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# SINTERING OF WARM FORMED COMPONENTS IN INERT GAS FIRED FURNACE

***RINGKASAN:*** *Kertas kerja ini membentangkan hasil kajian ujikaji pensinteran komponen logam yang dibentuk pada keadaan hangat menggunakan kaedah ekapaksi. Bahan suapan disediakan dengan cara mencampurkan serbuk besi ASC 100.29 dengan 0.4 wt% dan 0.8 wt% zink stearat untuk 30 minit. Bahan campuran berkenaan lalu dibentuk pada suhu 120 °C dan 180 °C. Mampatan hijau yang baik telah disinter dalam ketuhar gas argon pada jadual pensinteran yang berbeza-beza. Kadar pemanasan yang digunakan adalah 5 °C/minit dan 10 °C/minit di mana kadar penyejukan adalah kebalikan daripada kadar pemanasan. Kesemua sampel disinter pada suhu malar iaitu 1000 °C dengan membiarkan sampel pada suhu berkenaan untuk masa yang berbeza-beza iaitu 30 minit dan 60 minit. Produk yang telah disinter telah diciri melalui ujian mekanikal dan pemeriksaan mikrostruktur. Hasil kajian menunjukkan bahawa parameter pembentukan dan pensinteran memberikan kesan yang signifikan ke atas kualiti produk akhir.*

**ABSTRACT:** This paper presents the results of an experimental investigation of the sintering of metallic components formed at above ambient temperature. The feedstock was prepared through mechanically mixing of iron powder ASC 100.29 with 0.4 wt% and 0.8 wt% zinc stearate for 30 minutes. The powder mass was then shaped at 120 °C and 180 °C through uniaxial compaction method. The defect-free green compacts were then sintered at argon gas fired sintering furnace at different sintering schedules. The heating rates were 5 °C/minute and 10 °C/minute where the cooling rates were the reverse of the heating rates. The holding times were 30 minutes and 60 minutes whereas the sintering temperature was fixed at 1000 °C. The sintered products were characterized through mechanical testing and microstructure examination. The results revealed that both forming and sintering parameters significantly affect the final quality of products.

Keywords: Warm forming, sintering, mechanical properties, microstructure

## INTRODUCTION

The study of near-net-shape manufacturing through powder route has become essential since there is a need in cost reduction and improvement in mechanical properties such as higher density, strength, etc. Hence, the optimization between these two aspects, i.e., economics and mechanical properties has to be considered simultaneously. A major advance in this technology has been the warm forming process, which utilizes traditional powder forming equipment.

Warm forming is defined as compaction of metal powder at elevated but below its re-crystallization temperature (Höganäs, 1998). Sintering plays an important role in a full cycle of warm forming process in producing defect-free final products with excellent mechanical properties and microstructures. Sintering is a heat treatment process for bonding particles together into a coherent, predominantly solid structure via mass transport events. Such bonding improves the strength and other engineering properties of powder compacts. The standard way of performing the sintering operation is to subject the parts to a high temperature in a controlled atmosphere using a sintering furnace (German, 1996). The process is known as free sintering since no mechanical stress is applied on the parts. The effect of sintering is the change of inter-particle contact, which begins with rapid growth between particles because of the cold welding taken place in the green compact. At this stage, the void volume is reduced and finally as the surface tension and diffusion continue, the spheroidization of isolated pores occurs and it results in a relatively homogenous component (Simchi, 2003). Correct sintering is of paramount importance to the powder metallurgy process to ensure not only the development of the strength needed for the part to fulfill its intended role as an engineering component, but also that the dimensions of the part are correct (Xiao *et al.*, 2009).

The metal powder is generally mixed with a polymeric lubricant prior to the generation of defect-free yet high density green compacts to be sintered. During sintering, the lubricant is burnt out due to its low melting temperature which causes uneven density distribution and dimensional distortion if the sintering is not conducted through proper schedule (Nor *et al.*, 2008; Rahman & Nor, 2009). Powder forming at above ambient temperature is relatively new hence no information on the sintering characteristics of iron powder formed at different forming parameters is available in the literature. Therefore, the aim of this paper is to present the outcome of the investigation of sintering characteristics of iron powder compacts formed at above ambient temperature.

## MATERIALS AND METHOD

Main powder constituent was iron powder ASC 100.29 which has the particle size range of 20-180 µm. The powder manufactured by Höganäs AB Company has the composition of 1.5 % Cu, 0.5 % Mo, and 4 % Ni balanced with Fe. Zinc stearate ($C_{36}H_{70}O_4Z_n$) powder has been used as an admixed lubricant. The overall experiment consists of (i) feedstock preparation, (ii) green body generation, (iii) sintering, and (iv) sample characterization.

