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Effect of Lubrication on the Improvement of Uniformity in Uniaxial Powder Compaction*

Yukinori TANIGUCHI**, Kuniaki DOHDA*** and Zhrgang WANG***

Density distribution in powder compact caused by frictional force at die wall has been estimated. The pressure transmission ratio λ was defined for the estimation of the magnitude of frictional force occurrence on die wall. The density gradient α was also defined for the estimation of density distribution. The iron and pre-alloyed stainless steel powder were tested, and the performance of zinc stearate and paraffin wax applied as internal lubricant or die wall lubricant has been investigated in various conditions. The die wall lubrication becomes effective way to increase λ in comparison with the internal lubrication. Admixed lubricant prevents the occurrence of density distribution and uniform green compact is obtained in the critical amount of lubricant. Paraffin wax shows higher performance as a die wall lubricant compared with zinc stearate, and remarkable increase of lubrication effect is observed in the combination between zinc stearate as internal lubricant and paraffin wax as wall lubricant.

Key Words: Powder Compaction, Die Wall Lubrication, Density Distribution, Zinc Stearate, Paraffin Wax

1. Introduction

In metal powder compaction process using uniaxial die system, the powder compact made has usually density distribution inside. Density distribution causes the deviations from original shape of green compact during sintering process. Moreover the mechanical properties of product decline locally by un-uniform density. The uniformity of density in powder compact is known to be particularly sensitive to the friction between powders and die wall because the frictional force creates high stress gradients during compaction. The interparticle friction also affects uniformity, especially the occurrence of density distribution in packing powder into die cavity, and in early stage of densification. Therefore using lubricant becomes very important ways to decrease friction at tool walls or interparticle friction in powder compaction process. Usually, zinc stearate of 0.5 – 1.0 wt.% is admixed in metal powder beforehand. On the other hand, too much lubricant obstructs the densification of powder during compaction because lubricant is filled into the pore and disperses the forming pressure. In these viewpoints, die wall lubrication has advantage which can produce high density powder compacts without forming pressure increase. Some technical approaches that investigate the die wall friction have been published(1)–(4), but detailed investigation about the behavior of lubricant (applied as internal or die wall lubricant) including influence on uniformity of density has not been conducted. Therefore the behavior of admixed lubricant and die wall lubricant should be deliberated synthetically to optimize the lubrication for the improvement of uniformity of density in uniaxial powder compaction process.

This study provides some knowledge about the lubrication on the improvement of uniformity in uniaxial die compaction process. Iron powder and stainless steel powder were tested, and the performances of zinc stearate and paraffin wax have been investigated. A few experimental investigations have been carried out in order to consider the behavior of lubrication on the density distribution occurrence of powder compact regarding the effect of lubricants which is admixed into powder or deposited at die wall. The magnitude of frictional force on die wall during compaction and the axial density distribution of powder compact were estimated on various conditions in lubrication.

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2. Experimental Procedure

2.1 Force balance measurement

Force balance during compaction has been investigated by force balance test to estimate the frictional force occurrence on die wall surface. Figure 1 shows a combination of tools (upper punch, lower punch, and die with a φ20 mm cavity). Two load cells are installed to measure the difference between the upper punch force and the lower punch force. The frictional force transmitted through the die wall surface to the base also can be measured by transducer that consists of spacer with strain gauges. The variation of the height of compact during compaction is measured by dial gauge. These data are logged by PC continuously through the amplifier. Figure 2 shows the variation of the forces (upper punch force, lower punch force, and die force) with the height of compact. δ means a difference between upper and lower punch forces, and shows same value as the die force measured by transducer. Thus the frictional force between the powder and the die wall surface is expressed by δ as a difference between each punch forces.

2.2 Estimation of the axial density distribution

In this study, the density distribution of the powder compact is estimated as a slope of axial density variation along distance from upper punch surface. A special compaction method to separate a powder compact⁽⁵⁾ is used for measurement of the local density. Figure 3 shows a production method of the separable powder compact. Powder is filled into a cylindrical die and compacted in low pressure, and then upper punch is ejected and powder is refilled on the pre-compact. Finally, both of the pre-compact and the refilled powder are compacted at high pressure to densification. The powder compact made by this compaction method has separable plane inside, and can be divided at single plane which is perpendicular to the axial direction. In the measurement, powder compact is divided into four parts and these local densities are measured individually by Archimedes method. Thus the axial density difference of the powder compact is measured directly.

