Sound Generated During the Compaction of Alumina Reinforced Aluminum Powders

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***Abstract* – Many non-destructive techniques (NDT) are available to evaluate the internal defects of any materials. During the processing stages these techniques are very crucial task to be considered because earlier rejection of the compacted materials capable to save the manufacturing costs before they are experienced further processing levels. In this work, sound generated during the powder compaction of metallic and non-metallic powders are studied. Different reinforcing percentages are used to examine their effect on the sound generations. Sound detectors are attached on the surface of the mould and identical sound filtering software package is used to filter out the unwanted sound. Prior to compaction, surface roughness of the internal mould is determined and it is followed the industrial value of the surface roughness and another mould is highly polished. It is found that higher fraction of the reinforcing elements and the influence of surface roughness affected the rate of sound generation during the quasi-static powder compactions.**

I. INTRODUCTION

The compaction of powders is a major industrial route to produce materials and parts from metals, ceramics and polymers. In general, powder compacts are obtained via cold or hot uni-axial compaction or iso-static pressing in a first step. A secondary step involves high temperature to enhance either plastic deformation or sintering [1]. Tablet formation is the result of densification, inter-particle bonding and relaxation. Each component has its own compaction behavior. After rearrangement of the particles and building up of the pressure, the particles of the single materials behave brittle or visco-elastic [2, 3]. Additionally, the deformation behavior depends on other factors like particle size in relation to its critical brittle/ductile transition particle size [4] and compaction velocity [5]. After release of the applied load, the tablet shows a certain amount of relaxation before reaching its final porosity. Several investigators have examined the compaction behavior of binary mixtures. The effects of different parameters, such as compaction behavior [6], surface area [7] and compaction speed [8, 9], on the final tensile strength of the tablets compressed from blends have been reported. In many cases, the strength of the tablets compressed from the blend is found to be lower than the strength calculated by interpolation of the strength of tablets prepared from the pure materials.

The main problems encountered during powder compaction are density distribution leading to induce internal defects. The density distribution resulting from a powder compaction process is often non-homogeneous. This is mainly due to (1) inter-particle friction and (2) die wall friction [10]. At the beginning of compaction, when the rearrangement of particles governs the process, mechanism (1) is dominant. When the contact pressure increases between particles and movement (rotations and slip) between particles become limited, die wall friction becomes the important parameter influencing the density distribution. The modeling of crack formation during powder compaction has been carried out [11] and they found that the Simulations of the compaction process show that both shear stress and relative density distributions have influences on the crack initiation and propagation process. High shear stress and inhomogeneous relative density distribution in some region within the powder compact causes the crack to initiate and propagate as compaction proceeds. Different shear stress and relative density distributions are obtained for different compaction sequences, causing the crack to initiate and propagate at different compaction steps.

Therefore in this paper, experimental investigation is conducted to study the powder compaction behavior using acoustic approach. Different alumina powder volume percentages are used to reinforce the aluminum powders which is cold compacted quasi-statically at constant cross-head displacement. Acoustic probe is attached onto the external mould surface to analyze the behavior of sound during the compactions.

II. MATERIAL & EXPERIMENTS

A. *Material Preparation*

Three types of alumina volume fractions are chosen, they are 5, 10 and 15%. These specific alumina volume fractions are used to reinforce aluminum powder. Alumina and aluminum powders are mixed in ball milling for 2 hours at rotational speed of about 150 rpm. 0.5% stearic acid is added into powder mixture as binder and lubrication system to assist powder compaction especially to reduce interfacial friction between powders and internal wall of the mould.

