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Microstructure and tribological behaviors of diffusion bonded powder sintered Cu–Sn based alloys

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Abstract

Owing to good self-lubricating performance, tin bronze is widely used in industrial fields. As tin bronze parts manufactured by powder metallurgy, their tribological performances are influenced by raw powder. In this work, four types of self-lubricating copper alloy composites (CuSn10 (D), CuSn10, CuSn10Pb10 (D) and CuSn10Pb10) were prepared by sintering completely alloyed powder and diffusion alloyed copper tin powder. The morphology, element distribution and microstructure of raw powder and their sintered Cu alloy composites were observed. The tribological properties of Cu alloys were investigated by block-ring friction test under different working conditions and their worn surface and wear debris were analyzed. The results show that the diffusion alloyed powder has an irregular dendritic morphology and its sintered Cu alloy is more likely to produce twin structure which enhances the hardness and the bearing capacity of the material. Compared with completely alloyed powder sintered CuSn10 sample, the wear rate of CuSn10 (D) sintered from diffusion alloyed powder was reduced by 83.96%, 74.39%, and 67.63% under three typical working conditions. Under dry friction conditions, the wear rate of CuSn10 (D) is reduced by 63.64% than CuSn10, and CuSn10Pb10 (D) is 25% lower than CuSn10Pb10. The investigation on the wear tracks and wear debris of Cu alloy composites showed that the diffusion alloyed powder sintered samples are inclined to form a more consecutive and integral third-body layer on wear tracks and which contributes to the better wear resistance.

1. Introduction

Bimetallic composites are made of two different metal materials in different positions to achieve the comprehensive performance with the two metal materials [1]. As one component of bimetal construction, copper-based alloy plays an irreplaceable role in the journal bearing, pump, engine and coatings because of its outstanding self-lubricating properties [2, 3]. The preparation methods of copper based self-lubricating alloy composites include mechanical alloying [4–6], casting and powder metallurgy [7–9]. Traditional casting process tends to produce coarse reticular dendritic structure of α–Cu, which leads to intergranular segregation and negative segregation [10], and hot-cracking in metal materials [11]. All of these defects severely restricted the comprehensive performances of integral component. Powder metallurgy can avoid a series of shortcomings brought by the casting process, and possess the advantages of a simple process and cost saving [12].

The manufacturing of self-lubricating sliding bearing through sintering Cu powder on steel belt can be traced back to 1920’s. With the development of powder metallurgy, improving the tribological properties of Cu
Table 1. Powder details.

| Powder name | Proportion of metal components | Bulk Density (g cm\(^{-3}\)) | Particle size |
|-------------|--------------------------------|-------------------------------|---------------|
| CuSn10     | Cu: (89 ~ 91)%; Sn: (9 ~ 11)% | 2.70 ~ 2.95                  | +150 μm < 1%  |
| CuSn10(D)  | Cu: (89 ~ 91)%; Sn: (9 ~ 11)% | 2.70 ~ 2.95                  | +150 μm < 1%  |
| Pb          | Pb > 99.9%                    | 3.8 ~ 5.1                    | <50 μm        |

Table 2. The composition of the sample material (wt%).

| Number | Sample      | Cu   | Sn   | Pb  | Bi | Zn | Powder                  |
|--------|-------------|------|------|-----|----|----|-------------------------|
| 1      | CuSn10(D)   | Balance | 10 | —   | —  | —  | diffusion alloyed       |
| 2      | CuSn10     | Balance | 10 | —   | —  | —  | completely alloyed      |
| 3      | CuSn10Pb10 (D) | 10 | 10 | —   | —  | —  | diffusion alloyed       |
| 4      | CuSn10Pb10 | Balance | 10 | 10 | —  | —  | completely alloyed      |