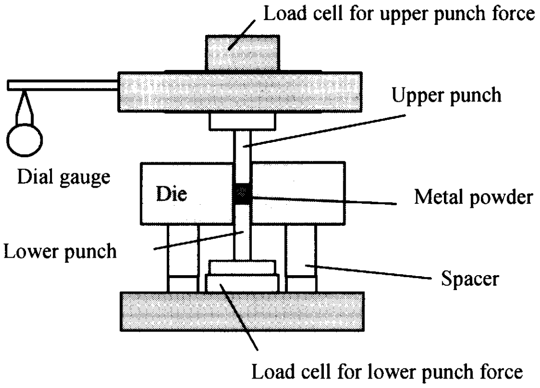


Fig. 1 Principle of the force balance test

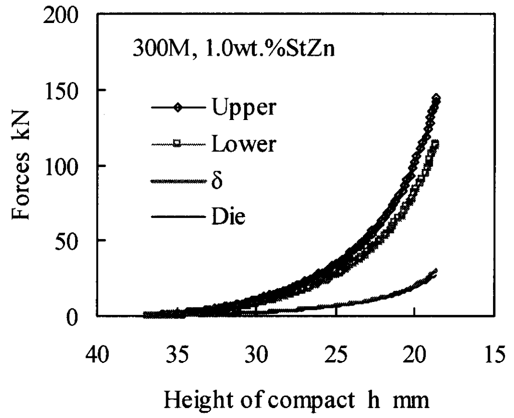


Fig. 2 Variation of forces with height of compact

2.3 Experimental conditions

Two kinds of different powders ware tested: atomized iron powder (Kobe steel, 300 M) and pre-alloyed atomized stainless steel powder (Daido steel, DAP430L). Each powders show irregular particle shape. Zinc stearate (StZn) and paraffin wax (Wax) were admixed to estimate its effects as an internal lubricant. Moreover, each lubricant was deposited on the die wall surface by spraying and drying with acetone to estimate its effects as a die wall lubricant. In the force balance test, each powder was compressed till 570 MPa of compaction pressure as a constant value. In the estimation of axial density distribution, each powder was compressed to its final height $H = 20$ mm in the end of compaction, so that the ratio of compact height to diameter is obtained as about $H/D = 1.0$. The weight

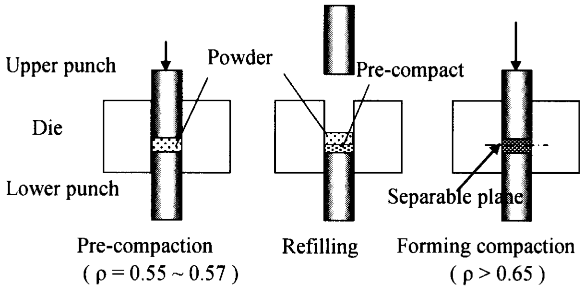


Fig. 3 Production method for separable specimen

Table 1 Experimental condition for the estimation of the axial density distribution

Powder material	300M (Atomized Iron) DAP430L (Atomized Stainless Steel)
Lubricant	Zinc Stearate, StZn Paraffin Wax, Wax
Amount of lubricant	0~2.55wt.%(StZn) 0~1.76wt.% (Wax)
Density of lubricant	1.14 g/cm^3 (StZn) 0.80 g/cm^3 (Wax)
Weight of powder	42.0g + lubricant amount g
H/D	about 1.0
Density ratio ρ	about 0.85

of powder is 42.0 g + lubricant amount g, and as a result density ratio ρ which is defined as the ratio of the compact density to materials density becomes $\rho = 0.85$. The density of each lubricant is 1.14 g/cm^3 in case of StZn, and is 0.8 g/cm^3 in case of Wax. Hence the critical amount of each lubricant becomes 2.55 wt.% in case of StZn, and becomes 1.76 wt.% in case of Wax. The experimental condition for the estimation of the axial density distribution is shown in Table 1.

