VOL. 11, NO. 10, MAY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

MECHANICAL PROPERTIES OF QUASI-STATIC AND ULTRASONIC COMPACTION OF STAINLESS STEEL POWDER METALLURGY

Y. Daud, M. Z. Hassan, S. Sarip, S. A. Aziz, N. A. D. Muhalim, N. A. Raman and K. R. Jamaludin
UTM Razak School of Engineering and Advanced Technology, Universiti Teknologi Malaysia, Kuala Lumpur, Malaysia
E-Mail: yusof.kl@utm.my

ABSTRACT

The application of ultrasonic vibration has been extended into the powder metallurgy compaction. Special design of ultrasonic compaction tool was used. In the present study, stainless steel powder was compacted under quasi-static and ultrasonic compression processes. The green compact specimens then sintered using vacuum furnace. In order to investigate the mechanical properties of the sintered specimens, series of compression and hardness tests were conducted. Stress-strain data and surface hardness profile were plotted from both conditions. The sygenistic effect of ultrasonic vibration with high compaction force enhanced strength and surface hardness properties of sintered part. The increase of plastic collapse strength and surface hardness were up to 5% and 2% respectively.

Keywords: ultrasonic compaction, powder metallurgy, sintering, compression test, hardness test.

INTRODUCTION

The application of ultrasonic in metal forming has been widely studied since 1900. It has been reported that by applying ultrasonic vibration during metal forming could reduce the forming force (Pohlman, 1966). Recently, the application of ultrasonic vibration has been extended into powder metallurgy processing (Rogeaux and Boch, 1985).

The development of concept of the ultrasonic compaction tool has been initiated by many researchers. Further advancement in tool design and the use of multi-transducer configurations has enhanced the properties of green compact (Tsujino *et al.* 2009).

Ultrasonic vibration can assist the compaction process of powder metallurgy by providing better mechanical properties of compacted powder parts. Previous studies have interested to investigate the properties of green compact such as density, Poisson's ratio and elastic modulus (Kikuchi, 2008). Rogeaux and Boch (1985) conducted an experimental study to investigate the application of ultrasonic vibration for ceramic powder compaction. They reported that the strength and density of green compact have the similarity in quality by comparing the green that compacted using isostatic press. In a recent investigation (Shi *et al.* 2014), the ultrasonic vibration used to assist the compaction process for micro part. In this study the ultrasonic vibration not only for better compaction, but simultaneously as a sintering agent since its ability to melt the particles.

Tsujino *et al.* (2009) suggested that various metal and ceramic powders such as copper, iron, and zirconia produced higher and uniform green compacted density when these powders compressed under longitudinal ultrasonic vibration. The simple ultrasonic tool of powder metallurgy was being designed by Daud *et al.* (2014). They found that the high grade aluminium alloy can be tuned in frequency of 20 kHz and vibrates in longitudinal mode.

In this study, the mechanical properties of the sintered specimens were investigated under quasi-static and ultrasonic loading condition. Data obtained from stress-strain curves and hardness properties were plotted and discussed.

METHODOLOGY

Specimen preparation

Compaction procedure was applied on the stainless steel powder material with the average particle size of 5 μm and agglomeration shape using Shimadzu universal hydraulic testing machine. The powder manually loaded into the ring mold. The experimental set-up rig for compaction process is shown in Figure-1. For the quasi-static compaction, the powder was compacted by descending the machine cross head at constant speed of 10 mm/min without applying ultrasonic vibration. The compaction process stops when the maximum force reached at 6.0 kN. The cylinder shape of green specimen was then manually removed from the mold. Each green compact specimen has a diameter of 8 mm and at a height of 11 mm. A few other specimens were prepared by repeating this procedure for two more maximum compaction forces of 6.5 kN and 7.0 kN.

The ultrasonic procedure was carried out using a compaction tool as tested by Daud *et al.* (2014). This test-rig consists of 3-step conical aluminium horn (lower punch tool) which its dimensions previously derived from the FE model. This horn is attached to the ultrasonic transducer, generator and secured using mounting structure. The working surface of the horn is able to excite 10 - 12 μm longitudinal mode amplitude at ultrasonic frequency of 20 kHz. Figure-2 shows the schematic diagram and photo of the ultrasonic compaction rig used in this study. In this procedure the stainless steel powder has been loaded into the ring mold. The mold has been placed on the mounting structure. An upper punch has been attached to the cross head of the machine and the lower punch is the ultrasonic horn.

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Figure-1. Powder loading in the ring mould (left) and the experimental set-up rig (right).

