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Characterization of sintering schedule for near-net shaping of warm formed mechanical components

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ABSTRACT

This paper presents the characterization of solid state sintering schedule for near-net shaping of warm formed metal powder compacts. Iron ASC 100.29 powder was used as main powder constituent during this investigation. The feedstock was prepared by mechanically mixed iron powder with 0.4 wt% zinc stearate as admixed lubricant. The powder mass was then formed as solid cylinder at 180ºC. The defect-free green compacts were sintered in an argon gas fired furnace at different sintering schedule. The sintered products were characterized through dimensional measurement, and mechanical testing. The results revealed that sintering schedule plays an important role in manufacturing near-net shape yet high strength components.

Introduction

The fast growth of near-net-shape manufacturing through powder metallurgy [p/m] in last few decades indicates that there is a high demand on this process which recently known to provide better mechanical properties such as higher density, and strength compared to traditional die casting method [1-3]. Powder metallurgy becomes essential since it has the ability to reduce cost as well as to produce complex parts. The facility of component manufacturing, material utilization, and economical advantages for large production are also the main criteria for the fast growth of powder metallurgy. In order to reduce pollutions to the environment, p/m processes produce less noise, no toxic and also recycled metals can be used back for other p/m process [4]. Creating a new composite material by mixing of different metal powder leads to special physical and mechanical properties also another advantage of p/m which is nearly impossible to be produced through casting method [5]. A major advance in this technology has been the warm forming process, which can utilize traditional powder forming equipment.

Warm forming is defined as compaction of metal powder at elevated but below its recrystallization temperature [6]. Generally, the warm forming process is influenced significantly by forming temperature. However, the precise and comprehensive research on other parameters such as loading and lubrication formulation widens the range of suitable forming temperature in warm powder compaction process, thus widen up the possibility to explore more towards mechanical and metallurgical behaviour of a compact as a function of forming temperature [7-10]. The final stage of a powder metallurgy process is the sintering which is the heat treatment of green compacts in controlled environment at a temperature of 60 -70% of the melting temperature of the main powder constituent [11]. The purpose of sintering is to bond together the powder particles to form a coherent body which has the required mechanical properties and microstructures. It is also known as the bonding of particles within the powder mass by molecular or atomic attraction in the solid state, by application of heat, causes strengthening of the powder mass and possibly resulting in densification and recrystallisation by transport mechanisms [12-13]. Forming of metal powder at above ambient temperature is considered as a relatively new technology hence the suitable sintering schedule in producing high quality mechanical components through warm forming route is not found anywhere. Therefore, this paper presents an experimental investigation on the effects of sintering schedules to the mechanical properties and microstructure of iron powder compacts formed through warm compaction route.

Materials and method

The main powder constituent used is iron ASC 100.29 produced by Höganäs with particle size of 30 -50 µm. Zinc Stearate supplied by Sigma-Aldrich is used as the lubricant to reduce interparticle as well as die wall frictions hence to avoid heterogeneous density distribution.

The feedstock was prepared by mechanically mixing the main powder constituent with 0.4wt% of zinc stearate for 30 minutes which is seemed to be suitable [17]. Cylindrical shape die was used for the compaction with the radius of 10.35mm and 60mm height.

Green Compact Generation

Sample generation consists of five consecutive steps, i.e., (i) powder mixing, (ii) die filling, (iii) heating of the powder mass together with the die assembly, (iv) compaction, and (v) ejection of green compacts from the die cavity.

The die cavity was filled by the premixed powder mass using a tube funnel. In order to avoid initial tap density, excessive powder is scrapped away. Powder mass inside the die together with the die assembly were heated to 180ºC. The powder mass is hold inside the die cavity for 30 minutes to ensure the uniform distribution of heat to the powder mass.

Multi-axial compaction is conducted simultaneously at pressure of 130kN. After the compaction finished, the upper punch is released to its original position. Bottom punch is used to push the green compact out from the die cavity as it was still inside the die cavity after the compaction.

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Sintering

The defect free green compacts were sintered in the sintering furnace at different sintering temperature, heating/cooling rate, and holding time. Sintering temperatures were varied between 850ºC - 1000ºC. Heating/cooling rates were set as 5º/minutes and 10º/minutes while two different holding times were considered, i.e., 30 minutes and 60minutes. Sintering process was carried out in lab scale furnace by burning argon gas.