based self-lubricating bearing lining materials become a research hotspot in recent years. For tribological performances of materials, wear rate is an important indicator for estimating lubricating material [13]. Numerous studies have reported that incorporating additives, such as graphite, molybdenum disulfide (MoS\(_2\)), titanium diboride (TiB\(_2\)), nickel, and silver powder, into alloy matrix can improve the anti-wear and mechanical properties of lubricating alloy [14–18]. However, the application of additives is limited because operating environment and lubricating condition influence the mechanical performances and service life of alloy. Moreover, Cu based self-lubricating composites are usually prepared through compacting and sintering mixed or atomized metal powder. Most of the metal powders used in the machine mixing method are elemental powders. The process of mechanical mixing alloy powder is liable to cause oxidation of metal powder, poor compaction of billet, uneven composition of alloy, and solute segregation defect [19–21], which all will bring about comprehensive performance degradation of Cu based self-lubricating composites. In order to avoid component segregation, the metal powder is completely melted in the sintering furnace, makes the components are fully mixed and alloyed, and then pulverized into fine droplets by the impact of fast-flowing liquid or gas, and then condensed into solid powder. This kind of powder prepared by the atomization method is called completely alloyed powder. It can completely guarantee the uniformity of the powder particles and fundamentally avoid various problems in the compounding process, but in the same way, the completely alloyed powder also reduces the compressibility and hardenability of the powder, and reduces the workability [22]. By contrast, diffusion alloyed powder is being paid more attention and used in recent years, diffusion alloying refers to heating the raw powder to near melting point and maintain temperature for a long time, so that the various components in raw particles diffused into each other. Then it is cooled at an appropriate temperature (diffusion annealing process), and finally diffusion alloy powder is obtained after pulverization. This kind of powder will form intermetallic compounds during the preparation process, while avoiding the disadvantages of uneven composition and solute segregation [23, 24], it can also greatly reduce the sintering activation energy, thereby reducing the sintering temperature and avoiding strength loss [25], and reduce the oxidation reaction and the content of matrix inclusions [26]. However, the mechanism and difference on tribological properties between diffusion alloyed powder and completely alloyed powder are still not clear yet. Therefore, Cu–Sn bronze matrix composites [27, 28], which have been widely used in tribology field for a long time, were selected as the metal matrix of the research object to investigate the effect of diffusion and completely alloyed powder on the tribological properties of their sintered alloy composites.

The aim of this work is to comparatively study the microstructures and tribological performances of CuSn alloy composites based on diffusion and completely alloyed powder. In this paper, we present our experiment and results on the tribological properties using the block-ring friction tester and the wear mechanisms. According to the observation and analysis of worn surfaces, the lubricating mechanisms of CuSn alloy composites sintered from two kind of raw powder are proposed.

2. Experimental details

2.1. Materials and preparation

The CuSn10 base powder used in this work is from Jiangsu Julian Metal Powder Co., Ltd., and the Pb powder is from Beijing Xingrongyuan Technology Co., Ltd. The powder details are shown in the table 1:

Table 2 shows the compositions of four CuSn based alloy composites in this study. (Note: ‘+150 μm < 1%’ means that the number of powders with a particle size greater than 150μm is less than 1% of the total.) The
CuSn10 sample was prepared through sintering diffusion alloyed CuSn10 powder and CuSn10Pb10 were prepared through sintering the mixture of diffusion alloyed CuSn10 and Pb powder. The quality of the powder used for sample mixing is shown in Table 3:

The bimetallic samples were prepared as shown in Figure 1. The metal powder was mechanical mixing according to the mass ratio in V type mixer for 5 h (only for CuSn10Pb10 (D)), then the powder was spread on steel backing. The first sintering was operating at 800 °C under reducing atmosphere protection for 1 h, followed by rolling. Then the second sintering and rolling were conducted at same process parameters. The test samples were tailored rectangle pieces (19.2 mm × 12.3 mm × 6 mm). The metallographic etchant for observing microstructure was prepared with 3.5 g ferric chloride (FeCl₃), 25 ml hydrochloric acid (HCl) and 75 ml distilled water.