At the initial stage, the power will be preloaded at 0.5 kN, then the upper punch has descended at constant speed of 10 mm/min. The ultrasonic vibration was applied by switching on the ultrasonic generator as the compaction process begins. The ultrasonic vibration was superimposed on the quasi-static compaction until the process stop at a load of 6.5 kN. A few specimens were prepared using this procedure and another compaction force of 7.0 kN was set for another series of ultrasonic compaction process.

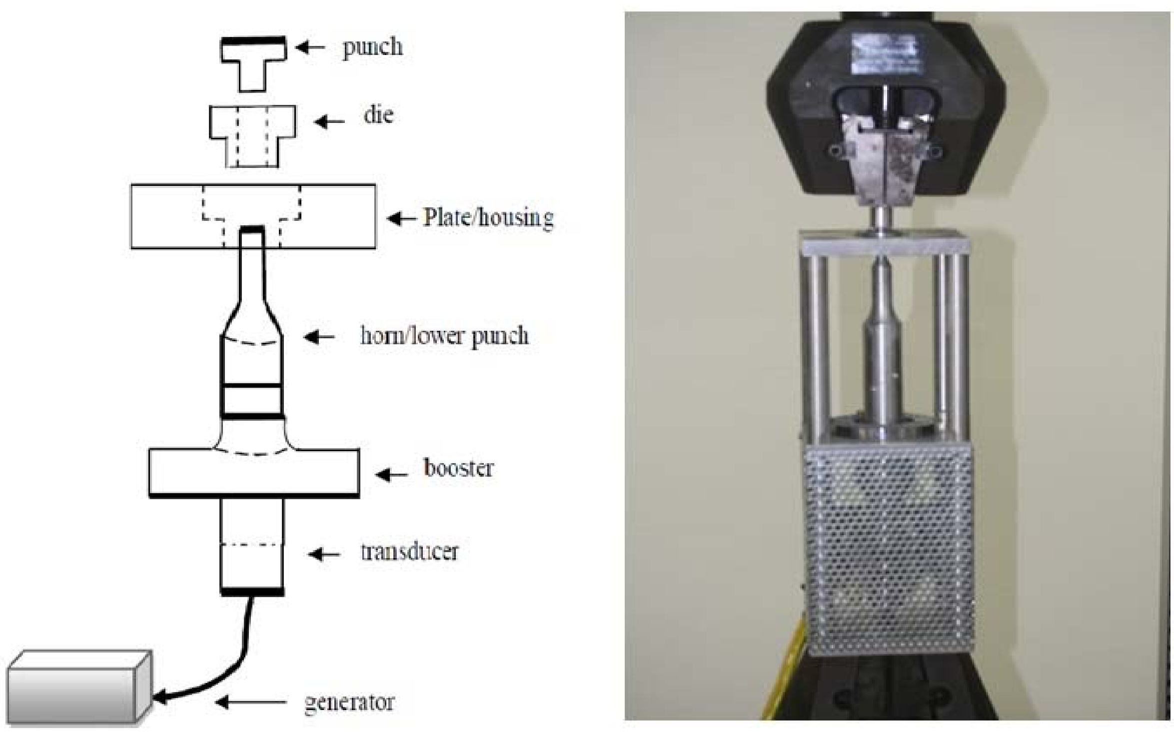


Figure-2. Schematic diagram and photo of ultrasonic compaction tool.

All static and ultrasonic green compact specimens were subsequently sintered using the circulation vacuum furnace. The sintering temperature was set at 1100 ^{o}C for the duration of two and half an hours. The specimens were then cooled in the furnace until to the room temperature. Table-1 shows the procedures for the specimen preparations.

VOL. 11, NO. 10, MAY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Table-1. Specimen preparation procedures.

Compaction Method	Maximum Force (kN)			Sintering Temperature (°C)	Sintering Time (Hours)
Quasi-static	6.0	6.5	7.0	1100	2 ½
Ultrasonic	-	6.5	7.0	1100	2 ½

Compression and hardness test

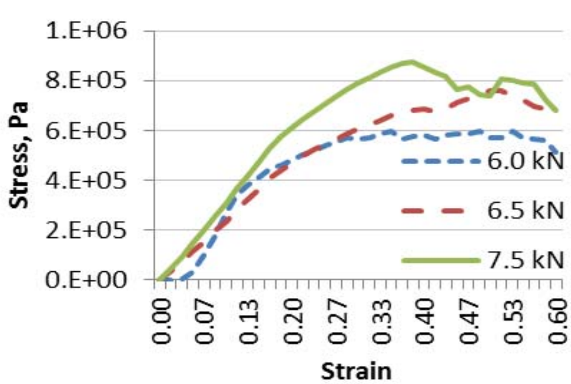
Both quasi-static and ultrasonic sintered specimens have been quantified using a series of compression and hardness tests. For the compression test the specimens were initially grounded top and bottom of the surfaces so that all specimens have the same height of 10 mm. The compression tests have been carried out using Shimadzu universal hydraulic testing machine. The specimens were statically compressed by setting the machine cross head at constant speed of 10 mm/min. The test stops when the specimen height has reduced to 50% of its original size or the specimens were breaking off. Stress-strain data from these tests were recorded using hardware and software system of the machine.

