CERAMIC POWDERS COMPACTION PROCESS

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Abstract: An experimental work of powder compaction process is done on two types of ceramic powders at room and elevated temperatures. The thermo-mechanical behavior of alumina ceramic powder during cold and warm compaction processes was studied. Experimental works were carried out in the laboratory for a simple cylindrical of compacted powder using a uniaxial die compaction machine. The parameters which were measured were force and displacement. This will provide information on the tooling movement and the required force for compaction of powders. The density is obtained by measuring the dimensions of the green compacted powder and sintered compacted powder. Two types of powder are used i.e. pure alumina (N0115) and alumina with acrylic binders (NM9620). The experimental work results were discussed in order to find the reason for such behavior and characteristic. From the compaction results, compactions at 150°C indicate that less force is needed to compact powder compared to compaction at room temperature. Both green and sintered density of compaction temperature at 150°C is higher and relatively close to the theoretical density.

Keywords: Powder metallurgy, Powder compaction, Ceramic powder

INTRODUCTION

The powder compaction process can be described as a process of forming any type of powder material by compaction in a container to a desired component shape, followed by heating to a temperature which is usually below the melting point of the powder material to perform sintering process of the green compact. This process is referred as '*powder metallurgy*' process since the feed stock used is in form of fine particles (or powder) to produce parts. Powder metallurgy has been in existence since 1920's with the development of the porous bronze bushing and the related technique for mass production [1]. The metallurgy process of powder compaction comprises three main operations which is powder mixing, powder compaction and sintering. Powder metallurgy refers to a range of manufacturing and metal forming practices that are used to produce net or near-net shape parts from mixtures of metal and alloy powders. The main objectives in forming process are to achieve green compact with high density and uniform density distribution according to the required shape and dimension.

The actual behavior of powder particles under the action of an applied compacting force is of fundamental importance to the powder metallurgy process. Darren W. Smith [2] suggested three general events take place in the powder during compaction:

- Stage 1: The particles undergo bulk movement such that they are rearranged into a more efficiently packed array.
- Stage 2: Both elastic and plastic deformation is imparted to the particles.
- Stage 3: The particles may fracture (fragment) as the compacting load is increased.

In all practical compaction stages, the first two stages are always encountered, but the last stage is only occurred at very high densities [3]. When the probability of additional bulk particle rearrangement is sufficiently low, substantial particle deformation may take place, resulting further densification which lead to the reduction of the porosity level of the powder mass. This is the major densification involved in the attainment of high green densities. Factors that controlled the extent of plastic deformation are the ductility, yield strength and strain hardening characteristics of the constituent particles.

Warm compaction is a process that took the advantage of the temperature gain to increase the densification during compaction. It requires that the powder has to be mixed with lubricant binder/system in order to provide good flow ability in the temperature range involved in warm pressing. The warm compaction technique is a process of pressing a preheated powder mix in a heated die. Warm-pressed powders can achieve a density 0.1-0.2 g/cm^3 higher than similar materials compacted at room temperature for steel powder material [4]. During ejection, the compacted powder will undergo a volume expansion. It is very important since it's determines the green density that will be achieved for a given applied pressure, part geometry, size and tooling [5]. By increasing the temperature, the volume expansion of the compacted powder can be significantly reduced. The reduction of volume expansion is mainly due to reduction of the spring back parallel to the compaction axis which results the increase of green density in compacted powder.

MATERIALS AND METHODS

This experimental work is carried out in order to provide information on the tooling movement and the required force for compaction of powder and to understand the powder behavior during the compaction process also the properties of the compacted powder. The material used for this experimental work are NO115 (pure alumina powder without binders) and NM9620 (alumina powder with acrylic binders). The properties of each material are shown in Table 1.

Table 1: Properties of the Ceramics

	Pure Alumina (NO115)	Alumina with Acrylic Binders (NM9620)
<u>Chemical analysis</u>		
Al_2O_3	Min. 98%	Min.96%
Na_2O		0 -1%
SiO_2	0 - 4%	-
Fe_2O_3	0 - 3%	-
Grain size diameter	15 μm	180-230 μm

Compaction Experiments

Compaction machine (as shown in Figure 1) was design to enable the production of a simple cylindrical of compacted powder in the laboratory. This was a single action die compaction where the powder is pressed from one end only with lower punch compressing the powder against the upper stationary punch; i.e. pressure is applied at one end only. Pressure is applied hydraulically.

