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Analysis of Densification Mechanism under Ultrasonic Compaction Using Force Balance model
超音波を用いた粉末成型の緻密化メカニズム分析

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1. Introduction

The authors had proposed a high power ultrasonic compaction system, which achieved a density increase of 5~10%. When the system was used SMC powder compaction, it was the promising way to solve the lower strength and magnetic properites. Expecially, the motor having the SMC powder core which was fabricated ultasonic compaction achived the high efficney of 5% compare to conventional method [1,2].

However, The densification mechanism of ultrasonic compaction has been unfouned. Therefor, in this paper, the reson why density was increased with ultrasonic action was studied. Moreover, in order to find out the densification mechanism, the force balanced model was proposed.

2. Force balanced model

The proposed system is expected to have densification mechanism as follows. As a first stage of ultrasonic compaction, the pressure is applied to SMC specimen in the die. Here, the density is determined by equilibrium of force as expressed in Equation 2.1. The applied force occurs to progress the densification of SMC.

However, the friction between die wall and powders and the friction of inter-particles prevent from undergoing the densification of SMC. And also densification is affected by the formation force. Therefore, the resultant density is accomplished by equilibrium state which is equalized applied force and resistance force.

$$\sum F = \sum \mu_b F_f^b + \sum \mu_i F_f^i + \sum F_t \quad (2\text{-}1)$$

Where;
$\sum F$: Applied force, $\sum \mu_b F_f^b$: barrier fiction force
$\sum \mu_i F_f^i$: inter particle friction, $\sum F_t$: formation force
μ_b : Friction coefficient between barrier and powder
μ_i : Friction coefficient between inner particles

As a second stage, the ultrasonic vibration was applied to die by using the BLT type ultrasonic transducers, while the pressure was applied as shown in the Figure 1 (b). It is well known that ultrasonic vibration is effective to reduce the friction [3], because it has very some amplitude and high frequency. So it was expected that the vibration of the die wall reduce the friction to die wall and inter-particle. As a result the improvement of the density of SMC was expected due to the lowered friction, Figure 1 (c).

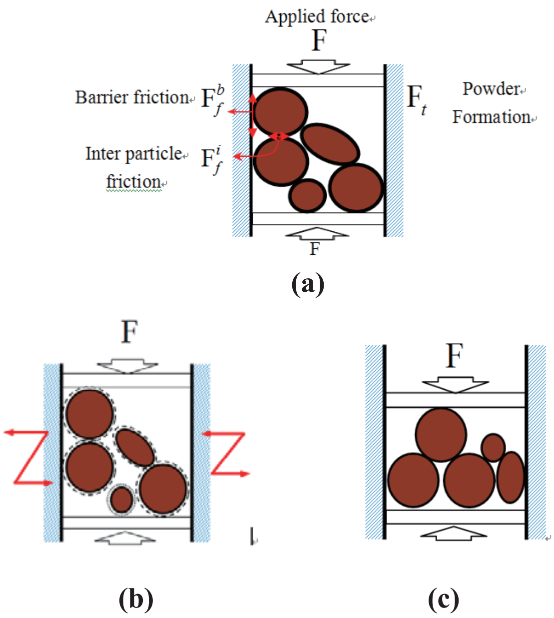

Fig. 1 Procedure of ultrasonic compaction;
(a) stage1: only pressure (b) stage2: pressure + ultrasonic,
(c) resultant state (after densification)

3. Experimental procedure

In order to verify the proposed force balaned model, the mixing ratio of powder and lubricant in the range from 0 to 0.8 wt% was varied since the lubricant is helpful in reduced the friction of the powders during compaction.