3. Experimental Results

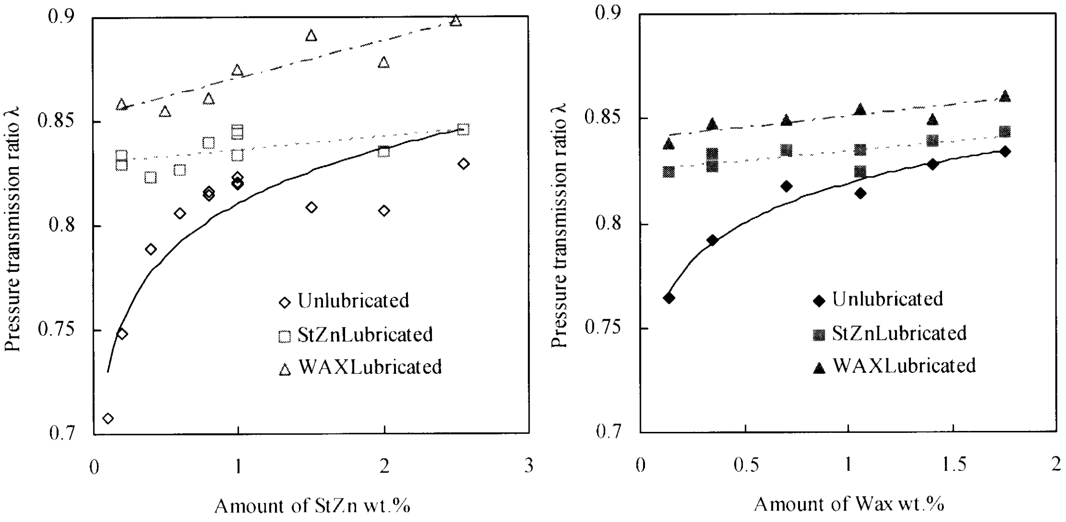
3.1 Behavior of lubricant on pressure transmission

The relation between upper and lower punch force in the force balance test shows almost linear, so that an assumption is possible as follows;

$$F_l = \lambda F_u \tag{1}$$

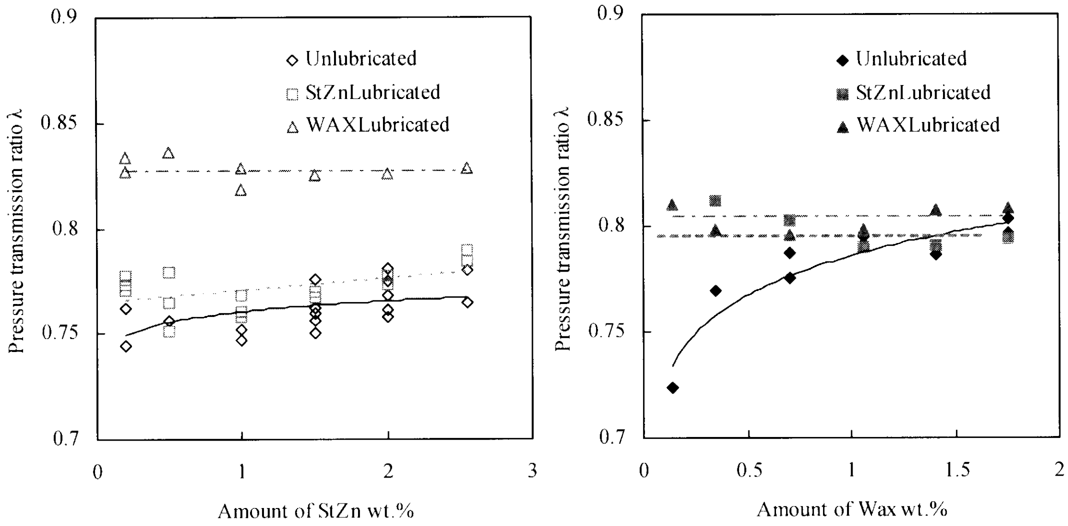
F_u and F_l is upper punch force and lower punch force respectively. Thus the pressure transmission ratio λ was defined to estimate the effect of lubrication. The relations between the λ and amount of admixed lubricant are shown in Figs. 4 and 5. The results that conducted die wall lubrications are also shown.

In the condition of unlubrication, λ increases rapidly with increasing the lubricant amount till 1.0 wt.% for the case of StZn, or 0.7 wt.% for the case of Wax. The amount of each lubricant shows the same value when converted into the volume. For example, when the powder is com-



(a) Zinc stearate (b) Paraffin wax

Fig. 4 Relations between the pressure transmission ratio λ and amount of admixed lubricant (Iron powder, 300 M)



(a) Zinc stearate (b) Paraffin wax

Fig. 5 Relations between the pressure transmission ratio λ and amount of admixed lubricant (Stainless steel powder, DAP430L) pacted to $\rho = 0.85$, these volume occupies 40% to the porosity of powder compact. The effect of admixed lubricant becomes negligible when the amount is increased any further.

