

The Effects of Sintering Schedule to the Final Properties of Iron Powder Compacts Formed through Warm Compaction Route

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Abstract— Powder forming at above ambient temperature with admixed lubricant to obtain the high quality green compacts is recently discovered, however the effects of sintering schedule to the mechanical properties and microstructures of final products are not explored yet. Therefore, a lab scale warm compaction rig is designed and fabricated to generate green compacts at different forming parameters. Iron ASC 100.29 is used as main powder constituent during this investigation. The defect-free green compacts were sintered in an argon gas fired furnace at different sintering schedule. The mechanical properties and microstructures of sintered parts were evaluated. The results revealed that the mechanical properties and microstructures of sintered products are affected by the forming temperature and sintering schedule. Therefore, the suitable forming temperature and sintering schedule are identified for the production of high quality components.

Keywords— Warm powder forming; sintering schedule; mechanical properties; microstructure.

I. 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 methods of manufacturing [1-3]. Powder metallurgy becomes essential since it has the ability to reduce cost as well as to produce parts having complex shapes. 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 any other methods of manufacturing [5]. A major advance in p/m technology is 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 properties and microstructures 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 the outcomes of an experimental investigation on the effects of sintering schedules to the mechanical properties and microstructures of iron powder compacts formed through warm compaction route.

II. MATERIALS AND METHOD

The main powder constituent used is iron ASC 100.29 produced by Höganäs with average 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 a radius of 10.35mm a depth of 60mm.

A. 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) forming of powder mass, 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 up to a temperature range from 30°C to 180°C. 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 a load 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.

B. Sintering

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

C. Sample Characterization

The sintered products were characterized for their mechanical properties and microstructures 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. The microstructures of the compacts were evaluated from the images captured through Scanning Electron Microscopy (SEM).

III. RESULTS AND DISCUSSIONS

The results from this study are presented and discussed by topic.

A. Relative Density

In producing parts for any mechanical applications, it is essential to have higher relative density because density is generally proportional to the strength [20]. 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].

Fig. 1 shows the relative densities of 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 5°C/minutes, the relative densities obtained for three different sintering temperatures show a significant effect. The highest sintered density was obtained for the sintering at 1000°C. Similar pattern can be seen for 10°C/minutes heating rate where the highest relative density is obtained by sintering at 1000°C. 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].

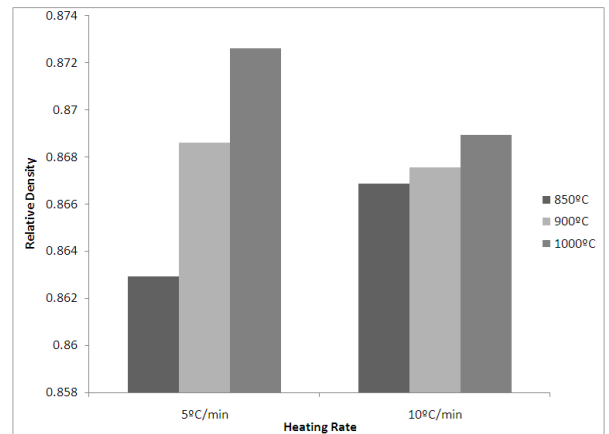


Fig. 1 Relative density of sintered parts formed at 180°C and 30 minutes holding time

The results obtained by sintering for 60 minutes are seemed to be different compared to the results of sintering for 30 minutes (Fig. 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. This might be due to the swelling of the samples kept at higher temperature for longer period of time [18].

B. Hardness

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

Fig. 3 and Fig. 4 show the hardness of sintered parts produced at various sintering parameters. At 30 minutes holding time (Fig. 3), the maximum hardness obtained for 5°C/minute heating rate and 900°C sintering temperature. Increasing the sintering temperature for a heating rate of 5°C/minute gave minimum effect to the hardness. However, for the holding time of 60 minutes, hardness obtained for the

heating rate of 5°C/minute and 10°C/minute shows some contradictions. Increasing the sintering temperature increased the hardness for 5°C/minute heating rate, however, the hardness dropped when the sintering temperature increased for the heating rate of 10°C/minutes. Faster heating rate means less time required by a sample to reach the sintering temperature. As a consequence, the powder particles are not consolidate internally leaving free pores inside the compact hence the hardness becomes slightly lower [21].