### Table 3. The quality of powder used in the mixed powder.

| Sample name    | Elemental composition | Total capacity (cm³) | CuSn10 (g) | Pb (g) |
|----------------|-----------------------|----------------------|------------|--------|
| CuSn10         | Cu, Sn                | 45 × 10 × 0.03       | 100.320    |        |
| CuSn10(D)      | Cu, Sn                | 45 × 10 × 0.03       | 100.521    |        |
| CuSn10Pb10     | Cu, Sn, Pb            | 45 × 10 × 0.03       | 92.238     | 10.1264|
| CuSn10Pb10(D)  | Cu, Sn, Pb            | 45 × 10 × 0.03       | 92.775     | 10.2864|

(Note: ‘45 × 10 × 0.03’ refers to the total capacity of copper alloy powder on the steel backing. And 45 × 10 represents the length and width of the evenly spread powder, which is also the length and width of the steel backing. 0.03 represents the thickness of the spread copper alloy powder.)

CuSn10 (D) sample was prepared through sintering diffusion alloyed CuSn10 powder and CuSn10Pb10 (D) were prepared through sintering the mixture of diffusion alloyed CuSn10 and Pb powder.

The bimetallic samples were prepared as shown in figure 1. The metal powder was mechanical mixing according to the mass ratio in V type mixer for 5 h (only for CuSn10Pb10 (D)), then the powder was spread on steel backing. The first sintering was operating at 800 °C under reducing atmosphere protection for 1 h, followed by rolling. Then the second sintering and rolling were conducted at same process parameters. The test samples were tailored rectangle pieces (19.2 mm × 12.3 mm × 6 mm). The metallographic etchant for observing microstructure was prepared with 3.5 g ferric chloride (FeCl₃), 25 ml hydrochloric acid (HCl) and 75 ml distilled water.

### 2.2. Characterization

The hardness of sintered Cu alloy on steel backing was measured by HBS-62.5 Brinell hardness tester, and test was performed at 15.625 kg, 2.5 mm diameters of ball indenter and 30 s dwell time. The average hardness of each sample was obtained from 3 different positions, as showed in Table 4.

The friction and wear test were performed on MHR-3 high speed block ring tester (figure 2), the material of the mate ring is GCr15, and the surface roughness is Ra ≈ 0.15. The test condition is shown in table 5. The 10 W/40 CD + lubricating oil was used in oil-less and oil-rich condition, and its viscosity is 30 mm² s⁻¹ at 40 °C.

An optical microscope (Axio Imager.A2m, Zeiss) was used to observe the morphology of powder and surface topology of Cu alloy samples. Wear volume was measure by a two-dimensional surface profilometer, and wear rate was calculated as the following formula: Wear rate = V/(F·L), where V, F and L are worn volume (mm³), load (N) and distance (m), respectively. The morphology of metal powder and wear track were observed by scanning electron microscope (SEM, FEI Quanta FEG 650). The element distribution of powder particles and
the surface of wear tracks were detected by an energy dispersive x-ray detector spectroscopy (EDS, JSM-5600LV) and the x-ray diffraction (XRD) diagram of wear track surface were performed by a Bruker D8 Discover.