Sample Characterization

The sintered products were characterized for their mechanical properties in order to evaluate the effects of sintering parameters. Densities were calculated from the dimensional measurement data of the products. Hardness was measured using Rockwell hardness test machine, FR-3 while three-point bending test was conducted using Instron 5567 universal testing machine (ASTM E290-09). Dimensional changes of the sintered products were measured through digital verniar calliper.

Results and discussions

Relative density

Relative density is, generally, directly proportional to the strength of a metal base product [13]. Hence, this study took into consideration the relative density as a comparison parameter. The higher density parts are produced from the larger contact area among powder particles during compaction which provides more efficient bonding during the sintering process [14-16].

Figure 1 shows the relative densities final products sintered at different temperatures and heating rate while the holding time is fixed to 30 minutes. Increasing of the sintering temperature for both heating rates has increased the relative density. At a heating rate of 5ºC/minutes, the relative densities obtained for three different temperatures show a significant effect. The highest sintered density was obtained for the sintering at 1000ºC. Similar pattern can be seen for 10ºC/minutes heating rate where the highest relative density is obtained by sintering at 1000ºC. These phenomena might be due to the decreasing of porosity during sintering process which allowed more contact and bonding effectiveness among the particles. A higher relative density is resulted due to the sintering at higher temperature. These results are coincident with the findings reported in [6].

The results obtained by sintering for 60 minutes are seemed to be different compared to the results of sintering for 30 minutes (Figure 2), which show a reversed pattern even though all other parameters are identical. The relative density is found to be decreased when the sintering temperature is increased at both heating rates, i.e., 5°C/minutes and 10°C/minutes. The longer holding time caused the relative density to decrease.

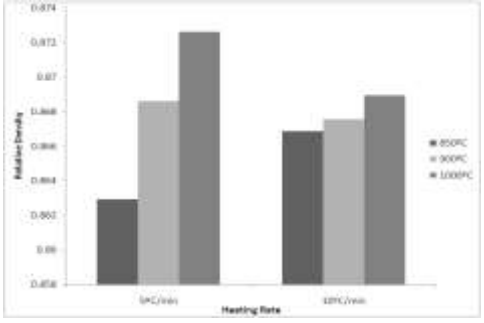

Figure 1. Relative density of sintered parts formed at 180°C and 30 minutes holding time

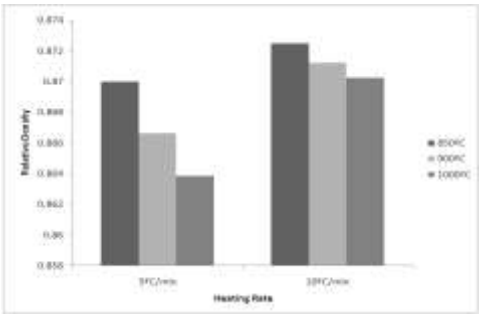

Figure 2. Relative density of sintered parts formed at 180°C and 60 minutes holding time

Hardness

The Rockwell hardness of sintered parts was measured to examine the effect of different sintering parameters to the hardness of sintered parts. The Rockwell hardness was measured at 5 points on the surface of the cylindrical shape parts and the average is considered as hardness.

Figure 3 and Figure 4 show the hardness of sintered parts produced at various sintering parameters. At 30 minutes holding time (Figure 3), the maximum hardness obtained for 5ºC/minute heating rate and 900ºC sintering temperature. Increasing the sintering temperature for a heating rate of 5ºC/minute gave minimum effect to the hardness. However, for the holding time of 60 minutes, hardness obtained for the heating rate of 5ºC/minute and 10ºC/minute shows some contradictions. Increasing the sintering temperature increased the hardness for 5ºC/minute heating rate, however, the hardness dropped when the sintering temperature increased for the heating rate of 10ºC/minutes.