In all tested conditions, each die wall lubricant efficiently increases λ when lubricant amount is few. Especially, paraffin wax shows the significant effect as the die wall lubricant and its effect becomes more efficient when StZn is used as the internal lubricant. In contrast the difference on effect of admixed lubricant between StZn and Wax is not observed in any other condition. Remarkable difference on the behavior of lubricants between iron powder and stainless steel powder does not exist but stainless steel powder shows lower λ value compared with iron powder.

3.2 Behavior of lubricant on density distribution

Figure 6 shows the relation between the local density

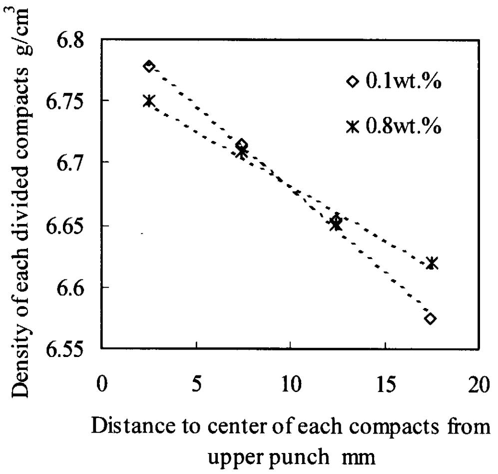
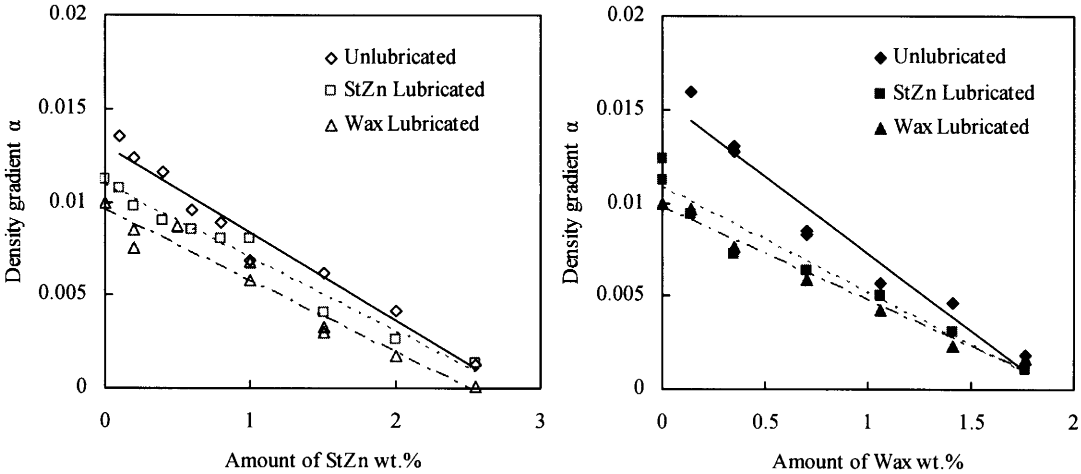
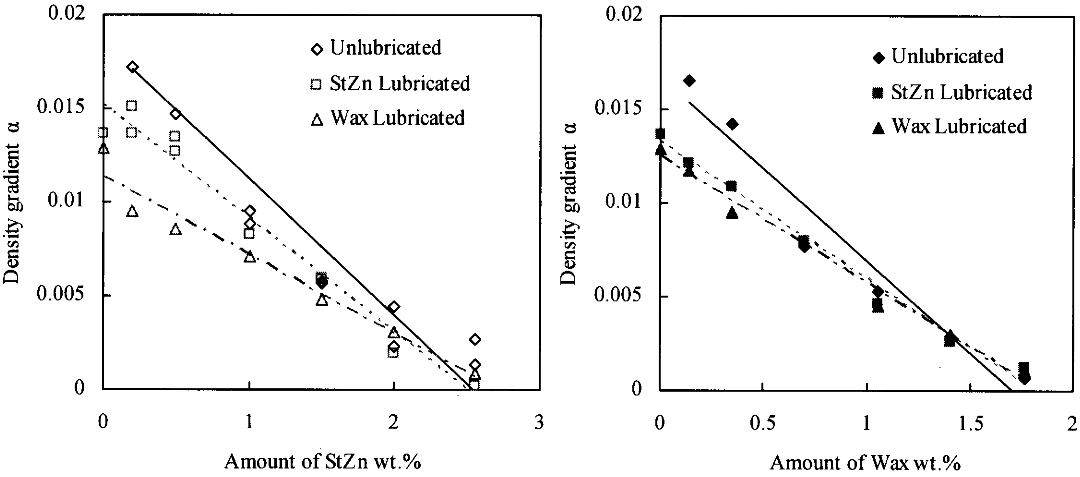