3. Results and discussion

3.1. Diffusion alloyed and completely alloyed powder
The SEM morphology of diffusion alloyed and completely alloyed CuSn10 powder are shown in figure 3. The diffusion alloyed CuSn10 particles have an irregularly dendritic structure, which can increase the contact area between particles to produce better binding force (figures 3(a), (b)). The size of diffusion alloyed CuSn10 particles range from 21.95 to 96 μm, and the average size is about 62.15 μm. Completely alloyed CuSn10 powder is regularly spherical or ellipsoidal particles. Their size distributes from 22.73 to 84 μm, and average size is 51 μm
(figures 3(e), (f)). The element distribution of the diffusion alloyed and completely alloyed CuSn10 particles are shown in figures 3(c), (d), (g), (h), respectively. Two tin-rich spots could be observed on the surface of diffusion alloyed CuSn10 particle (figure 3(d)), while the Sn element homogeneously distributes in the completely alloyed CuSn10 spheres (figure 3(h)). The difference on morphology and structure between two types of powder originate from their different manufactured process. The completely alloyed CuSn10 powder was manufactured by adding Sn to the Cu melted before atomization. The manufacture process results in homogeneous microstructures and uniform hardness even on a microhardness level. Hence, it could be seen that a homogeneous distribution of Sn element in each sphere as shown in figure 3(h). The diffusion alloyed CuSn10 powders are partially alloyed through diffusion bonding the alloying additions to the base Cu particles. Compared to the completely alloyed powders, diffusion bonded powders can retain the compressibility of the base copper and form heterogeneous sintered microstructures consisting of lightly alloyed particle cores with a continuous network of more highly alloyed interparticle bonds (figure 3(d)).

The XRD patterns of diffusion bonded and completely alloyed CuSn10 powders are shown in figure 4. Two kinds of powders have high purity and similar peaks. The most obvious two peaks are located at ~43.5° and 50.6° present α–CuSn phase [29, 30]. In the range from 70° to 100°, there are three small sharp peaks at 74.2°, 90° and 95.2°, all of which could be attributed to Cu, the corresponding hkl is (111), (220) and (311). It is worth noting that each one of them has a left shoulder peak located at 72.9°, 87.7° and 92.7°, respectively. These small peaks are belonged to Cu–Sn phase, the corresponding hkl is (111), (002), (022), (113) and (222). The relative intensity
of the three shoulder peaks in diffusion alloyed CuSn10 powder is a little weaker than them in completely alloyed powder, which indicates the alloying degree of CuSn10 in the latter is a little more than the former.

### 3.2. Sintered Cu composite samples

Before observing the metallurgical structure, the sintered Cu composite samples were polished for eliminating the oxides and impurities on the surface. The surface appearance and metallographic structure of CuSn10 (D) and CuSn10 samples are shown in figure 5. The CuSn10 (D) sample (figure 5(a)) has more pores than CuSn10 sample (figure 5(c)) sintered from completely alloyed powders. The pores formed during the solid solution of Sn and the Cu base, and the more pores, the more Sn dissolve in the Cu matrix, which will enhance the performance of Cu–Sn solid solution [31]. Moreover, more micro pores have better oil storage capacity under oil lubricating condition and facilitate the formation of lubricating oil film, which is beneficial to improve lubrication and anti-wear performance of Cu composites. CuSn10 (D) sample has more fine grains (figure 5(b)), which have an average size of 19.95 μm. Small grains make the material have higher strength and hardness at room temperature [32]. Material will undergo plastic deformation when it is subject to stress, and the stress will allocate to more grains, which reduce the component force on each grain, then the material obtains better bearing capacity. In addition, the smaller the grain size, the more grain boundary can inhibit the propagation of the fracture when the material is stressed [33], which can improve the strength and hardness of the material. The metallurgical structure of CuSn10 sample sintered from completely alloyed powder is shown in figure 5(d). It has an average grain size of 58.18 μm. Larger grain size reduce the toughness of the material and embrittles the material. Furthermore, CuSn10 sample has sharper grain boundary and less micro pores, so stress concentration is inclined to occur material inside and the grains will be cutting each other caused by dislocation motion, then result to the decrease of overall performance of the material [34].

