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Lubrication effectiveness of composite lubricants during P/M electrostatic die wall lubrication and warm compaction

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Abstract: The lubrication effectiveness of the composite lubricants, 50wt% ethylene bis-stearamide (EBS) wax + 50wt% graphite and 50wt% EBS wax + 50wt% BN, during the powder metallurgy (P/M) electrostatic die wall lubrication and warm compaction was studied. The results show that the combination of 50wt% EBS wax and 50wt% graphite has excellent lubrication performance, resulting in fairly high green densities, but the mixture of 50wt% EBS wax and 50wt% BN has less beneficial effect. In addition, corresponding die temperatures should be applied when different die wall lubricants are used to achieve the highest green densities.

Key words: powder metallurgy; composite lubricant; electrostatic; die wall lubrication; warm compaction

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1. Introduction

It is well known that increasing the density is the best way to increase the performance of powder metallurgy (P/M) parts [1]. Low green density leads to low green strength, which may be troublesome in many cases, since it may lead to lamination of marks, formation of cracks, edge blunting, and breaking of parts prior to sintering [2]. However, one of the disadvantages of using the admixed dry powder lubricant is that both the green density and the strength of the metallic part are less than those of no lubricant admixed due to the fact that the density of the lubricant particles is less than that of the metal powder particles and that the lubricant particles break the bonding between the metal particles. In fact, the density of common lubricants used is usually lower than that of the metal powders used. Another conventional lubrication in P/M is wet lubrication; however, wet lubricants promote clumping of the metal powders and adversely affect the flow characteristics of P/M materials, thereby limiting their successful application [3].

P/M electrostatic die wall lubrication is an advanced lubrication technique for making high density green compacts. This technique utilizes the balancing action between the electrostatic attractive force and repulsive force, thus resulting in the formation of a continuous, thin, and homogeneous dry lubricant film on the die wall [3-6]. This novel method overcomes the disadvantages of traditional wet lubrication and dry internal lubrication. As a result, it lubricates die wall better and results in higher density and better surface finish.

During warm compaction, it is required that powders and die be both preheated. It can increase the green density, and reduce the ejection pressure and the anelasticity by warm compaction [7-8]. The combination of P/M electrostatic die wall lubrication and warm compaction gives soft but not molten lubricant layer which is deformable [9]. This will effectively decrease the damage to the die in the course of ejection, thereby leading to a higher green density and a better surface finish.

The selection criteria for lubricants during warm compaction are: (1) the vitrification point of the lubricant has a good collocation with press temperature; (2) the lubricant has certain compressive strength and easily forms a piece of film on the metal particles surface during compaction; (3) the lubricant can prevent or decrease the oxidation of metal powders; (4) it can decompose below the sintering temperature and should not cause pollution to the environment; and (5) it should be cheap and easy to obtain.

The composite lubricants—50wt% EBS wax + 50wt% graphite and 50wt% EBS wax + 50wt% BN have some advantages as the following. (1) Graphite is

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very cheap and has good lubrication effect, which reduces commercial cost and improves economic benefits. In addition, graphite has good compressive strength. (2) It is required to increase the melting point of die wall lubricant during warm compaction, but simple polymers have their limits at this point. (3) BN acts as free-cutting additive powder, if it adheres to the surface of compacts during compaction and volatilizes incompletely during sintering, and therefore additional machinability can be achieved.

This study reports the experimental results of such composite lubricants and shows the practical merits of such lubricants for making high density green compacts.

2. Experimental

The 316L stainless steel powder mixed with 0.2wt% W-special wax powder was used as raw material. The powders were heated to 120°C and the die was heated to 130 or 150°C. EBS wax (particle size ≤74 μm), graphite (particle size ≤10 μm), BN (hexagonal, particle size 10-15 μm), mixtures of 50wt% EBS wax + 50wt% graphite and 50wt% EBS wax + 50wt% BN were used as die wall lubricants.

The weighed 316L stainless steel powder mixtures were compacted into cylinders with 10 mm in diameter and 8-10 mm in length. A total of 6-8 samples were compacted at the same compaction pressure. After warm compaction, densities of the samples were measured using the standard float water method for the powder metallurgy samples.

3. Results and discussion

3.1. Effect of composite die wall lubricants during warm compaction

The compacts had smooth, black, and lustrous appearances when pure graphite was used as die wall lubricant. Whereas the lubrication effect was fairly poor when pure BN was used, and harsh grating resulted during ejection, which would be harmful for both the compacts and the die.