B. *Mould Preparation*

Solid cylindrical steel mould is used to fabricate a mould. 30 mm internal mould diameter is produced using conventional drilling machine. The dimensions of the mould are 40 mm

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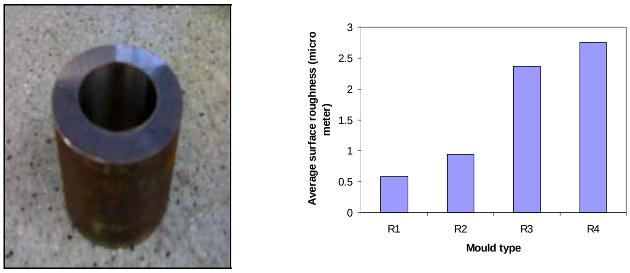
height, 50 mm external diameter and 30 mm internal diameter. Three different drilling speeds are used to produce different internal surface roughness; 540, 370 and 260 rpm as shown in Figure 1, and the existent mould are also used as reference mould. The prepared moulds are sectioned into two pieces in surface roughness tester is used to measure the roughness; the surface roughness of the mould is listed in Table 1.



(a) (b)

Figure 1 (a) The machined mould used in this study and (b) The average surface roughness of the drilled moulds.

TABLE 1
Measured surface roughness of the drilled internal surface mould

Mould	Surface Roughness, R_a (μm)			Average (μm)
	1	2	3	
R1	0.58	0.57	0.59	0.58
R2	0.94	0.97	0.92	0.94
R3	2.44	2.31	2.36	2.37
R4	2.66	2.74	2.86	2.75

C. Powder Compaction Technique

The schematic of powder compaction set-up is shown in Figure 2. The acoustic probe is attached at outside mould surface to detect any sound generated during the powder compaction. A layer of organic grease provided a gap between probe and mould surface. This is done to reduce the interfacial interference sound occurred between probe and surface of the mould and the probe is tightly attached so that there is no movement of the mould.

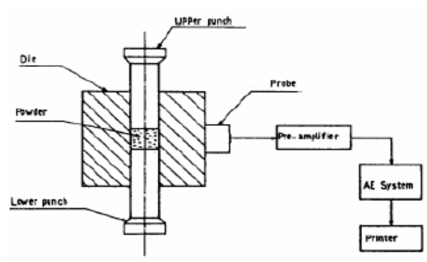


Figure 2 Schematic arrangement of the powder compaction set-up.

The composite mixtures are poured into the mould and the upper punched lightly compacted the powders. This pre-compact is essence to differentiate between the actual powder compaction or other. Any possible cause mechanical vibration or shock will be minimized in order to clearly interpret the output signal. During powder compactions, pre-amplifier is used to gain weak mechanical signals and all the signals are monitored automatically using software provided in computer. Other alien signals are analyzed and removed from the main spectrum and only main or reliable signals are taken into account for further investigations.

D. Scanning Electron Microscope (SEM) Observation

The compacted powders are ejected from the mould and then those samples are prepared and placed into SEM chamber for next examinations. The emphases of the investigations are focused at the edge of the samples where at the region of frictional interaction occurred.

E. Fluorescent Penetrant Testing

Before fluorescent testing conducted on the samples, the samples surfaces are cleaned from any contaminations in order eliminate any interference during observations. The fluorescent liquid is sprayed onto sample surface and the sprayed samples are kept for several minutes to ensure fluorescent penetrates into material discontinuities. Finally, fluorescent is removed from the surface.

III. RESULT AND DISCUSSION

Figure 3 shows the sound generated during the compaction of alumina reinforced aluminum powders. Generally, similar sound generation responses are recorded by the probe. Two distinct regions are clearly depicted in the diagram; there are (i) linear response of the powder deformation and (2) non-linear sound response. Obviously, it can be seen here that in all cases internal surface roughness play a key factor in generating higher sound response. At the first stage, powder rearrangement and reorientation occurred as increasing the compaction force. This behavior is represented by the sound response increased gradually in this initial region. Linear elastic deformations also are expected to occur after powder rearrangement. For higher internal mould surface roughness, the slope of the initial deformation steeply increased due to the breakage of asperities of the mould surface when the powders moved downward. The sound response of the existent and better surface roughness mould, the rate of the sound is almost undetectable by the probe. At the final compaction, sound detection slightly occurs but it is not severe enough to damage the microstructural morphology. Scanning electron microscope (SEM) is conducted to observe the microstructures especially at the interface between mould internal surface and the powders. The microstructural morphology of the compacted powders using different internal surface roughness is shown in Fig. 4. Obviously, there are very distinct features of the microstructures. For very fine surface roughness, the powders still intact with no powder fracturing which is agreed with the sound respond detected by the probe placed outside of the mould. While for rougher surface roughness, excessive plastic deformation occurred during the powder compaction. Plastic deformation leading to fracture created passive acoustic sound that detected by the probe. The fracture of the powders

