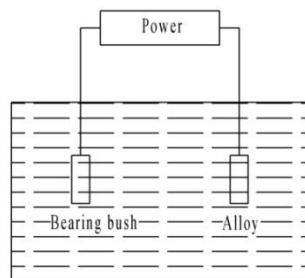


**Figure 5.** The principle of electroplating

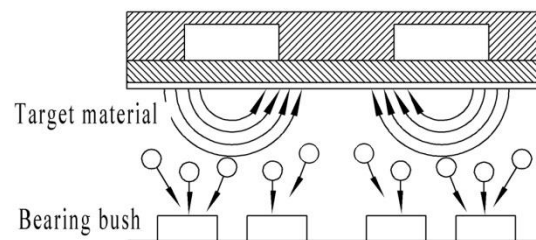


**Figure 6.** The principle of magnetron sputtering

### 2.3. Properties of electroplating

In order to improve the tribological properties and decrease the oxidation of bearing bushes, three elements, four elements and even five elements chemical plating are applied [17-19]. Electroplating of bearing bush is shown in figure 5. The bearing bush was set as cathode, and the material of coating was set as anode. The more thick the coating thickness, the more porosity would be obtained. The coating thickness should not beyond 5  $\mu\text{m}$  was suggested by Yu [20]. The bond strength of coating produced by electroplating was from 26.8 MPa to 33.6 MPa which studied by Elsaka [21]. The CoF of Ag coating made by electroplating was 0.18 which shown by Arash. Its bond strength was from 18 MPa to 24 MPa [22]. The porosity of Ni-Al based coatings via electroplating was from 4.29 % to 10.55 %. The bond strength is lower than that of centrifugal casting and sintering. In order to improve performances of electroplating, some rare earth materials such as Ln, La and Ta were studied and added to improved performances of materials [23, 24]. However, the plating solution is harmful to the environment, and it will be restricted in the future.

### 2.4. Properties of magnetron sputtering

Different from electroplating, magnetron sputtering does not pollute environment. The bond strength of Ti/ZrSiN with different Si content was from 25.2 MPa to 57.3 MPa which shown by Zhang [25]. The shortages of magnetron sputtering are the low efficiency and thin coating thickness. The proper thickness of  $\text{CuCr}_{0.93}\text{Mg}_{0.07}\text{O}_2$  thin film deposited by reactive magnetron was from 70 nm to 280 nm [26]. Magnetron sputtering is an effective way that many materials can be deposited on bearing bushes. For example, Ti/Cu/N coatings,  $\text{Cu}_x\text{Sn}_y$ , CrN/Ag, TiN/Cu coatings can be deposited, and their CoFs were lower than 0.15 [27, 28]. The porosity of Cr single coating and CrN coating was 3.72 % and 5.83 % which studied by Wu. However, with the filling action, the porosity of two composite coatings was 0.39 % [29]. The fatigue strength will be improved 10 %-30 % if the porosity is decreased 1%-2% [30]. Thus, the low porosity of bearing bush should be obtained.

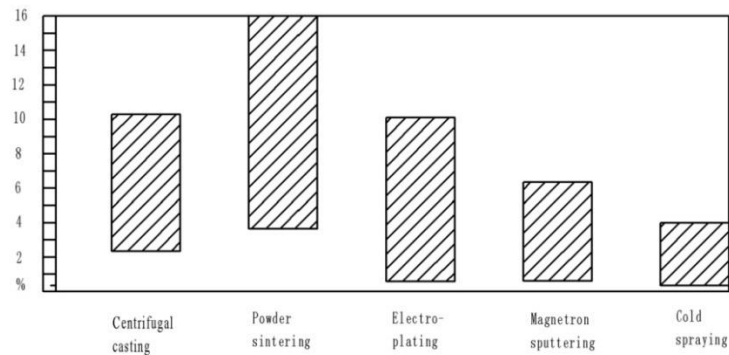


**Figure 7.** Porosity of different manufacturing technologies

### 3. Comparisons of different manufacturing technologies

The performances of bond strength, porosity, layer thickness, frictional coefficient and corresponding materials of centrifugal casting, sintering, electroplating and magnetron sputtering are briefly introduced respectively. In order to describe properties of different manufacturing technologies clearly, and find the best method, the high pressure cold spraying is discussed. Based on the reviews of references, the porosity of different manufacturing technologies is shown in figure 7 [31-33].