### Feedstock Preparation

In order to prepare a homogenous blend of feedstock, iron powder was mixed mechanically with 0.4 wt% and 0.8 wt% zinc stearate for 30 minutes (Rahman & Nor, 2007).

### Green Body Generation

The compaction experiment has been conducted using previous published experimental procedure (Rahman *et al.*, 2011). It consists of powder filling inside the die, powder and the die assembly heating, powder forming, and the ejection. The powder mass was shaped at two different temperatures, i.e., 120 °C, and 180 °C. The powder mass with the die assembly were heated to the required temperature and hold for 30 minutes in order to get the uniform temperature distribution (Ariffin *et al.*, 2001). The compaction load was fixed to 130 kN, which is considered suitable to generate green samples of adequate strength (Rahman *et al.*, 2010). The warm compaction rig is shown in Figure 1.

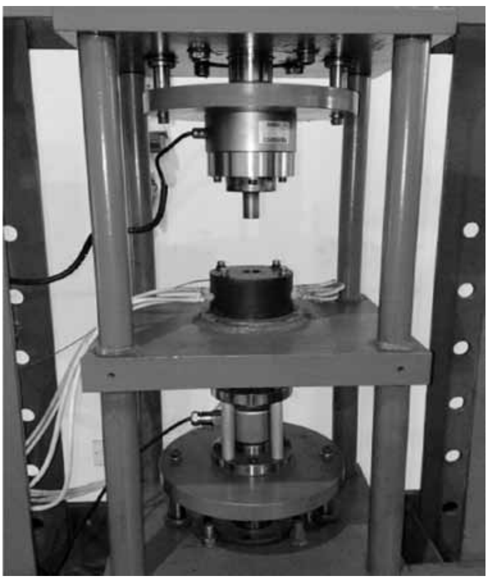

***Figure 1.*** *Warm compaction rig sintering.*

The green compacts were sintered in an argon gas fired sintering furnace by varying the sintering time (30 and 60 minutes), and heating rate (5 °C/minute and 10 °C/minute). However, the sintering temperature was kept at constant value, i.e., 1000 °C.

### Product Characterization

The final products were characterized for their relative densities and strengths. The microstructure of the sintered products was analyzed using Scanning Electron Microscope.

## RESULTS AND DISCUSSION

Figures 2 and 3 show the density variation against heating/cooling rate at different holding time for the green compacts with different lubricant content. It can be observed that as heating rate increases, the density decreases. This is caused by the higher volume reduction when the samples were sintered at 5 °C/minute compared to 10 °C/minute. Lower heating rate promotes grain growth, thus eliminates pores that leads to density increment better than higher heating rate. It is also evident that the density of sample formed at 120 °C with 0.8 wt% of zinc stearate tends to have better density. As the melting temperature of zinc stearate is 130 °C, the effective medium of lubrication is around 120 °C compared to 180 °C. Therefore, 120 °C forming temperature has given higher relative density during compaction process and as the samples are sintered at the same schedule, higher relative density of final product is achieved at a higher density sample. Furthermore, due to the addition of higher weight percent of lubricant, i.e., 0.8 wt%, some zinc stearate is trapped inside the powder mass, which reduced the inter particle friction and eased the motion of powder particles, as a consequence, the volume became smaller hence the density became higher compared to the addition 0.4 wt% lubricant.