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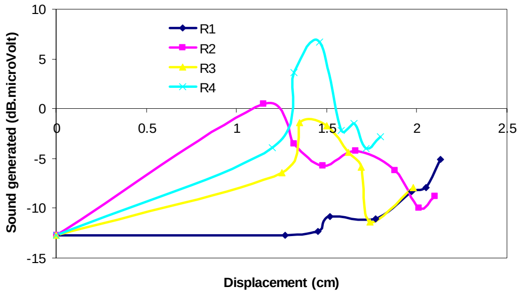
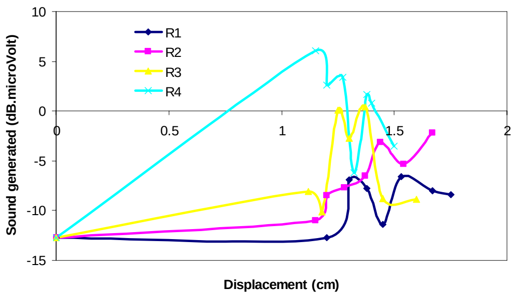
becomes more severe when rougher surface roughness is used. This is because powders require more sliding shear stresses to overcome surface asperities.



(a)



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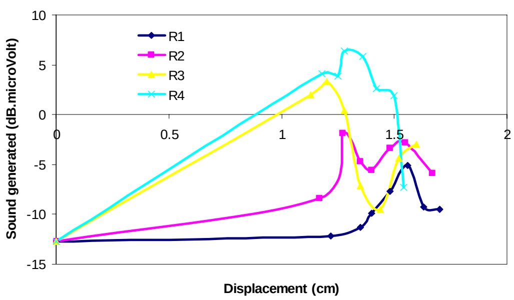
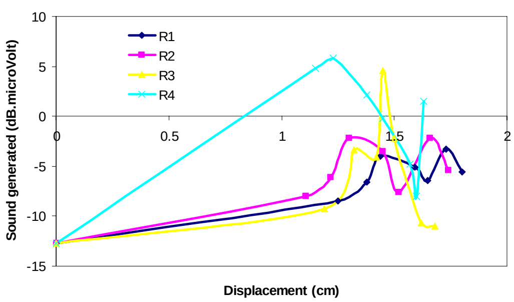
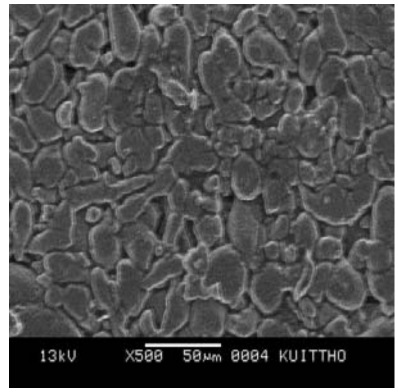


(C)

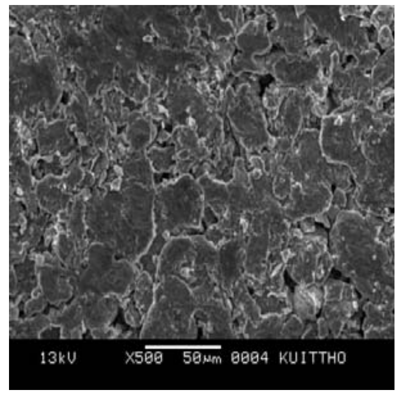


(d)

Fig. 3 Sound generated during powder compactions of (a) pure aluminum, (b) 5% alumina, (c) 10% alumina and (d) 15% alumina reinforced aluminum alloy.