As shown in Fig. 1, at the same warm compaction temperature (powders are heated to 120°C, die to 130°C), graphite as a single lubricant shows the best lubrication effectiveness; EBS wax shows better effect and BN shows the worst effect. The highest green densities can be achieved when the composite lubricant 50wt% EBS wax + 50wt% graphite is used. Its lubrication effect is much better than that of single lubricant EBS wax or graphite. This can be explained as follows: graphite has very high melting point (3527°C) [10], and so it is in almost the same state when warm compacted at 130°C or at room temperature. Whereas EBS wax has relatively low melting point (142-144°C) [11] and has some fluidity at 130°C, resulting in the improvement lubrication effect in the composite lubricant containing EBS wax. In addition, graphite has good compressive strength. Thus, the composite lubricant becomes a more excellent die wall lubricant than that used separately. The superiority of the composite lubricant is more obvious at high compaction pressures. It can be seen from Fig.1 that the green density of 316L stainless steel compacted at 915 MPa can be up to 7.40 g/cm^3 when such composite lubricant is used as the die wall lubricant.

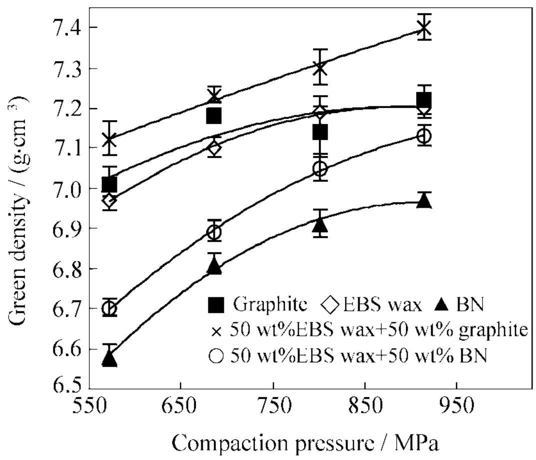

Fig. 1. Influence of different die wall lubricants on the green density of 316L stainless steel.

On the contrary, the composite lubricant 50wt% EBS wax + 50wt% BN has a intermediate lubrication effect between pure EBS wax and pure BN. This proves that the addition of EBS wax does improve the lubrication effectiveness of BN. For example, 316L stainless steel green compacts have the densities of 7.20, 7.13, and 6.97 g/cm^3 at 915 MPa when pure EBS wax, composite lubricant 50wt% EBS wax + 50wt% BN, and pure BN lubricate the die wall, respectively.

Fig. 2 shows the morphology of 316L stainless steel warm compacted at 801 MPa when the powders were heated to 120°C, die to 130°C, and the composite lubricant 50wt% EBS wax + 50wt% graphite was used as the die wall lubricant. It can be seen that the particles show dramatic distortion and tightly associate with each other. A large amount of subgrains can be seen inside the particles, and the grain sizes are less than 2-3 μm. The compacts with large amount of fine subgrains lead to accumulation of high strain energy, which will be transformed into the driving force during the subsequent sintering, thereby activating the sintering process [12].

The combination of composite die wall lubricants and warm compaction can achieve higher green densities, which is due to the following two reasons. (1) Composite lubricants can achieve better lubrication effectiveness than single lubricants because EBS wax has better lubrication effect during warm compaction than at room temperature, and graphite has good compressive strength. Thus, the composite lubricant becomes a more excellent die wall lubricant than that used separately. The superiority of the composite lubricant is more obvious at high compaction pressures. (2) Plastic deformation of metal powders can be enhanced by warm compaction, which leads to a dramatic improvement in the compression effect of metal powders. Thus, higher green densities can be achieved.

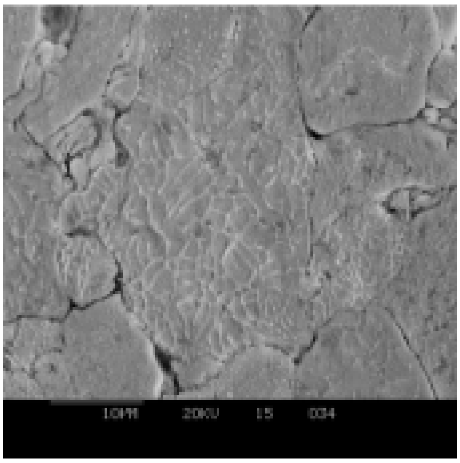

Fig. 2. Morphology of 316L stainless steel warm compacted with the composite die wall lubricant 50wt% EBS wax + 50wt% graphite.

