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DENSIFICATION OF THE NANOPOWDER BY USING ULTRASONIC VIBRATION COMPACTION

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Abstract. In this paper, the ultrasonic vibration during compaction of nanopowders is proposed in order to increase the density and reduce the friction without the increase of compaction pressure. The results showed that the friction between die and powder during compaction process was reduced and the density of the compacted nanopowder was improved. The high power ultrasonic vibration system of 6 kW with 12 transducers was designed to form a high density nano-powder effectively. The compaction results of nanopowder core showed that the density of specimen can be improved about 5~15% at the determined optimal condition. And also, the homogeneously dense, unstrained green compact can be formed. Moreover, using the force equilibrium equation in the compaction process, verification of the improvement of density which is caused by ultrasonic compaction was carried out.

1. INTRODUCTION

Recently, in order to obtain the high mechanical properties, the powder to be used powder metallurgy became nanosize. Especially, the use of nanotungsten carbide powder is increased with various applications such as cutting tools, wear parts and diamond tools due to their good properties. However, some technical issue is occurred in the compaction process. It is difficult to compact because of their small powder size which brings some problem such as lower density, poor mechanical property and fracture of compacted specimen [1-3]. Hence, in this paper, it is proposed to introduce the ultrasonic vibrations during compaction of tungsten nanopowders to increase the density and reduce the friction without the increase of compaction pressure. The high power ultrasonic vibration system of 6 kW with 12 transducers was designed to form a high density nanopowder compacts effectively. Moreover, the optimal compaction condition of the nanopowder, some effects such as vibration amplitude, pressure, position of compaction, ratio of diameter per height were considered from the previous research.

2. EXPERIMENTAL PROCEDURE

The nanopowder which was used for ultrasonic compaction was commercially available tungsten nanopowder (Daegu Tech Co.). The microscopic image and material property of nanopowder was shown in Fig. 1 and Table 1, respectively.

The ultrasonic mold system designed is shown in Fig. 2. It consists of ultrasonic transducer which converts electric power to ultrasonic power, an upper and lower punch and the die where nanopowder is compacted and supporting fixture for transporting the ultrasonic vibration to the die. Here, vibration compacting die is designed for operating 20 kHz half wavelength longitudinal vibration and a press frame has a hydraulic static compacting pressure source. Fixture was designed in order to support the die at minimum vibration point as shown in Fig. 2a. The vibration source with six Bolt-clamped Langevin type PZT transducers was also used. The

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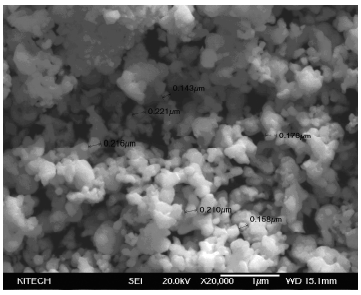

Fig. 1. SEM image of tungsten nanopowder (Deagu Tech. Co.) for ultrasonic compaction.

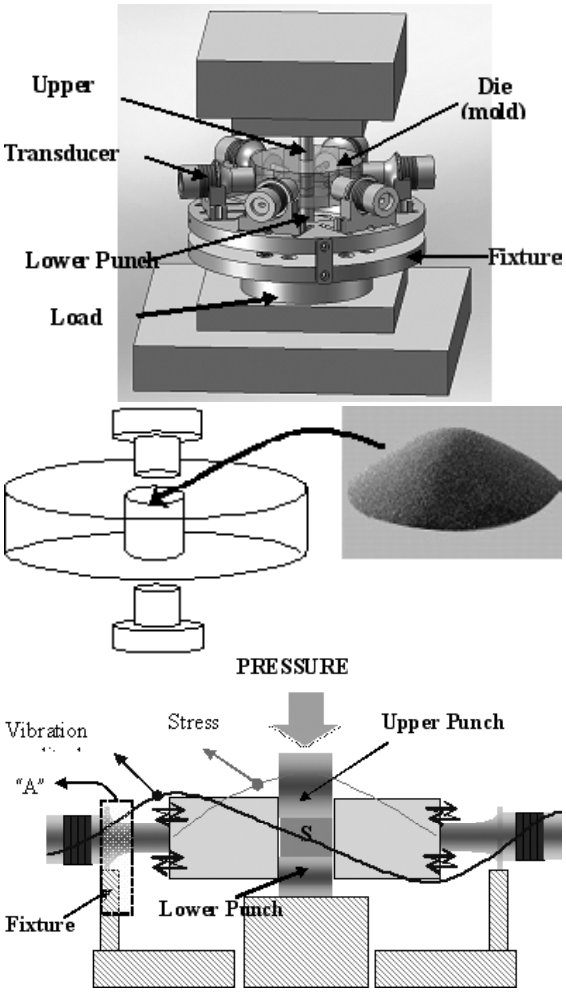

Fig. 2. Illustration of (a) structure, (b) basic operation, and (c) sectional view with vibration and stress distribution of ultrasonic vibration compaction system.