Fig. 6 Relation between the local density of compact and the distance from upper punch surface



(a) Zinc stearate (b) Paraffin wax

Fig. 7 Relations between density gradient α and the amount of admixed lubricant (Iron powder, 300 M)



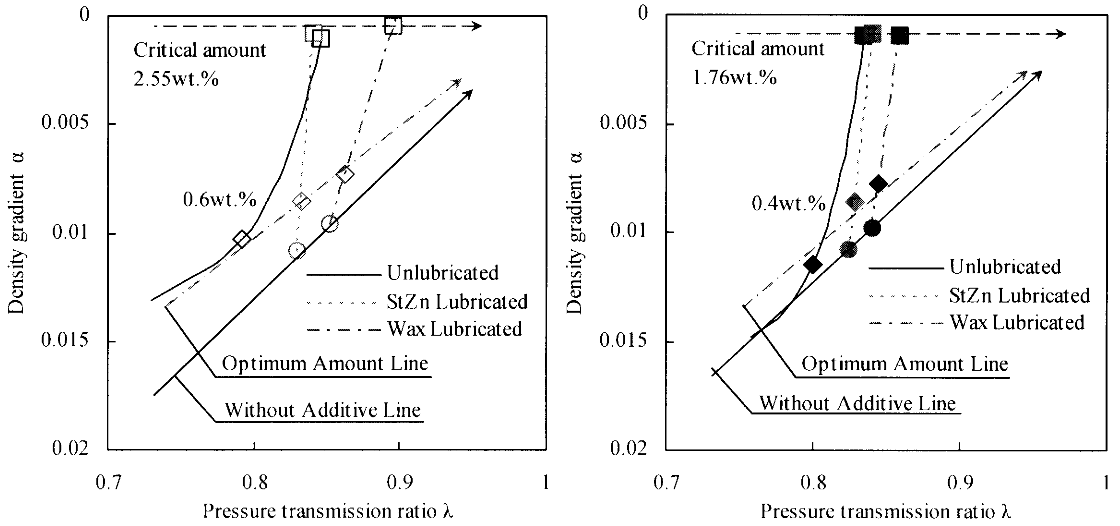
(a) Zinc stearate (b) Paraffin wax

Fig. 8 Relations between density gradient α and the amount of admixed lubricant (Stainless steel powder, DAP430L) of compact and the distance from upper punch surface. Compact density decreases with increasing the distance from upper punch and this relation is found to be linear function. Therefore the magnitude of axial density variation can be defined as a gradient of this line. In this study, density gradient α was adopted for the estimation of the effect of lubrication on the uniformity of density.

Figures 7 and 8 shows the relations between density gradient α and the amount of admixed lubricant. α decreases almost linearly with increasing lubricant amount, and uniform compact is obtained in the critical amount. The die wall lubrication is also effective but its effect is relatively low compared with the effect of internal lubrication. The differences on the effect of lubrication between StZn and Wax is comparatively few whether it is applied as internal lubricant or wall lubricant, except the combination with StZn as internal lubricant and Wax as wall lubricant. This tendency corresponds with the behavior of lubricants on the pressure transmission ratio λ.