3.2. Influence of die temperature on green density

Warm compaction temperature has significant effect on green density. As shown in Fig. 3, when the mixture of 50wt% EBS wax + 50wt% graphite is used as the die wall lubricant, 316L stainless steel powders have higher green densities at the die temperature of 130°C compared with those at 150°C. This is attributed to the fact that EBS wax has melted at 150°C and has considerably affected the lubrication effect of the composite lubricant, whereas the lubrication effect of graphite has been little influenced when the die temperature is increased only by 20°C from 130 to 150°C. So, the composite lubricant 50wt% EBS wax + 50wt% graphite has worse lubrication effectiveness at the die temperature of 150°C than at 130°C. It indicates that the operating temperature of this composite lubricant should not be above 130°C.

However, when the composite lubricant 50wt% EBS wax + 50wt% BN lubricates the die wall, 316L stainless steel compacts have similar green densities at the die temperatures of 130 and 150°C. The differences of the green densities between the two temperatures are less than 0.1 g/cm^3 from 572 to 915 MPa, as shown in Fig. 4. This is due to the fact that BN is more suitable for lubricant at high temperatures [10]. It has better lubrication effectiveness when the die temperature is increased from 130 to 150°C. Whereas the molten EBS wax might weaken the lubrication effect simultaneously, leading to the comparative lubrication effectiveness at two die temperatures. So, 316L stainless steel compacts have comparative green densities.

In short, corresponding die temperatures should be applied when different die wall lubricants are used to achieve the highest green densities.

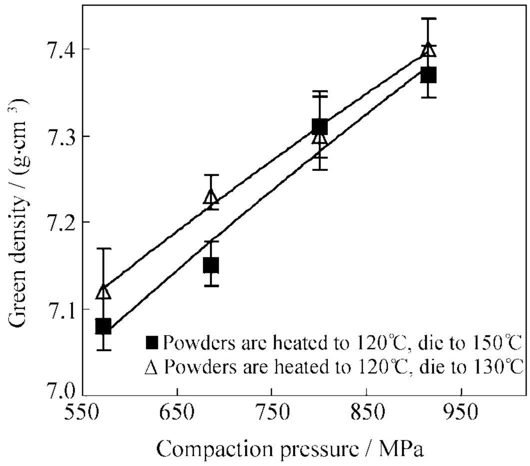

Fig. 3. Influence of various die temperatures on the green density of 316L stainless steel (50wt%EBS wax+50wt% graphite as the die wall lubricant).

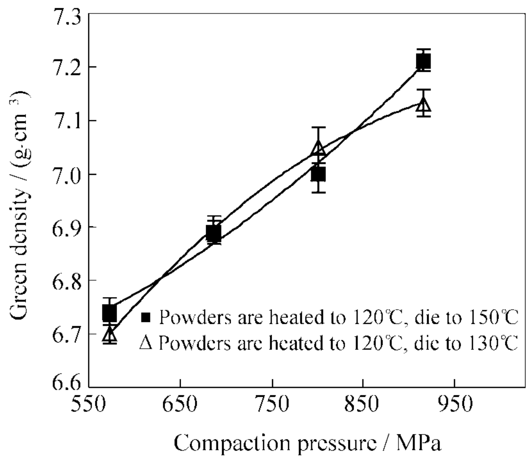

Fig. 4. Influence of various die temperatures on the green density of 316L stainless steel (50wt%EBS wax + 50wt% BN as the die wall lubricant).

Another important phenomenon during this experiment was that graphite and BN adhered to the surface of the compacts after warm compaction. As die wall lubricants, they only remained on the surface and did not penetrate to the inside. So they would not influence the properties of 316L stainless steel. BN on the surface can give additional machinability.

4. Conclusions

(1) Graphite as a single lubricant shows the best lubrication effectiveness; EBS wax shows better effect and BN shows the worst effect.

(2) The composite lubricant 50wt% EBS wax + 50wt% graphite has better lubrication effect compared with that used separately. Higher green densities can be achieved when such composite lubricant lubricates the die wall.

(3) Corresponding die temperatures should be applied when different die wall lubricants are used to achieve the highest green densities.

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