For sintering purposes, the compacted powders were sent to the Maju Scientific Sdn. Bhd. and the temperature rate is set according to Table 2.

Table 2: Sintering Sequence

Temperature (^{0}C)	Rate (^{0}C/min)
RT-200	3.4
200-300	2.5
300-400	1.7
400-800	3.4
800-1300	5.8
1300-1550 (or1600)*	1.7
1550 (or1600)-1300	5.0
1300-RT	10.0

* The temperature is maintained about 60 minutes.

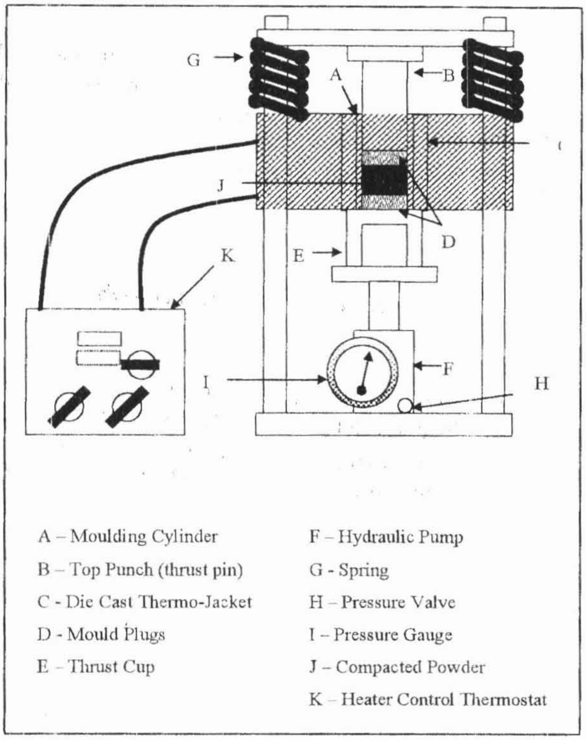


Figure 1: Compaction Machine

RESULTS AND DISCUSSIONS

For each process, it will form a curve that illustrate the force build up as the compaction proceed where the upward force of lower punch acted against upper mould plug hold by the stationary upper punch. Figure 2 shows the behavior of cold and warm compaction process for two types of ceramic powders, pure alumina powder and alumina powder with acrylic binder.

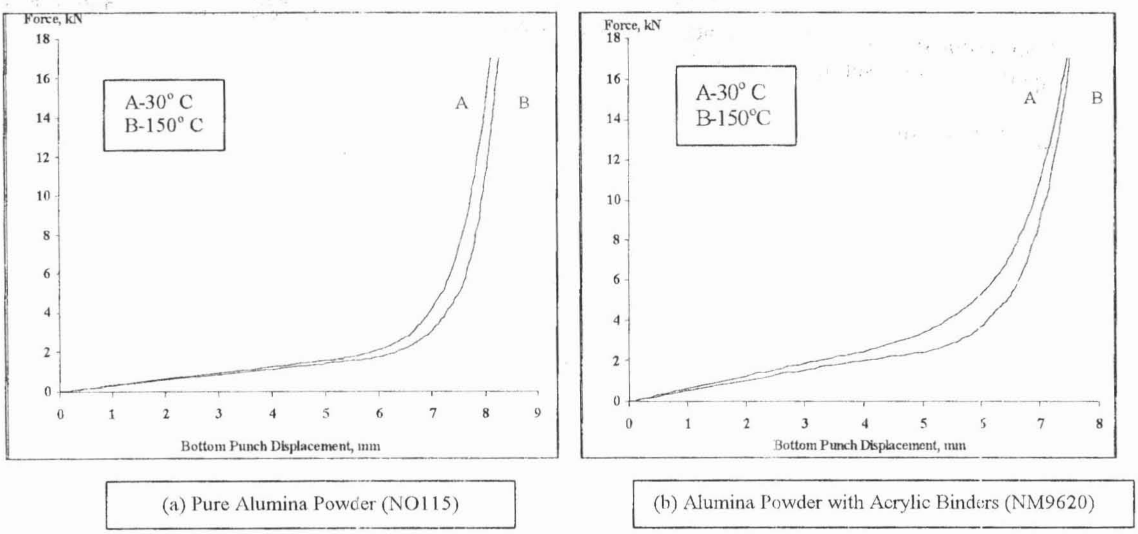
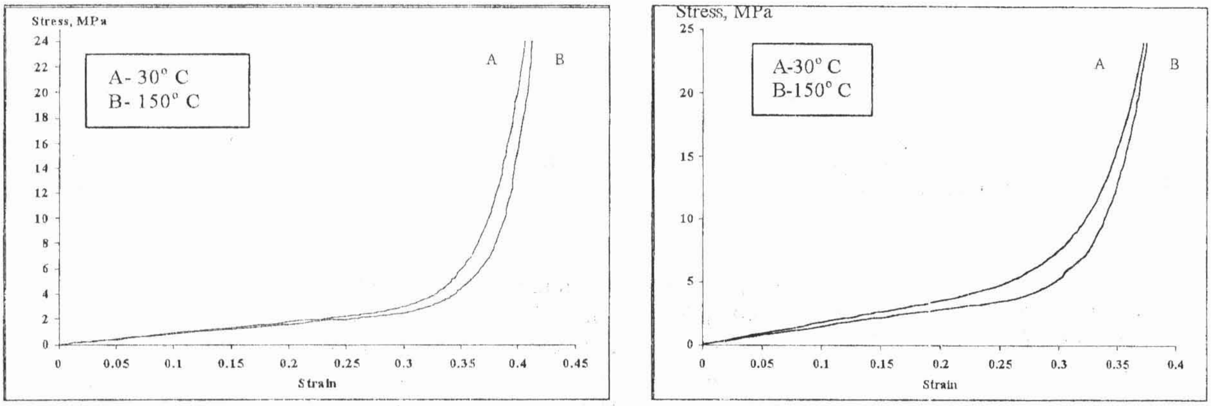