For the hardness test procedure, the specimens were initially mounted using the hot compression mounting technique for holding purposes. The exposed surfaces have then been polished using a fine grade polisher. Subsequently the polished surface has been indented using Rockwell diamond indenter. The hardness (HRA) values were recorded. This test has been carried out using a series of indentation started from the center of the specimen toward the outer surface. Then hardness surface profile has been plotted.

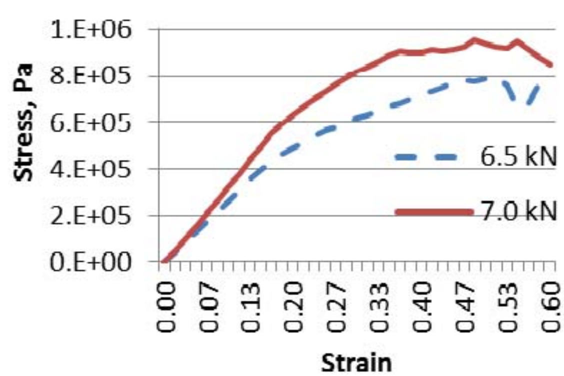
RESULTS AND DISCUSSION

Compression test

Series of compression test were carried out for the statically and ultrasonically compacted and sintered specimen. Figure-3(a) shows the stress-strain relationship of the compression test for three different compaction forces applied. It has been expected that the highest flow stress recorded for the specimen that being compacted at maximum force of 7.0 kN. It followed by the specimen 6.5 kN and 6.0 kN respectively. Subsequently, the flow stress for all specimens reduced significantly as the specimens start to buckle and break off. This could suggest higher force applied during compaction process has significantly increased the strength of sintered specimens. Similar relationship also observed for those compacted specimens using ultrasonic vibration. Figure-3(b) shows that the higher compaction force applied during ultrasonic vibration provides higher specimen strength.



(a) Quasi-static compaction



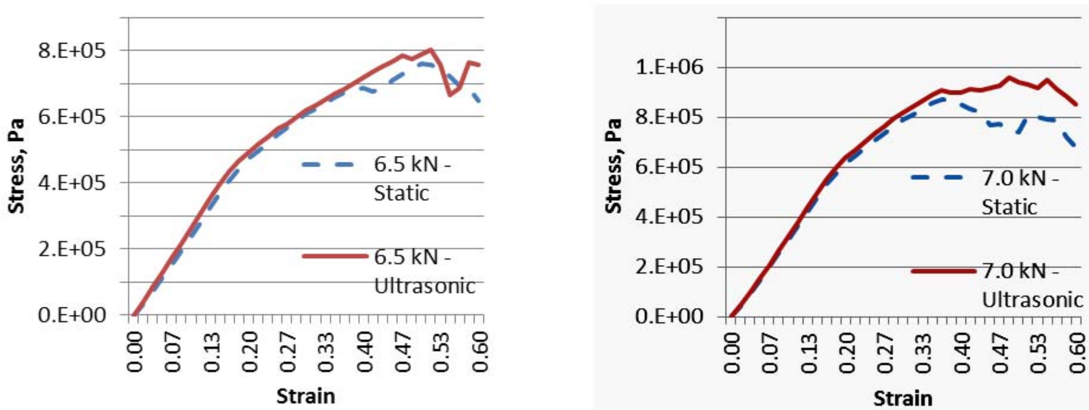
(b) Ultrasonic compaction

Figure-3. Compression test for quasi-static and ultrasonic compaction at different compression forces.

Figure-4(a) and 4(b) show the comparison of stress-strain data for static and ultrasonic compaction process. Similar stress-strain profile was recorded whether in quasi-static or ultrasonic process. However, for the ultrasonic compaction the maximum stress is higher than the static compaction. The plastic collapse strength increased by 5% as shown in Figure-4(b). In post buckling, the stress for ultrasonic specimen drop gradually compared to static specimen. This proved that the ultrasonic vibration is capable to compact the powder particles and increased the uniformity of the specimen strength after sintering.