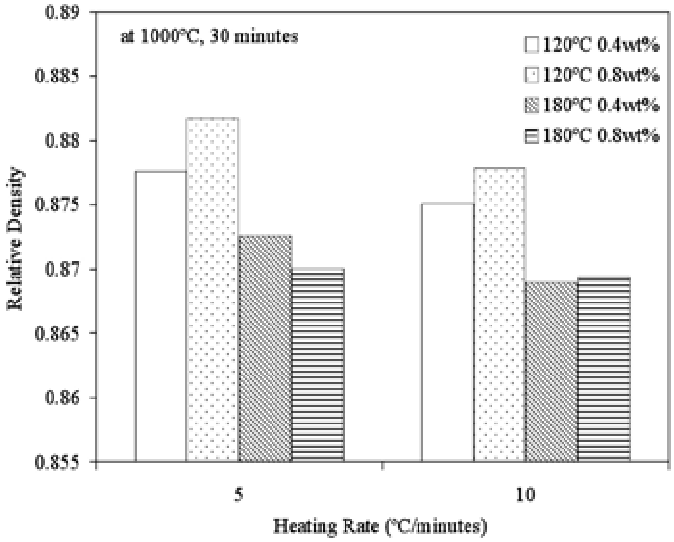


***Figure 2.*** *Sintered densities at different heating rate, 30 minutes holding time.*

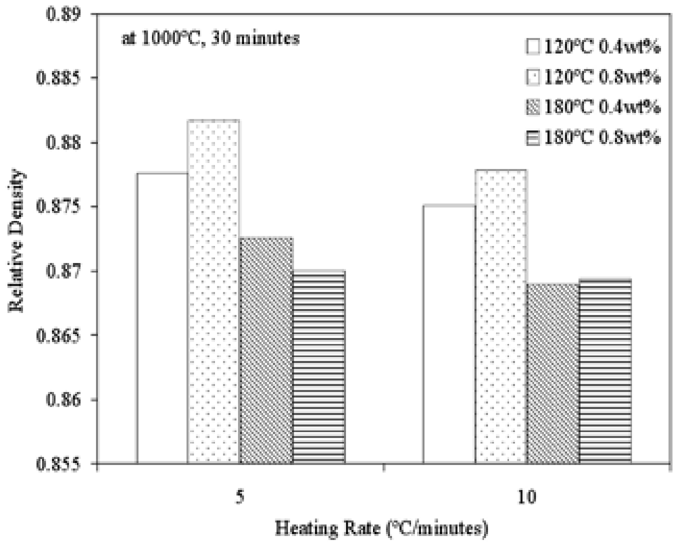


***Figure 3.*** *Sintered densities at different heating rate, 60 minutes holding time.*

In powder metallurgy, the strength of the product is the most vital factor to be considered. The higher the strength indicates the high quality of the product. Therefore, it is necessary to produce product with higher strength. Figures 4 and 5 show the variations of strength against heating/cooling rate. It can be observed that the strength increases as the heating rate increases. The reason is that at high heating rate i.e., 10 °C/minute, grain growth is inhibited, thus higher strength is achieved (Rittidech & Tunkasiri, 2009).