Figure 6 shows the surface morphology and metallurgical structure of CuSn10Pb10 (D) and CuSn0Pb10, respectively. By comparing surface morphology of two samples (figures 6(a), (c)), it could be found that the morphological characteristics are similar to the morphology in figure 5, i.e., the CuSn10Pb10 (D) sample sintered from diffusion alloyed powder have more micro pores than CuSn0Pb10 prepared by completely alloyed powder. The average grain size of CuSn10Pb10 (D) (68.79 μm) is larger than CuSn10Pb10 (34.24 μm). It is worth noting that there is more twin structure in Cu composites sintered by diffusion alloyed powder (figures 5(b), 6(b)). The twins are formed as a result of the change of stacking fault energy caused by the sintering temperature difference and stacking fault between grains. Although the twins will decrease the plasticity of Cu composites, they also improve the hardness and strength of Cu alloy, which will enhance the anti-wear performance.
properties of Cu alloy to a certain extent. But the twins also increase the friction coefficient and inhibit the self-lubrication performance. Compared with the twins, the grain size has a more obvious strengthening effect on hardness of Cu composites alloy, which explains why the hardness of CuSn10Pb10 (D) sample with more twins and larger grain size is lower than CuSn10Pb10 with smaller grains.

3.3. Tribological performance
3.3.1. Oil-rich condition
The figure 7 shows the friction coefficients (COF) and wear rates of four Cu composites samples prepared by sintering diffusion alloyed or completely alloyed powder on steel backing under oil-rich condition. Under the
condition of oil-rich lubrication, the COF of Cu alloy sintered by diffusion alloyed powder (CuSn10 (D) and CuSn10Pb10 (D)) are higher than which sintered by completely alloyed powder (CuSn10 and CuSn10Pb10) at three different load-velocity conditions (figure 7(a)). Cu composites sintered by diffusion alloyed powder almost have higher COF at all working condition parameters. But the Cu alloy sintered by diffusion alloyed powder have better wear resistance. For CuSn10Pb10 material with lubricating soft Pb phase, the wear rates of CuSn10Pb10 (D) are lower than which of CuSn10Pb10 at the condition of 64 N-2745 rpm and 150 N-500 rpm (figure 7(b)). Comparing two CuSn10 samples, the CuSn10 (D) has the much lower wear rates than CuSn10 sintered from completely alloyed powder. Adopting the diffusion alloyed CuSn10 powder reduces the wear rates by 83.96%, 74.39% and 67.63% at three conditions of 64 N-2745 rpm, 100 N-2000 rpm and 150 N-500 rpm, respectively. Furthermore, in four samples, CuSn10 (D) has the lowest wear rate of 4.9074E−8 mm³/(N·m) at 150 N-500 rpm.

3.3.2. Oil-less condition

During the operating of mechanical equipment, the oil lubrication is not sufficient at the start and stop stage, hence, investigating the tribological performances of Cu alloy at oil-less condition has practical significance. In figure 8(a), under oil-less condition, the COF of four Cu composites increased with the load. The gap between friction surface of sample and mate ring decrease with the normal load, and the thin oil film cannot separate the friction surface completely. At this moment, the friction pairs are in boundary lubrication state. With one drop oil every 3 s, the consumed oil film at the interface cannot be replenished immediately, so the oil film is unable to fully play its lubrication role. However, the lubricating phase (Pb and Bi) in Cu composites make up for the lack of oil lubrication, so the CuSn10Pb10 has the lowest friction coefficients in four samples. The CuSn10 (D) sample has the highest COF until the load increased to 800 N, but the COF of two CuSn10 samples without lubricating constitutes are still higher than other samples. When the load increased above 800 N, the
CuSn10Pb10 sample sintered from completely alloyed powder has been worn out at 800 N, while the CuSn10Pb10 (D) sample sintered from diffusion alloyed powder not only has the lower wear rate at low and medium load, but also operated steadily at high load (figure 8(b)). For CuSn10 (D) based on diffusion alloyed powder and completely alloyed powder sintered CuSn10 sample, the former has the lowest wear rate at each load in the four samples. It suggests that the Cu alloy sintered from diffusion alloyed powder has the more excellent wear resistance.