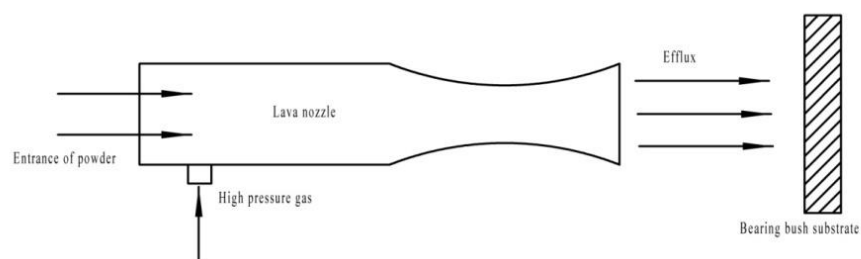


**Figure 8.** The principle of cold spraying

It is found that the porosity of cold spraying is the smallest. The principle of cold spraying is shown in figure 8. With the supersonic speed of carried gas, the coating is consolidated with the next flying powders. Thus, its porosity is condensed and low. The bond strengths of all manufacturing technologies are shown in figure 9 [34]. The temperature of centrifugal casting and sintering are higher than that of electroplating, magnetron sputtering and cold spraying. Without inert gas protection or vacuum environment, the oxidation of casting and sintering are higher than that of other three manufacturing technologies. However, coating thickness and production efficiency of electroplating and magnetron sputtering are lower than that of casting, sintering and cold spraying. Take the cold spraying as an example. As a deposition efficiency of 90 %, and powder carried speed of 30 g/min the

30300 mm<sup>2</sup> per minutes can be obtained if the coating thickness is 1mm. The comparisons of different manufacturing technologies are shown in table 1 [35, 36].

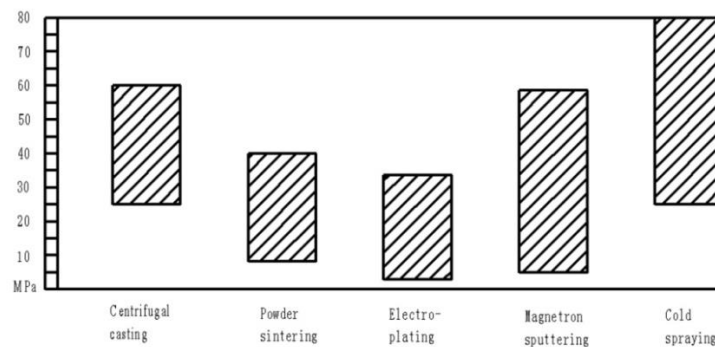


**Figure 9.** Bond strength of different manufacturing technologies

**Table.1** Performances of different coatings

| Manufacturing technologies | Production efficiencies | Oxidation | Layer thickness |
|----------------------------|-------------------------|-----------|-----------------|
| Centrifugal casting        | Middle                  | High      | >1mm            |
| Sintering                  | Middle                  | High      | >1mm            |
| Electroplating             | Low                     | Middle    | <20μm           |
| Magnetron sputtering       | Low                     | Low       | <15μm           |
| Cold spraying              | High                    | Low       | >1mm            |

The microstructures of copper and tin alloy of different manufacturing are shown in figure 10 [37-40]. It is found coating made by casting and sintering has some micro cracks. The compactness of coating made by cold spraying, magnetron sputtering are higher than that of electroplating, sintering and casting.

#### 4. Conclusion and suggestion

From above discussions, it is found that the porosity and oxidation of centrifugal casting and sintering are higher than that of other three manufacturing technologies. However, the vacuum environment can reduce the porosity. The other method is special module design, with the full chamber of molten alloy liquid, the air was expelled and the porosity was down [41]. The oxidation and porosity of electroplating and magnetron sputtering are lower than that of casting and sintering. However, their production efficiencies are lower too. The green plating should be studied because the common

solutions are environment pollutions. Cold spraying is a potential way to produce bearing bush. The main shortages of cold spraying are the high CoFs of coating. However, with the development of new materials, the common bearing bush manufacturing technologies may be replaced by cold spraying.

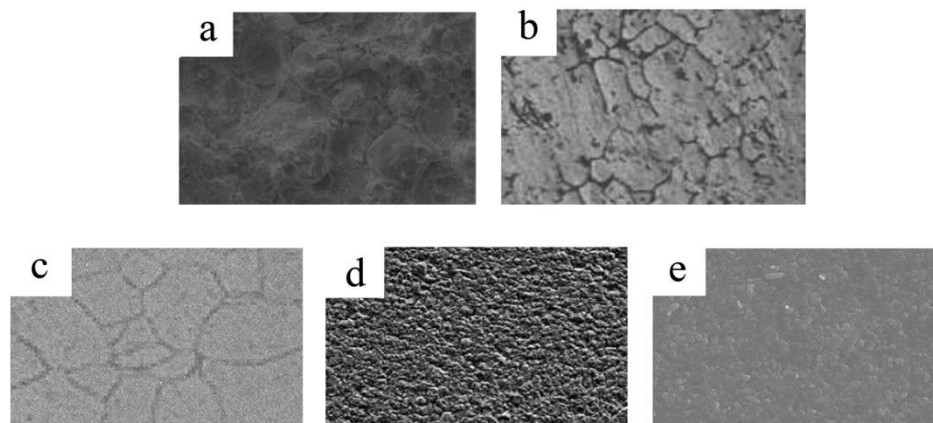


**Figure 10.** Microstructure of Cu-Sn alloy of different manufacturing technologies: (a) Cold spraying; (b) centrifugal casting; (c) Sintering; (d) Electroplating; (e) Magnetron sputtering

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