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Die wall lubricated warm compaction of iron-based powder metallurgy material①

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[Abstract] Lubricant is harmful to the mechanical properties of the sintered materials. Die wall lubrication was applied on warm compaction powder metallurgy in the hope of reducing the concentration level of the admixed lubricant. Iron-based samples were prepared by die wall lubricated warm compaction at 175 ℃, using a compacting pressure of 550 MPa. Emulsified polytetrafluoroethylene(PTFE) was used as die wall lubricant. Admixed lubricant concentration ranging from 0 to 0.5% was tested. Extremely low admixed lubricant contents were used. Results show that in addition to the decrease in ejection forces, the green density of the compacts increases with the decrease of admixed lubricant content until it reaches the maximum at 0.06% of lubricant content, then decreases with the decrease of admixed lubricant content. The mechanical properties of the sintered compacts that contain more than 0.06% admixed lubricant are better than those of the samples that contain lesser lubricant. No scoring was observed in all die wall lubricated experiments.

[Key words] warm compaction; die wall lubrication; powder metallurgy iron-based material
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1 INTRODUCTION

It is well known that increasing density is the best way to improve the performance of the powder metallurgy (PM) parts. Conventional PM processing can produce iron-based parts with a density less than 7.1 g/cm^3 (a relative density of approximately 90%). Their mechanical properties are substantially worse than those of their full density counterparts. Warm compaction is a low cost and simple process that can obtain high relative density PM parts[1~3]. With minor modification on the conventional equipment and approximately 20% higher on the cost of conventional cold compaction, green compact density of 7.5 g/cm^3 can be obtained by single pressing. The only difference between the warm compaction and the conventional compaction is that the powder has to be treated with special lubricant, then the powder was raised to the prefixed temperature and pressed in the die, which maintained at the warm compaction temperature. Industrialization of the technique matured in the mid 1990s. Since then, it attracts a lot of attention worldwide. In China, Cao et al[4, 5] developed a series of iron-based powder specially for warm compaction use. Several authors studied the effects of processing parameters on the properties of the sintered iron-based alloys and the densification mechanism of warm compaction[6~9]. Fabrications of particulate reinforced iron-based composite using warm compaction technology were also studied[10~12].

The success of warm compaction technique relied on the correct use of special lubricant; however, it is well known that there is a dilemma in using lubricant. Lubricants are essential for the die compaction of metal powder to overcome friction and avoid scoring. On the other hand, the presence of lubricant may lower the sintered density and decrease the mechanical properties of the compact. Practically no lubricant can burn off completely during sintering and leaving ashes inside the compact, thereby, hinder the diffusion process during sintering. Meanwhile, gas pressure generated by dissociation or evaporation of the lubricant during pre-sintering or sintering stage may create more voids in the compact and lower the compact's dimension stability. The vaporized lubricant is harmful to the quality of the sintered compacts and to the furnace. The admixed lubricant also lowers the flow rate of powder and lingers the compaction cycle time. Therefore, the elimination of admixed lubricant in metal powder blends has long been a dream for PM industry.

Admixed lubricant is important for compacting metal powders in a die, since it reduces the inter-particle friction, particle-die wall friction and ejection force. As

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pointed out by many workers[13, 14], the most important role for lubricant is to overcome die wall friction rather than inter-particle friction. Several researchers[15~20] have investigated die wall lubrication as an alternative to admixed lubricant in metal powders and some effort has been spent towards systems that can provide die wall lubrication. Ball et al[20] applied dry powder lubricant on die wall using a tribostatic spray gun and this system successfully marketed in 1996[21]. The aim of this study is to study the effect of die wall lubrication on warm compaction powder metallurgy in hope to reduce the minimum required concentration level of the admixed lubricant.

2 EXPERIMENTAL

Chemical composition of the samples in mass percent is 2 %Ni, 0.4 %Mo, 0.6 %Mn, 0.45 %Si, 0.4 % C(graphite) and with Fe as the balance. Unless mentioned, all concentration reported in this paper were in mass percent. Atomet 1001 atomized iron powder, which was produced by Quebec Metal Powders, Canada, was mixed with other alloying elemental powders and special lubricants. The particle sizes of the iron powder was ⩽147 μm. Carbonyl nickel with a size of ⩽5 μm was used. The particle size of other elemental powders were ⩽74 μm. The mixing time was 90 min. The admixed lubricant concentration used in this study was ranging from 0 to 0.5%. Extremely low admixed lubricant contents of 0.02%, 0.06%, 0.125% and 0.25% were used.