3.3.3. Dry friction
When the lubricating oil is not well supplied, the friction pair is in dry friction state, so the self-lubricating property of lining material directly influence the service life of the machine [35]. The COF and wear rates of four Cu alloys under dry friction condition shows in figure 9. There is a negative correlation between friction coefficient and wear rate. The CuSn10Pb10 has the highest wear rate and lowest COF, and the CuSn10 (D) has the lowest wear rate, while its COF is only slightly higher than CuSn10Pb10 (D). Compared with CuSn10, the wear resistance of CuSn10 (D) was improved by 63.66% and CuSn10Pb10 (D) is 25% higher than CuSn10Pb10.

3.4. Wear track analysis
In order to figure out that why the Cu composites sintering from diffusion alloyed powder have the better self-lubricating properties than those sintered from completely alloyed powder, the worn surfaces of different Cu alloy samples were investigated. The SEM images of CuSn10 (D) and CuSn10 are shown in figure 10. In the wear
track of the CuSn10 (D) sample (figure 10(a)), there is no obvious furrows but a few tiny scratches on the relatively smooth worn surface. If zooming in the worn area, flake-like third-body layer adhered on the worn surface can be observed (figure 10(b)). The third-body layer formed by grinding and compacting the debris during the friction process, played a role of avoiding direct contact with friction pair surfaces [36, 37], and substituted the original Cu alloy sample surface. Although the third-body layer inhibited the directly plough of asperities on the mate ring and retarded the wear, it also be destroyed under constant frictional stress [37, 38]. The fractured third-body layer is shown in figure 10(b) inset, and another new layer stacked on the original layer because the wear debris (figure 10(c)) re-adhered by grinding. The irregularly shaped wear debris of CuSn10 (D) sample is shown in figure 10(c), and its element content is shown in figure 10(d). Intense Fe signal was detected in the CuSn10 (D) wear debris, which suggests that Fe exploited from the mate ring during friction and mixed in the wear debris from Cu alloy surface. When the asperities of the mate ring and the asperities of the Cu alloy shear each other, CuSn10 (D) also plough the mate ring to exploit the Fe. Figure 10(e) shows the wear scar of CuSn10 sample, in the figure that less continuous layers and a lot of scattered wear debris can be seen. EDS element analysis was performed on the area within the virtual frame in the enlarged image of the wear scar (figure 10(f)). The result is shown in figure 10(h). A large amount of Fe element was detected (figure 10(h)).

Figure 10(g) shows the wear debris of completely alloyed powder sintered CuSn10 is flake-like.

Being similar to the CuSn10 (D), consecutive third-body layer is also found on the worn surface of diffusion alloyed powder sintered CuSn10Pb10 (D) (figure 11(a)). Because the CuSn10Pb10 (D) has soft Pb phase, the third-body layer formed by a great quantity of wear debris was ploughed by hard asperities on the mate ring and
generated obvious furrows on the layer surface. In addition, as shown in figure 11(b), a few areas filled with wear debris are distributed on the third-body layer, which can be attributed to two reasons. One is the inhomogeneous distribution of exploited wear debris. The area accumulated more wear debris formed a consecutive third-body layer early under continuous grinding, while the area with fewer wear debris became a pit. Another might be the compression and squeezing action on the third-body layer or copper alloy substrate from the asperities on the mate ring. The harder asperities squeezed the wear debris and third-body layer to thicken the other third-body layer area and turned the squeezed areas into pits. The wear debris has a shape of small irregular particles as shown in figure 11(c). Moreover, those wear debris in the pits would participate the friction process again, and scratched the mate ring to cause the exploitation of Fe. The exploited Fe would accumulate at the ridge of pits on the third-body layer and be compacted. The figure 11(d) also shows the intense Fe signal around the pits.