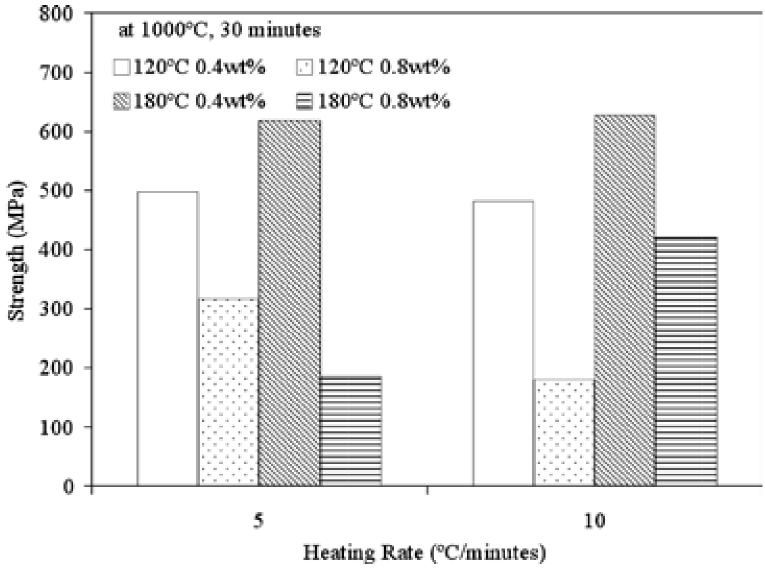


***Figure 4.*** *Sintered strengths at different heating/cooling rate, 30 minutes holding time.*

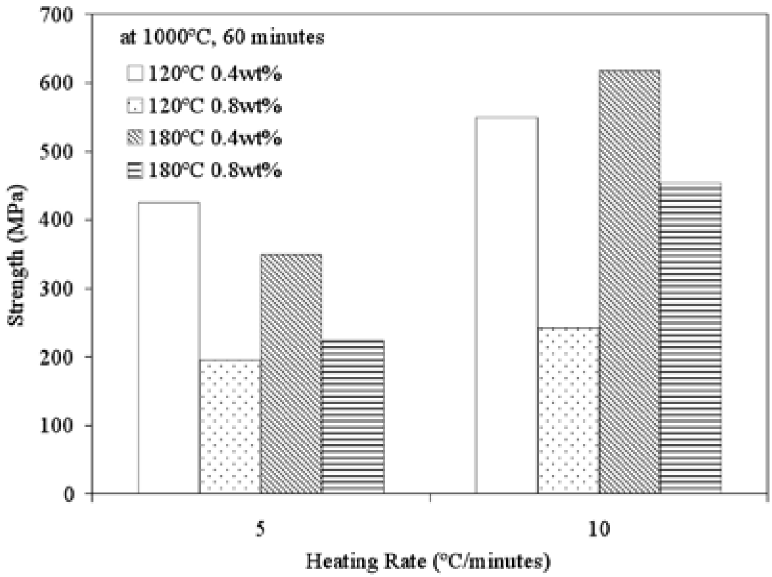


***Figure 5.*** *Sintered strengths at different heating/cooling rate, 60 minutes holding time.*

Results of microstructure analyses (Figure 6) revealed that at a certain sintering schedule, forming parameters influenced the microstructures of the final products. At higher forming temperature, i.e. 180 °C, smaller grains were observed compared to forming at lower temperature, i.e. 120 °C. This finding correlates with the argument reported earlier (Rahman *et al.*, 2010). At higher lubricant content, more void or pores were observed. The interconnected pores are also observed at the green compacts with higher lubricant content.

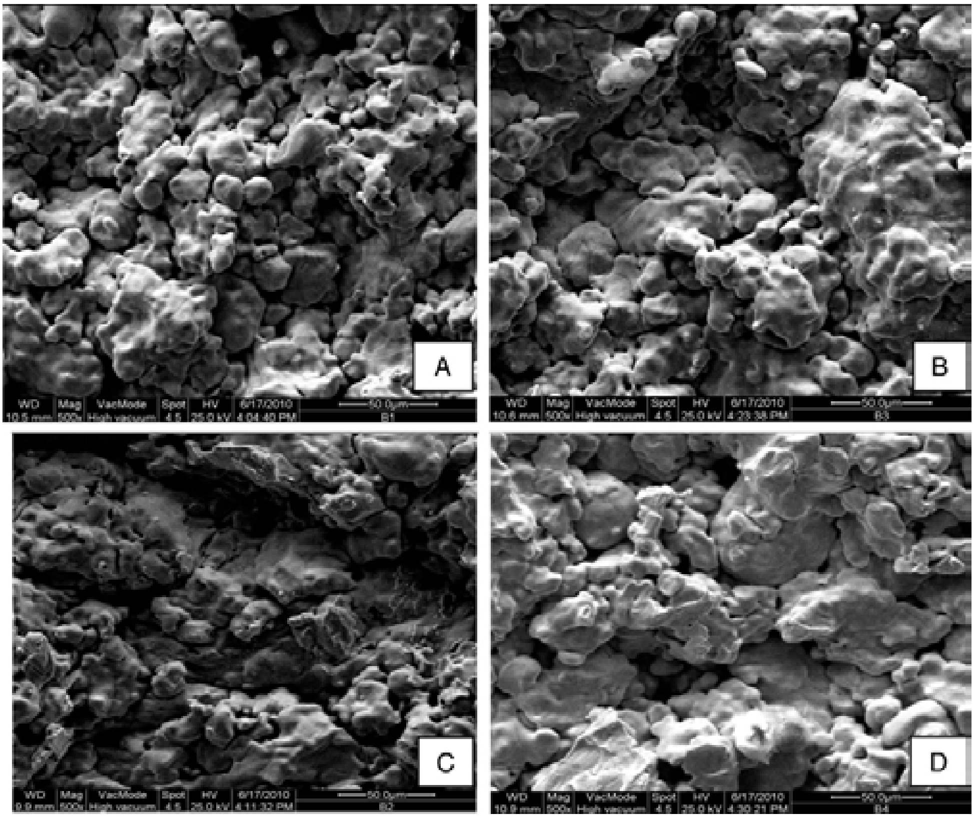


***Figure 6.*** *Microstructures of sintered products formed at different compaction parameters (A) 120°C; 0.4wt%, (B) 180°C; 0.4wt%, (C) 120°C; 0.8wt%, and (D) 180°C; 0.8wt%.*

## CONCLUSION

This study reported the investigation on the effects of sintering parameters to the final characteristics of iron based components formed through warm forming route. It can be concluded that the powder forming parameters and sintering schedules have close relationship to the mechanical properties and microstructures of the sintered products. Compaction at higher temperature is found to produce lighter yet high strength components.

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