The pre-heated mix powders were pressed into standard tensile specimens(ISO 2740-1973) in a steel mold, which was heated to a temperature of 175 ±2 ℃. Emulsified polytetrafluoroethylene(PTFE) was brushed on the inner surface of the die wall as die wall lubricant. A compacting pressure of 550 MPa was used. Samples were degassed at 600 ℃ for 1.5 h in the pre-heating chamber of a pusher type furnace with all its chambers protected by a dissociated ammonia atmosphere. Sintering was carried out at a temperature of 1 200 and 1 250 ℃ for 1.5 h in the sintering chamber then held at 850 ℃ in the cooling chamber for 1 h and subsequently cooled to room temperature. Green density, sintered density, tensile strength and elongation percentage were measured. Green and sintered densities were measured by water displacement method. A computer controlled universal tensile testing machine was used to measure the ultimate tensile strength and elongation.

Samples for ejection force measurement was cylindrical in shape with 20 mm in diameter and 20 mm in length. These samples, which contain 0.5% of special lubricant, were warm compacted at 175 ℃ using compaction pressure of 550 and 700 MPa. For comparison purpose samples compacted with and without die wall lubrication were prepared. Ejection forces were read from the gauge equipped in the hydraulic press. Data reported in this study were the average of at least three separate measurements.

3 RESULTS AND DISCUSSION

Fig. 1 shows the relationship between density and admixed lubricant concentration for samples prepared by die wall lubricated and non-die wall lubricated warm compaction using a compaction pressure of 550 MPa and a compaction temperature of 175 ℃. In this study our results indicate that warm compaction without die wall lubrication for samples containing 0.125% or less of admixed lubricant is not practical due to the insufficient lubrication during the ejection process. Compared with non-die wall lubricated samples, the die wall lubricated samples have higher densities. In the admixed lubricant concentration range of 0 to 0.5 % both green and sintered densities increase with the decrease of lubricant concentration until it reaches the maximum at 0.06 % of lubricant content, then decreases with the decrease of admixed lubricant content.

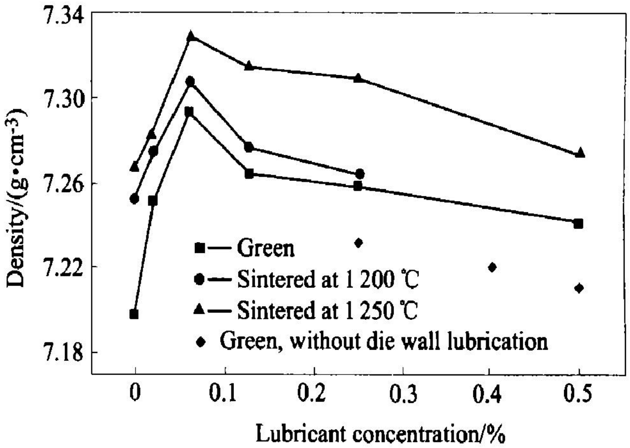

Fig. 1 Relationship between density and lubricant concentration

Friction between the compact and the die wall will increase the ejection force. If the admixed lubricant content is too low, it is not enough to reduce the ejection force to an acceptable level. If there is too much lubricant, density and mechanical properties of the sintered compact will be lowered. Result shows that die wall lubricated warm compaction can produce compacts with higher densities than those obtained from regular warm compaction. This result is expected, since PTFE has a very low friction coefficient and as mentioned earlier, the major friction problem is between the powder and the die wall, PTFE on the die wall reduces a great portion of the friction during compaction and thus increases the effective pressure on the powder. This increase in effective pressure on the powder is responsible for the increase in compact's density and there is no reason to suspect that the die wall lubrication will alter the densification mechanism of the warm compaction process. As shown in Fig. 1, the density of warm compacted samples with die wall lubrication increases with the decrease in admixed lubricant concentration until it reaches the maximum at 0.06% of lubricant content, then decreases with the decrease of admixed lubricant content. The presence of admixed lubricant occupies spaces in the compact in expense of the relatively heavier metal powders and unavoidably lowers the green density of the compact. Interparticle friction can be reduced by admixed lubricant and therefore beneficial to the densification of the powder compacts and gives compacts with better quality. For sample contains very little amount of admixed lubricant, the inter-particle friction will hinder the particle rearrangement during the compaction process and thus reduce the green density to certain extent. Therefore, there exists an optimal admixed lubricant concentration that can produce compact with highest green density. In this study, the optimal content is 0.06%. When the lubricant concentration is less than 0.06 % the lubrication between the powder particles is not strong enough to facilitate the particle rearrangement and leads to the drop in compact density.