Figure 2: The Behavior of Compacted Powder Under Different Temperature

From figure 2(a), the force needed to compact the NO115 powder is about 10.4 kN at compaction temperature of 150^{0}C relatively low compare to 14.2 kN at compaction temperature of 30^{0}C for the same bottom punch displacement which is 8mm. From figure 2(b) it is shown that for 7mm of bottom punch displacement of NM9620 powder, the required force is 8.45 kN for compaction temperature of 150^{0}C is relatively low compare to 10.45 kN for compaction temperature of 30^{0}C. The result in figure 2(a) and figure 2(b) clearly shows that at higher operation temperature, the yield strength of the material become lower and therefore less force is required. This result is similar to what Hoganas has obtained with iron powder [6].



(a) Pure Alumina Powder (NO115)

(b) Alumina Powder with Acrylic Binders (NM9620)

Figure 3: The Behavior of Strain-Stress for Compacted Powder Under Different Temperature

Figure 3 shows the stress-strain behavior for two types of ceramic powders, pure alumina powder and alumina powder with acrylic binder. From these figures (a and b), both powders show a linear increase up to 50% of the compaction after which the force build up more rapidly during cold compaction. Since the ceramic powders generated by spray drying are essentially spherical in shape, the particle packing in the die cavity during filling will be higher and the particle rearrangement phase will be significantly small [7]. Figure 3 also indicate that when both powders compacted at 150°C, it undergoes greater particle rearrangement stage compared to the powders compacted at room temperature which lead to the more pore closure between the powder particles. This phenomenon explains the increase of densities of both powders when compacted at higher temperature. For both powders, the required stress for same amount of strain increment is reduced when the powders compacted at temperature 150°C compared to the powder compacted at room temperature. This phenomenon indicates that the ability to compact the powder decreased when compacted at higher operational temperature.

From table 3, the green density attained during compaction temperature at 150°C is 2.55 g/cm^3 compared to the 2.45 g/cm^3 during compaction at room temperature for NO115 powder. For NM9620 powder, the green density achieved during compaction temperature at 150°C is 2.46 g/cm^3 compared to the 2.36 g/cm^3 during compaction at room temperature. For both powders, it can be seen that the increase of green density is 0.1g during the compaction temperature at 150°C. As reported by Gagné [4], warm-pressed powders can achieved a density 0.1-0.2 g/cm^3 higher than similar materials compacted at room temperature. From the table, it also can be seen that the NO115 powder attained a solid density 61% when compacted at room temperature while the NM9620 powder attained a solid density 59% when compacted at room temperature .The values attained for both powders is nearly close to the value attained by previous researchers which is 55% for the same fill depth and compacted temperature [8]. For powder compacted at 150°C, NO115 powder attained a solid density 61% while the NM9620 powders attained a solid density 59%. This shows that by raising the temperature of the compaction process, the green density attained for both powders are also increased. The comparison for both powders cannot be done since both of them are different in grain size diameter.