(a)



(b)

Fig. 4 SEM observations of (a) finer surface roughness and (b) worst surface roughness.

In order to observe the physical shape of the crack formed during the quasi-static compaction, fluorescent penetrating testing is conducted on the samples. The observations are performed on the interfacial side slide against the surface of the mould. Figure 4 shows the pictures of fluorescent observations of 10% alumina reinforced aluminum composites. Figure 4a – 4c show no obvious crack formation induced during compactions. Obviously, Figure 4d reveals the crack formed during powder compaction. Circumferential crack is detected with brighter fluorescent light. At the ends of the main crack, crack branching also formed. This mechanism indicated that the crack propagated perpendicular with axial compression force. According to Figure 3, there is no strong relationship on the sound generation with fiber volume fractions but the crack formation is strongly related to surface roughness.

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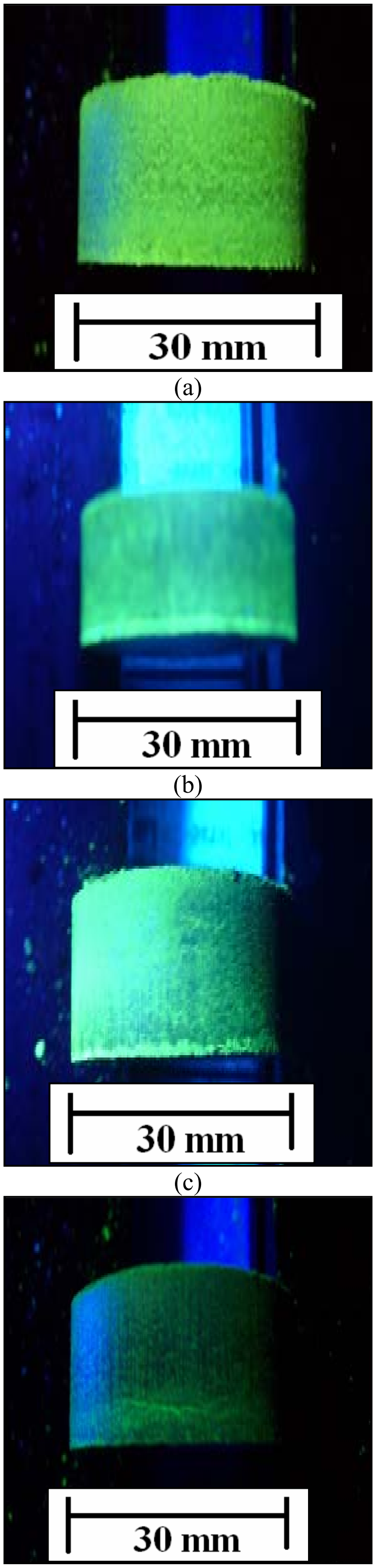

Fig. 5 Effect of surface roughness on the crack formations during powder compaction of (a) 0.58 µm, (b) 0.94 µm, (c) 2.37 µm and (d) 2.75 µm.

IV. CONCLUSION

Experimental investigation has been carried out to study the sound generation during the powder compaction of alumina reinforced aluminum composites. During the compactions, no strong relationship between sounds generated during compaction and fiber volume fraction of alumina powders but the surface roughness strongly related to the formation of circumferential crack perpendicular to axial loading compressive loading. Scanning electron microscope (SEM) revealed the powders fractured during the compaction created passive acoustic sounds, the fractured powders becomes more severe for rougher surface roughness compared than finer surface roughness. Clear crack pattern is conformed using fluorescent penetrating technique.

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