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

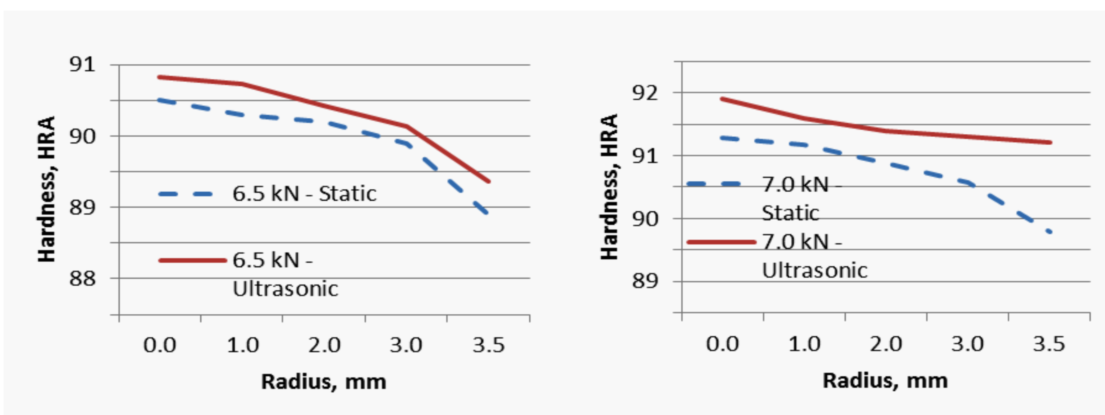


(a) Compaction force, 6.5 kN **(b)** Compaction force, 7.0 kN

Figure-4. Compression tests stress-strain - comparison between quasi-static and ultrasonic compaction.

Hardness test

Figure-5(a) and 5(b) show the hardness profile of top specimen surface recorded from specimen center toward the outer diameter quasi-static and ultrasonic and compaction. In general, for both compaction process, the hardest point was recorded at the specimen center and reduced gradually toward the outer surface. By comparing both compaction techniques, the ultrasonic compaction process recorded higher HRA value. This could suggest a higher HRA value can be achieved at higher compaction force combined with ultrasonic vibration. Again the ultrasonic vibration assisted in compacting the powder particles efficiently during the compaction process. This could be explained by the high frequency vibration applied to the lower die has encouraged the powder particle to arrange in closer manner. The surface hardness was increased up to 2% as shown in Figure-5(b). The inter-particle necking and bonding process have more efficient during sintering. Hence, ultrasonic enhanced specimen uniformity and reduced porosity.



(a) Compaction force, 6.5 kN **(b)** Compaction force, 7.0 kN

Figure-5. Comparison of hardness profiles for quasi-static and ultrasonic compaction.

CONCLUSIONS

The compression and hardness properties of quasi-static and ultrasonic compacted and sintered were presented. The ultrasonic compaction process is successful to enhance compression strength and surface hardness profile of the sintered part as compare to quasi-static compression. This could be explained by the capability of ultrasonic vibration applied at the lower punch to rearrange the powder particle closer, then produced more dense and uniform green and sintered parts. The microscopy investigation could be carried out in the future to get a better explanation of the present finding.

REFERENCES

[1] Blaha, F. and Langenecker, B. (1955). Tensile deformation of zinc crystal under ultrasonic vibration, Naturwissenschaften, 42, pp.556.

ARPN Journal of Engineering and Applied Sciences

[2] Daud, Y. *et al.* (2014). Design of ultrasonic compaction tool for powder metallurgy, Applied Mechanics and Materials, 465 – 466, pp.1016-1020.

[3] Kikuchi, S. *et al.* (2008). A design of ultrasonic compaction tools for metal powder magnetic core of motors, IEEE International Ultrasonics Symposium Proceedings, pp.2142-2145.

[4] Nevill G. E. and Brotzen, F. R. (1957). Effect of vibrations on the yield strength of a low-carbon steel, First Technical Report, The Rice Institute, Solid States Science Division, Air Force Office of Scientific Research, ARDC, Washington, Technical Document No. AFOSR-TN-57-170.

[5] Pohlman, R. and Lehfeldt, E. (1966). Influence of ultrasonic vibration on metallic friction, Ultrasonics, 4, pp.178-185.

[6] Rogeaux, B. and Boch, P. (1945). Influence of ultrasonic assistance to powder compaction on the Weitbull modulus of sintered alumina, Journal of Material Science Letter, 4, pp.403-404.

[7] Shi,Y. W. *et al.* (2014). A micro-ultrasonic powder moulding method to fabricate Sn–Bi alloy micro parts, Journal of Materials Processing Technology, 214, pp.2668–2675.

[8] Tsujino, J., *et al.* (2009). Compacting of various metal, alloy and ceramic powder using 20 khz ultrasonic vibration compacting equipments with upper and lower vibration punches, IEEE International Ultrasonics Symposium Proceedings, pp.1985-1988.