Table 3: Density of Green Compacted Powder

Powder	Density (g/cm^3)	Compaction Temperature 30^{0}C	150^{0}C
Pure Alumina (NO115)	Theoretical Density	3.98	3.98
	Fill Density	1.38	1.38
	Fill Relative Density*	0.35	0.35
	Green Density	2.45	2.55
	Green Relative Density*	0.61	0.64
Alumina with Acrylic Binder (NM9620)	Theoretical Density	3.98	3.98
	Fill Density	1.45	1.45
	Fill Relative Density*	0.37	0.37
	Green Density	2.36	2.46
	Green Relative Density*	0.59	0.62

* Relative to the theoretical density

From table 4(a), at 1550°C firing temperature the sintered density attained for compacted powder temperature at 150°C is 3.76 g/cm^3 compared to the 3.72 g/cm^3 for compacted powder at room temperature. For firing temperature at 1600°C, the sintered density attained for compacted powder temperature at 150°C is 3.81 g/cm^3 compared to the 3.79 g/cm^3 for compacted powder at room temperature. The gain in sintered density for powder compacted at room temperature and at 150°C is due to the decrease in the amount of porosity as the sintering temperature is raised. In term of compaction temperature, the gain in sintered density for the compacted powder of two different firing temperatures is relatively small.

Table 4(a): Density of Sintered Compacted Powder for Pure Alumina Powder

Powder	Density (g/cm^3)	Compaction Temperature 30^{0}C	150^{0}C
Pure Alumina (NO115)	Theoretical Density	3.98	3.98
	Density (Firing Temperature 1550^{0}C)	3.72	3.76
	Sintered Relative Density*	0.94	0.95
	Density (Firing Temperature 1600^{0}C)	3.79	3.81
	Sintered Relative Density*	0.95	0.96

* Relative to the theoretical density

From table 4(b), at 1550°C firing temperature the sintered density attained for compacted powder temperature at 150°C is 3.68 g/cm^3 compared to the 3.58 g/cm^3 for compacted powder at room temperature. For firing temperature at 1600°C, the sintered density attained for compacted powder temperature at 150°C is 3.75 g/cm^3 compared to the 3.71 g/cm^3 for compacted powder at room temperature. The gain in sintered density for powder compacted at room temperature and at 150°C is very significant due to the decrease in the amount of porosity left by the acrylic binder after it melts at 400°C as the sintering temperature is raised. In term of compaction temperature, the gain in sintered density for the compacted powder at firing temperature 1550°C is 0.1 g/cm^3 compared to 0.04 g/cm^3 at firing temperature 1600°C. This indicates that the sintered density attained when the compaction temperature of the compacted powder is raised is relatively small when the sintering temperature is raised.

Table 4(b): Density of Sintered Compacted Powder for Alumina Powder with Acrylic Binders

Powder	Density (g/cm^3)	Compaction Temperature 30^{0}C	150^{0}C
Alumina with Acrylic Binders (NM9620)	Theoretical Density	3.98	3.98
	Sintered Density (Firing Temperature 1550^{0}C)	3.58	3.68
	Relative Sintered Density*	0.9	0.93
	Sintered Density (Firing Temperature 1600^{0}C)	3.71	3.75
	Relative Sintered Density*	0.931	0.945

* Relative to the theoretical density

CONCLUSIONS

From the compaction process, it can be seen that the thermo-mechanical behavior of both powders are the same where for a higher operational temperature, less force is required to perform the compaction for the same displacement of bottom punch. By increasing the compaction temperature, both types of powders are easier to compact because of the reduction in yield strength of the powders. For the mechanical properties, there is an increase in green density for both types of powders when the compaction temperature is raised. In term of sintering temperature, there is an increase in sintered density on both types of compacted powders when the sintering temperature is raised for different compaction temperature. The only setback in this experiment is the comparison between these two types of powders could not be done since both types of powders are different in size of grain diameter.

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