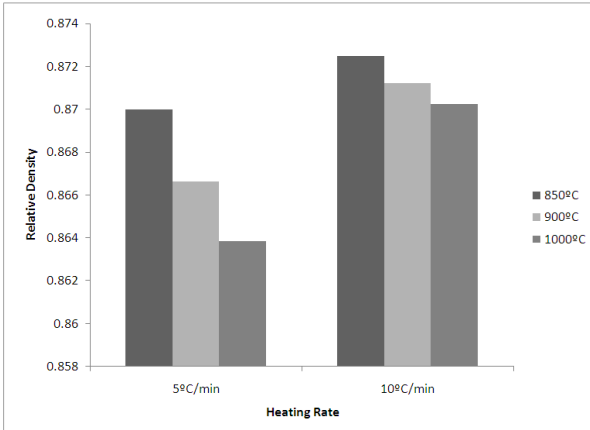


Fig. 2 Relative density of sintered parts formed at 180°C and 60 minutes holding time

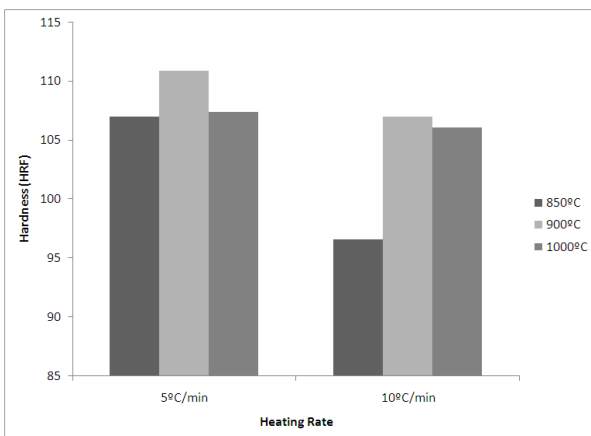


Fig. 3 Hardness of sintered parts formed at 180°C and sintered for 30 minutes

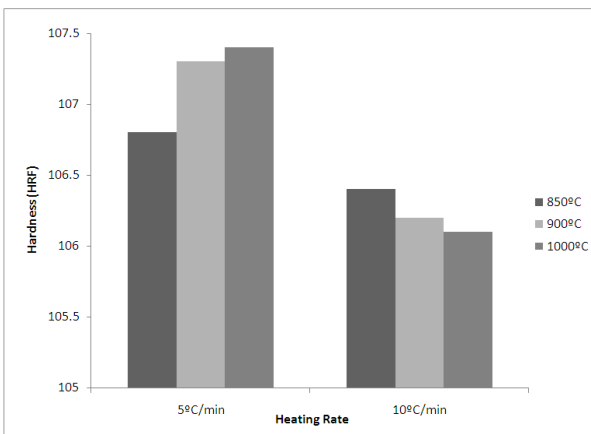


Fig. 4 Hardness of sintered parts formed at 180°C and sintered for 60 minutes

C. 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. Fig. 5 shows the bending strength of sintered components formed at 180°C. The variations of strength values can be observed for the heating rate of 5°C/minute as the sintering temperature is increased. For the heating rate of 10°C/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 1000°C regardless the other parameters (Fig. 5). At higher sintering temperature, i.e., 1000°C, the bonding among iron particles are occurred properly hence the bonding strength became higher [19]. Therefore, components sintered at higher temperature have higher strength.

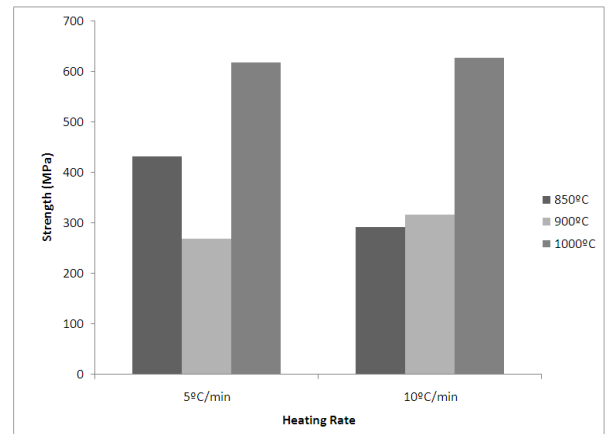


Fig. 5 Strength of sintered parts formed at 180°C and sintered for 30 minutes

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

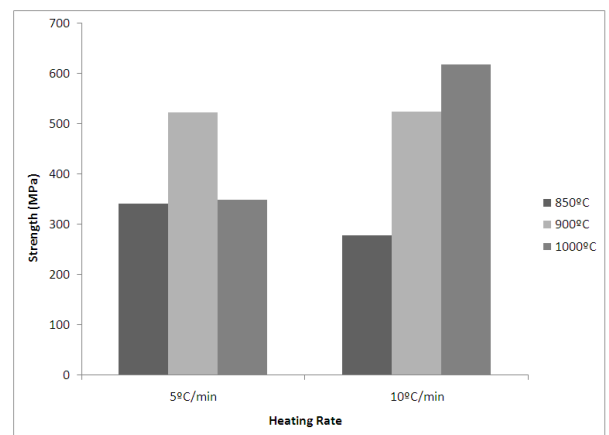


Fig. 6 Strength of sintered parts formed at 180°C and sintered for 60 minutes

D. Dimensional Change

Dimensions of the green as well as the sintered compacts are measured using digital vernier 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 traced 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 900°C, 10°C/minute sintering rate and 60 minutes holding time.