Unlike CuSn10Pb10(D), completely alloyed powder sintered CuSn10Pb10 sample has no integral and consecutive third-body layer, only a small amount flake-like structure adhered on its wear track (figures 11(e, f)) and Cu alloy substrate exposed. Besides, the wear debris of CuSn10Pb10 has obvious flake shape (figure 11(g)), which is different from CuSn10Pb10(D) (figure 11(c)). At the ridge of third-body layer flake, there are a lot of cracks and scattered debris (the red box area in figure 11(f)). According to the element analysis in figure 11(h), the third-body layer and scattered debris were from Cu alloy substrate and very little Fe was transferred from the mate ring. It suggests that the strength of the third-body layer is not strong enough so that inclined to break and peel off, and is difficult to form a continuous and complete third-body layer. The figure 11(g) shows the a few pieces of third-body layers and plentiful wear debris. The discontinuous third-body layer was interrupted by wear debris.

Therefore, it is speculated that the formation of integral and consecutive third-body layer has some relationship to the shape of wear debris. The Cu composites sintered from diffusion alloyed powder are more likely to form the irregular sphere wear particles, while the Cu composites sintered from completely alloyed powder are inclined to generate the flake-like wear debris, which is averse to form the integral and consecutive third-body layer on wear tracks.

The figure 12 schemes the formation of third-body layer. At the initial stage of friction, the asperities on the surface of friction pairs contact and shear each other. Under the continuous shear and plough, amounts of asperities exploit from friction material substrate and accumulate at the interface to form wear debris. Being subjected to the grinding and compressing, the wear debris at interface deformation adhere together and bond to be a flake. With the continuous exploitation of asperities and accumulation of wear debris at the ridge of flake, the third-body layer continue to grow and form an integral and consecutive third-body layer at final.

The XRD diagrams of wear tracks on CuSn10Pb10(D) and CuSn10Pb10 samples are shown in figure 13. The four characteristic diffraction peaks (110) (002), (022) and (113) of CuSn in the original surface and wear scar area of the two samples are indexed, and the Pb characteristic peak (111) is indexed at 2θ = 31°. The characteristic diffraction peak of cuprous oxide (Cu2+ 10) is indexed at about 2θ = 93.6° and the crystal face index is (440). According to reports in the literature [38], there is more copper oxide in the friction layer on the Cu alloy substrate, which helps to form a third-body layer on the surface of the substrate. More Pb diffraction
peaks (200), (220) and (320) appear at 36.3° ~ 62.3° in the wear track and original surface of the completely alloyed powder, this confirms the uniformity of the composition of the completely alloyed powder.

4. Conclusions

Four Cu alloy composites were prepared through sintering diffusion alloyed powder and completely alloyed powder. The morphology and chemical distribution of two powder were observed, and the surface morphology and metallurgical structures of Cu alloys sintered from two type of powder are compared. The tribological properties of Cu composites were investigated under three lubricating condition (oil-rich, oil-less and dry friction) and their wear tracks, wear debris and third-body layer formed during dry friction were investigated. The results and conclusions are followings:

(1) The diffusion alloyed CuSn10 powder has an irregular dendritic structure, while the completely alloyed CuSn10 powder has a shape of regular sphere. The Cu alloys sintered from diffusion alloyed powder have more pores on surface and twin crystal structures than which sintered from completely alloyed powder.

(2) At different lubricating conditions, although Cu composites sintered from diffusion alloyed powder have slightly higher friction coefficient, they have excellent anti-wear performances. At dry friction condition, compared with CuSn10 sintered from completely alloyed powder, the CuSn10 (D) sample sintered from diffusion alloyed powder reduced the wear rate by 63.66%. The anti-wear properties of CuSn10Pb10 (D) increased 25% when compared with CuSn10Pb10. It suggests that adopting diffusion alloyed powder as raw material can improve the anti-wear properties of Cu alloy.
(3) Under dry friction, the wear debris generated from diffusion alloyed powder sintered Cu composites is irregular sphere like particles, and easier to form integral and consecutive third-body layer. The formation mechanism of third-body layer is also schemed.

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Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

Disclosure statement

No potential conflict of interest was reported by the author(s).

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