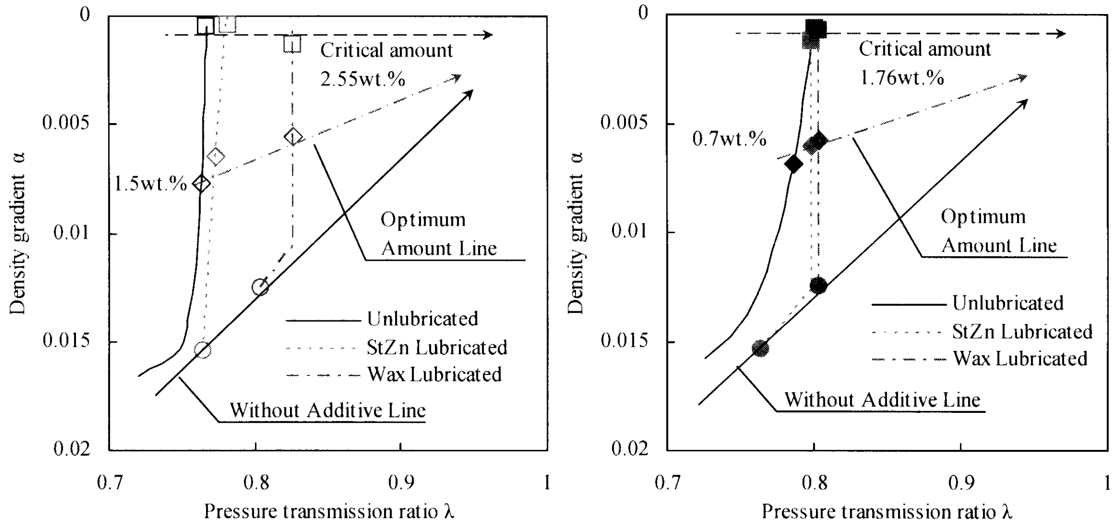
4. Discussions

Figures 9 and 10 shows the relation between density gradient α and pressure transmission ratio λ approximately estimated by this study. This relation will help conceptually the estimation of the effect of lubricant (applied as internal or die wall lubricant) on the uniformity



(a) Zinc stearate (b) Paraffin wax

Fig. 9 Relation between density gradient α and pressure transmission ratio λ (Iron powder, 300 M)



(a) Zinc stearate (b) Paraffin wax

Fig. 10 Relation between density gradient α and pressure transmission ratio λ (Stainless steel powder, DAP430L) of density, and the optimization of lubrication in uniaxial powder compaction process. The die wall lubrication efficiently increases λ and decreases α consequently, and its effect becomes efficient for the condition that the amount of admixed lubricant is very few since the frictional force is increased due to the occurrence of galling that is promoted by poor lubrication. On a theoretical estimation, increasing of λ means the improvement of uniformity and α will reach to 0 in case of $\lambda = 1$. Therefore the performance of lubricant as die wall lubrication is expressed as the coordinate on the $\lambda - \alpha$ relation and estimated as the *Without Additive Line*. Wax shows higher performance as a die wall lubricant compared with StZn. It is seen that the Wax has viscosity of a certain degree and the adhesion of the lubricant layer to the die surface is relatively strong. In contrast the lubricant layer of StZn is considered to easily tear since its characteristic is quite granule powder and its adhesion seems to be poor.

On the other hand, increasing of admixed lubricant amount is more effective way to obtain uniform compact, and the *Optimum Amount Line* means that compaction pressure shows the minimum value when lubricant amount is on this line. If the lubricant amount becomes higher than this line, the powder compact with more uniform density is obtained. However instead, the compaction pressure that spends to densification becomes higher. The improvement of the uniformity of density is emphasized with increasing lubricant amount since the friction coefficient on die surface significantly decreases with increasing lubricant amount. However, the radial stress during compaction rapidly increases by lubricant filled into pore(6). As the result, it is considered that α was decreased without significant increase of λ. The characteristic of admixed lubricant will mainly depend on the sufficiency rate of lubricant to the porosity since the remarkable difference between StZn and Wax as internal lubricant does not exist.

In the combination between StZn as internal lubricant and Wax as wall lubricant, remarkable increase of its lubrication effect was observed especially in case of stainless steel powder (Fig. 10 (a)). The synergy effect of lubricant powders will appear perhaps in some combinations but detailed investigation is necessary to explain this effect. In comparison with iron powder, stainless steel powder shows lower λ and higher α. It indicates that stainless steel powder shows high frictional force occurrence comparatively, and the optimum amount becomes higher. This tendency will be related to compressibility of each powder since stainless steel powder needs higher pressure to densification due to its higher strength of particle.

5. Conclusions

A few experimental investigations have been carried out in order to estimate the effect of lubrication on the improvement of uniformity on axial density. The pressure transmission ratio λ and the density gradient α were defined for the estimation of the magnitude of frictional force and density distribution respectively. Iron powder and stainless steel powder were tested, and the performances of zinc stearate (StZn) and paraffin wax (Wax) have been investigated. The results are summarized as follows;

(1) In the condition of unlubrication, λ increases rapidly with increasing the lubricant amount till 1.0 wt.% for the case of StZn, or 0.7 wt.% for the case of Wax.

(2) α decreases almost linearly with increasing lubricant amount, and uniform compact is obtained in the critical amount of admixed lubricant.

(3) Wax shows higher performance as a die wall lubricant compared with StZn.

(4) In comparison with iron powder, stainless steel powder shows lower λ and higher α.

(5) In the combination between StZn as internal lubricant and Wax as wall lubricant, remarkable increase of its lubrication effect was observed especially in case of stainless steel powder.

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