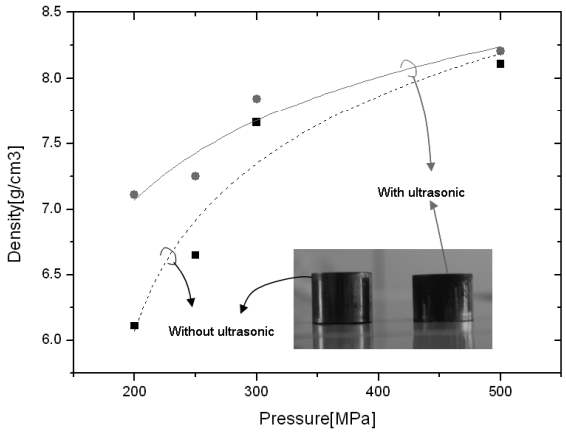

Fig. 3. Comparison of density of tungsten nanocompacts with and without ultrasonic action.

compaction sequence of soft magnetic powder is shown Fig. 2b. Firstly, powder was inserted into die hole, and then the both upper and lower punches were moved and pressurized the powders. Then the ultrasonic wave was applied on the die by using the ultrasonic transducers.

The ultrasonic compaction was carried out at a center hole where generates the most high stress, while static pressure from the upper and lower direction compacts nanopowder specimen, as shown in Fig. 2c. Moreover, the radial extensional vibration is used to have uniform vibration displacement amplitude on the side wall of the center hole. In Fig. 2, the supporting fixture of compaction die was located at the point "A" where the vibration amplitude was the lowest in order to increase the transmission efficiency of ultrasonic energy.

3. EXPERIMENTAL RESULTS AND ANALYSIS

3.1. Results of density study

From Fig. 3, as the ultrasonic vibration was applied for the compaction, the maximum density improvement of 1.0~0.18 g/cm^3 was achieved. When the applied pressure was 200 MPa with ultrasonic action, the density was increased about 15% while

Table 1. Material properties of tungsten nanopowder for ultrasonic compaction.

Size μm	Total Carbon %	Free Carbon %, max	Oxygen %, max	Dopant
0.4-0.5	6.12-6.20	0.08	0.80	Cr 0.8-0.9%

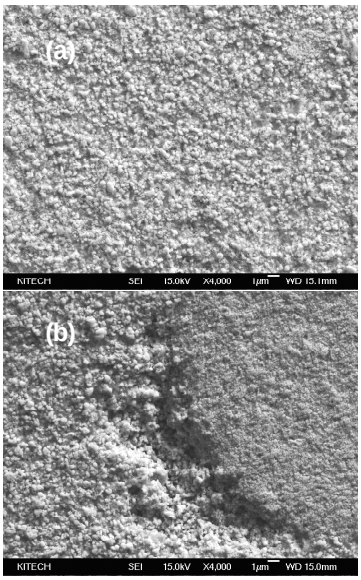

Fig. 4. SEM image of tungsten nanocompacts (a) with ultrasonic action and (b) without ultrasonic action.

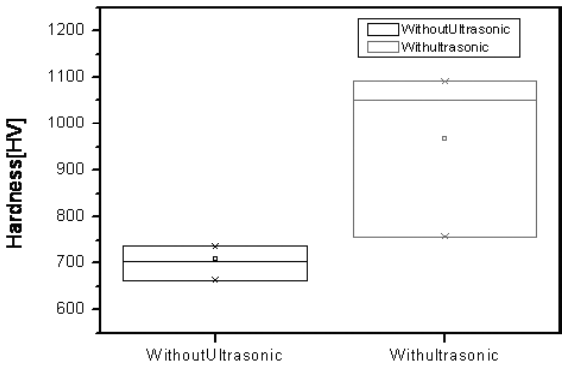

Fig. 5. Comparison of hardness of compacted specimen between without ultrasonic action and with ultrasonic action.

density was increased only 2~3% at the pressure of 250 MPa. From the results, it was found out that the density increase effect due to ultrasonic compaction was quite obvious at the low compaction pressure regime.