E. Microstructures

The SEM images of final products formed from iron powder mixed with 0.4wt% zinc stearate and sintered at different sintering schedules are shown in Fig. 7. It is evident that for the lower sintering rate and higher sintering temperature (Fig. 7a) the iron particles are bonded properly to each other. As the sintering temperature increases, the recrystallization also takes place. As a consequence of recrystallization, the grain size decreases, hence the strength of the components also increases [13].

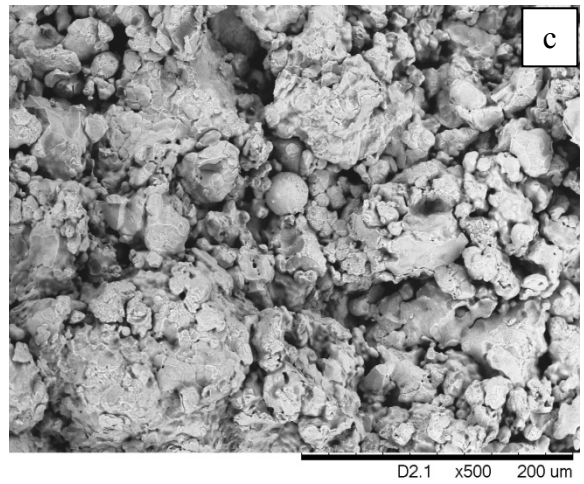
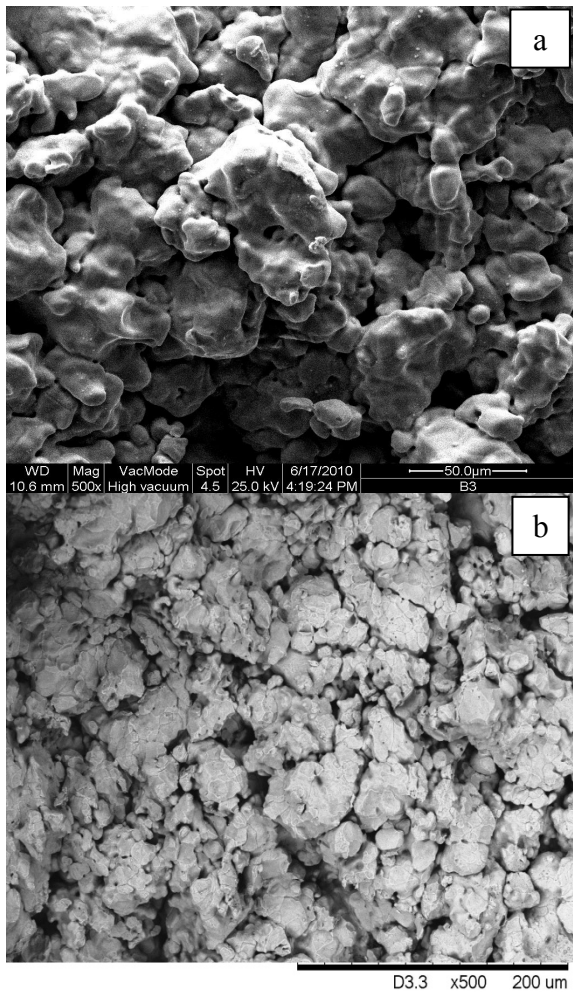


Fig. 7 SEM images of final products formed at different compaction parameters and sintered for 60 minutes by varying the other sintering parameters: (a) 1000°C, 5°C/minute; (b) 900°C, 5°C/minute; (c) 900°C, 10°C/min

IV. CONCLUSIONS

A lab-scale experimental investigation on the effect of sintering schedules to the mechanical properties and microstructures of components formed through warm compaction route was conducted. The results revealed that sintering schedules affect the mechanical properties and microstructures of sintered products. The suitable sintering temperature is found to be 1000°C. The high quality, i.e., high density and perfect microstructure sintered products are obtained by forming the powder mass at 180°C and sintered at 1000°C at a heating rate of 5°C/minute for 60 minutes.

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