Figs. 2 and 3 show the tensile strength and elongation versus the admixed lubricant concentration for samples sintered at 1 200 ℃ and 1 250 ℃, respectively. Samples were prepared by die wall lubricated warm compaction at a compaction pressure of 550 MPa and a compaction temperature of 175 ℃. Both tensile strength and elongation are closely related to the sintered density of the samples. Although compacts containing 0.06% of admixed lubricant will give the maximum density, the overall mechanical properties of the sintered compacts that contain 0.125% or more of admixed lubricant is slightly better than those of the samples that contain less than 0.125% of admixed lubricant. The reason for this is that the insufficiency of admixed lubricant will enhance the uneven density distribution and thus leads to lower mechanical properties.

The ejection force data in this study were read from the gauge equipped in the hydraulic press, it is not accurate enough for quantitative analysis. All these data indicate that samples with die wall lubrication show lo-

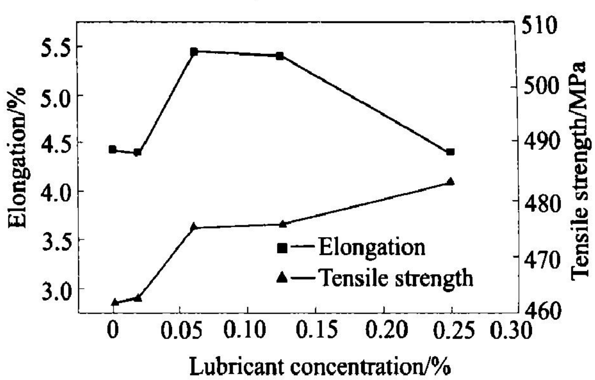

Fig. 2 Elongation and tensile strength vs lubricant concentration for samples sintered at 1 250 ℃

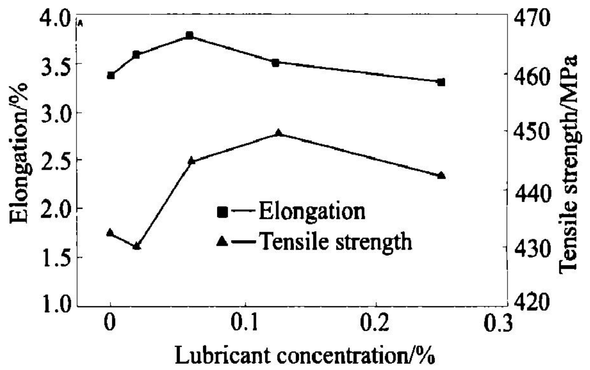

Fig. 3 Elongation and tensile strength vs lubricant concentration for samples sintered at 1 200 ℃

wer ejection forces. At compaction pressure of 700 MPa the ejection force for die wall lubricated case was 16 kN compared to 27 kN for the non-die wall lubricated case, the ejection force for die wall lubricated sample was approximately 60% of that of the non-die wall lubricated sample. At compaction pressure of 550 MPa the ejection force for die wall lubricated case was 11 kN compared to 17 kN for the non-die wall lubricated case, the ejection force for die wall lubricated sample was approximately 65% of that of the non-die wall lubricated sample. No scoring was observed in all die wall lubricated experiments even for samples that contain no admixed lubricant.

Degoix et al[22] investigated the effect of lubrication mode and compaction temperature on the properties of Fe-2Ni-2Cu-0.85Mo-0.8C. Their results did not agree well with our results. They used 0.25% PTFE as lubricant in three different ways: 1) dry admixed to the powder; 2) die wall lubricated by PTFE-alcohol suspension without admixed lubricant; and 3) wet mixed using PTFE-alcohol suspension. Samples were prepared by compacting the powders with a pressure of 690 MPa at room temperature and 150 ℃. The green compacts were sintered at 1 300 ℃ for 50 min. They found that the wet mixed lubricant gave the worse results in density and strength, and the dry admixed lubricant gave the highest sintered density and strength, and lowest in ejection forces under their experimental condition. The die wall lubricated warm compaction at 150 ℃ gave the highest green density. Their sintering temperature was 1 300 ℃, which was higher than the sintering temperature we used in this study. The biggest contradiction between our results and their results are about the ejection forces. They found that die wall lubricated warm compaction needed a bigger ejection force. Their result showed that die wall lubricated warm compaction needed an ejection force of 40. 1 kN instead of 34. 8 kN for admixed lubrication. Where, our data indicated that the ejection force for die wall lubricated sample was approximately 60% of that of the non-die wall lubricated sample. The reason for this is that the way they apply the die wall lubricant by using PTFE-alcohol suspension is not effective. There is no guaranty of PTFE adhered on the die wall. In our case PTFE emulsion was used, a film of PTFE remains on the die wall can be seen. Our results indicated that under experimental condition used in this study die wall lubricated warm compaction would give the highest green density and lowest ejection force. Combination of die wall lubrication and warm compaction can reduce the required concentration level of the admixed lubricant and meanwhile provide PM products with higher density and better quality. It is a feasible way to produce high performance PM parts if suitable die wall lubrication system was applied.

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