The SEM image between with ultrasonic compaction and without ultrasonic compaction was compared in the Fig. 4. While the density distribution of specimen compacted by ultrasonic action showed very uniform structure, the micro structure of the specimen compacted without ultrasonic action exhibited not fully compacted regions.

3.2. Hardness results

The hardness of tungsten nanopowder was evaluated with and without ultrasonic action for verifying the mechanical properties increment. Hardness was measured because it is well known that the strength is proportion to hardness of specimen. From Fig. 5, when the ultrasonic action was applied, the hardness of tungsten nano compact before sintering was increased about 20% due to more uniform and tighter structure. Hence it was expected that ultrasonic action during the nanopowder compaction process can increase the mechanical property.

3.3. Analysis of densification mechanism of ultrasonic compaction

In order to verify the improvement of density which is caused by ultrasonic compaction, densification mechanism can be proposed as follows [4-5]. As a first stage of ultrasonic compaction, the pressure is applied to nanopowder specimen in the die. Here, the density is determined by equilibrium of force as expressed in Eq. (1). The applied force occurs to progress the densification of nanopowder compact. However, the friction between die wall and powders and the friction of inter-particles prevent from undergoing the densification of nanopowder compact. 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:

$$\sum F = \sum \mu_b F_f^b + \sum \mu_i F_f^i + \sum F_t, \qquad (1)$$

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 (strain stress)

μ_b: Friction coefficient between barrier and powder particles

μ_t: Friction coefficient between inner particles each other.

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 Fig. 6b. It is well known that ultrasonic vibration is effective to reduce the friction [6-7], because it has very small amplitude and high frequency. Even though the friction coefficient is constant, the friction between die wall and particle will be reduced, because contact time between die wall and particles is decreased due to very fast redial extensional ultrasonic vibration of die. Moreover, the friction of inter- particles can be reduced by resonance of particle due to ultrasonic vibration. So it was expected

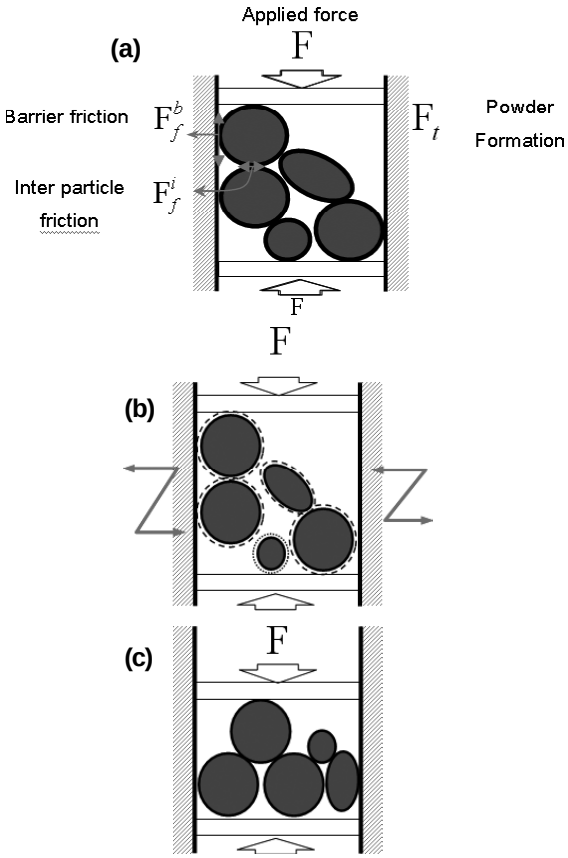

Fig. 6. Illustration of compaction mechanism following sequence, (a) stage 1- only pressure, (b) stage 2- pressure + ultrasonic action and (c) stage 3 - resultant state (after densification).

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 nanopowder compact was expected due to the lowered friction, Fig. 6c.

4. CONCLUSION

In this paper, by using the proposed ultrasonic compaction system, it was found that the density of nanopowder compact was increased by 10% compare to conventional compaction process. Moreover hardness was also increased by 20% compare to without ultrasonic action. From the comparison of SEM image, the ultrasonic action during compaction process makes it possible to have structure to uniform density distribution of tungsten nanocompacts. From verifying the improvement of density which is caused by ultrasonic compaction, it was found out 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 nanopowder compact was expected due to the lowered friction. The wider usage of ultrasonic action during compaction process is expected due to increasing the density and mechanical properties and lowered compact pressure. The ultrasonic must be quite helpful to compaction to solve the problem of nanopowder compaction such as fracture of specimen or mold and limitation of compaction pressure.

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