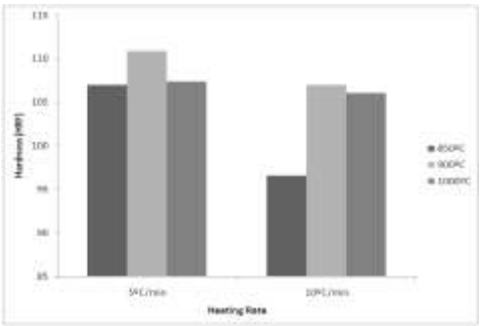

Figure 3. Hardness of sintered parts formed at 180°C and sintered for 30 minutes

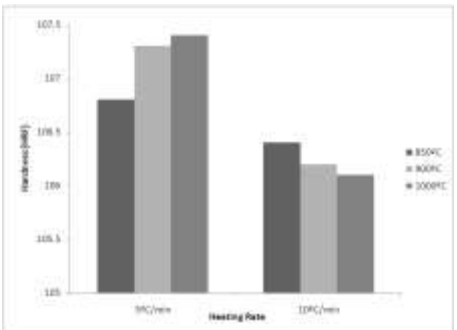

Figure 4. Hardness of sintered parts formed at 180°C and sintered for 60 minutes

Strength

In powder metallurgy, strength of the product is the most vital factor to be considered. The higher strength indicates the better quality of the product. Therefore, it is necessary to produce products with higher strength. Figure 5 shows the bending strength of sintered components formed at 180ºC. The variations of strength values can be observed for the heating rate

of 5ºC/minute as the sintering temperature is increased. For the heating rate of 10ºC/minute, it is observed that the increasing of sintering temperature increased the strength. Strength of parts is significantly affected by the sintering temperature for both sintering rate even though the holding time is identical for both cases, i.e., 30 minutes. The values of bending strength are found to be highest for the sintering at 1000ºC regardless the other parameters (Figure 5).

In the case of sintering for 60 minutes (Figure 6), the strength increased as the sintering temperature increased at a heating rate of 10ºC/minute. It is unlike when sintered at a rate of 5ºC/minute where the strength varied as the sintering temperature increased.

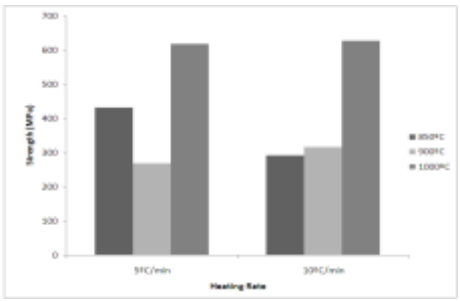

Figure 5. Strength of sintered parts formed at 180ºC and sintered for 30 minutes

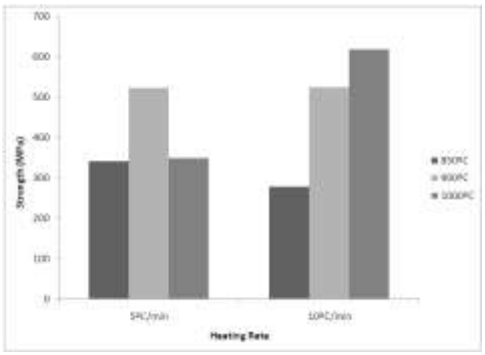

Figure 6. Strength of sintered parts formed at 180ºC and sintered for 60 minutes

Dimensional Change

Dimensions of the green as well as the sintered compacts are measured using digital verniar caliper from where the volumes of the compacts were calculated. It is found that the percentage of dimensional change is very minimal, which almost cannot be seen by naked eyes.

Generally, dimensional changes are increased as the heating rate increased to 900°C and decreased further for all other sintering parameters.

Therefore, it is observed that heating rate affected the dimensional changes of the products during sintering process. The highest dimensional change is found to be 1.38% for the sintering temperature of 900ºC, 10ºC/minute sintering rate and 60 minutes holding time.

Conclusions

The results revealed that the sintering schedule affected the properties of sintered products. The suitable heating/cooling rate is found to be 5°C/minute whereas the sintering temperature is 1000°C, and the sintering time is 60 minutes. The maximum measured dimensional change was 1.38%. The measured bending strength of the sintered product was around 600 MPa which is seemed to me considerable for any mechanical applicayion.

Acknowledgements

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