Also, ultrasonic vibration, which was found that it helps reducing the friction of the particles, was applied to compare the density differences of each SMC sample. Figure 2 shows illustrations of this experimental concept. Figure 2 (a) describes the procedure of conventional powder compaction involving lubrication while Figure 2 (b) shows the

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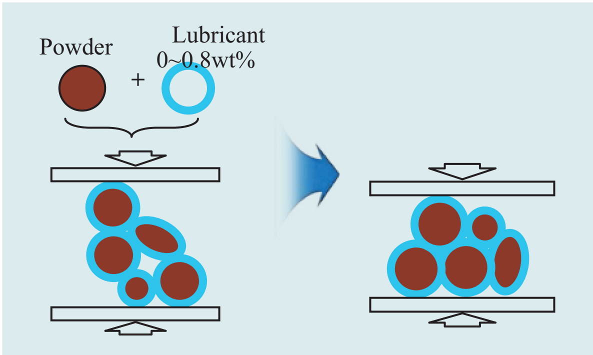
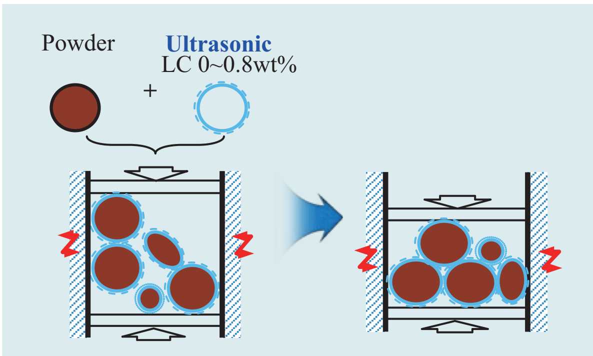
procedure of densification by ultrasonic with lubrication.



(a)



(b)

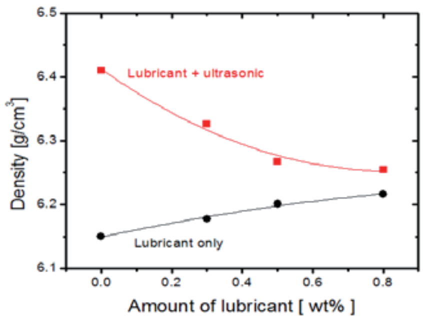
Fig. 2 Illustration of densification mechanism
(a) Compaction concept when it includes only the lubricant
(b) Compaction concept with lubricant and ultrasonic

4. Results and Discussion

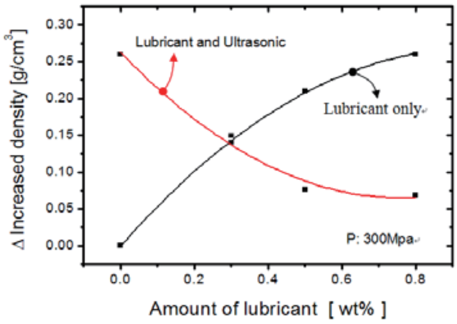
Figure 3 exhibits the density of powder compacted on varying the amount of lubricant at pressure of 300MPa with and without ultrasonic vibration. In conventional compaction process, without ultrasonic, the more the amount of lubricant use, the higher the density get due to its slip enhancing effect. More than 0.26g/cm3 of density increment were measured with usage of 0.8wt% of lubricant. The experimental result of the density with ultrasonic was also exhibited in Figure 3.

As shown, when ultrasonic vibration was applied, its effect on the slip of the powders and consequent result in the increase of density was very significant even the powder was not lubricated. Moreover, more increment of density was achieved with usage of lubricant. Therefore, it is quite obvious that the ultrasonic vibration enhances the slip during repacking stage as lubricant do and improves density of the specimen.

The resultant SEM (Scanning Electron Microscope) microstructures of compacts with and without ultrasonic vibration are shown in Figure 4. There were larger amount of porosity exhibited in the compacts with conventional way than that with ultrasonic vibration. Even with the same compressive pressure, the density increment by reduction of porosity between the particles was clearly observed in the microstructure.



(a)



(b)

Fig. 3 Comparison between ultrasonic and lubricant on densification effect (a) Density due to amount of lubricant, (b) Increased density by ultrasonic action

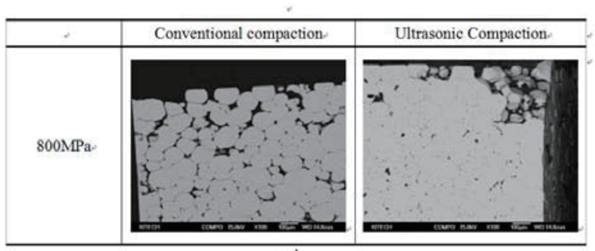


Fig. 4. SEM microstructures of powder compacts with and without ultrasonic vibration

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