Songklanakarin J. Sci. Technol.
31 (5), 555-559, Sep. - Oct. 2009

Songklanakarin Journal
of Science and Technology
http://www.sjst.psu.ac.th

Original Article

Effect of non-reactive hard particles on sintered Fe material

Thanyaporn Yodkaew*, Monnapas Morakotjinda, Nattaya Tosangthum,
Ornmanee Coovattachai, Rungtip Krataitong, Pisan Siriphol, Bhanu Vetayanugul
and Ruangdaj Tongsri

Powder Metallurgy Research and Development Unit (PM_RDU)
National Metal and Materials Technology Center, Khlong Luang, Pathum Thani, 12120 Thailand.

Received 28 September 2007; Accepted 30 January 2009

Abstract

The presence of non-reactive hard particles (Al_2O_3) causes some effects on P/M processing of sintered Fe materials. With constant compacting pressure and sintering conditions, particle size and quantity of Al_2O_3 particles caused reduction of green and sintered densities. Tensile strengths, elongation and hardness of the sintered material were maximum when 2 wt.% of Al_2O_3 particles with particle size between 20-32 um was added. The presence of Al_2O_3 particles may reduce sinterability of the Fe powder.

Keywords: hard particles, sintered Fe, sintered properties

1. Introduction

In powder metallurgical processing, two steps, namely compacting and sintering are important. In the compacting process, the relationship between compacting pressure and green density (density of a compressed part) is one of the prerequisite pieces of information needed to be known by researchers and industrial press operators. In general, green density is increased with increasing compacting pressure (German, 1994(A) and Coovattanachai *et al.*, 2006(A)). Simply stated, the role of compacting pressure is to compress the powder particles into a shape, increase the density, and provide strength to the compact. Increase of green density with increasing compacting pressure is limited at some compacting pressure values, beyond which only slight increase of green density can be obtained. In sintering process, heating schemes for a green compact, hold time, atmosphere, and cooling are important processing parameters (German, 1998(B)). Most research papers have been concerned with P/M processing of straight materials e.g. pure metals or alloys. However there have been some works dealing with the effect of impurities or additives on powder metallurgical processing of metal or alloy plus impurities or additives. It has been shown that impurity of the powders reduced their compressibility (German, 1994).

In this investigation, foreign particles of non-reactive Al_2O_3 were added to pure iron powders and the mixed powders were processed. This work aimed to determine some basic behaviors of the sintered Fe- Al_2O_3 materials processed under different conditions. In this article, all processing parameters, including compacting, debinding and sintering conditions, were fixed. Only Al_2O_3 particle content and size were varied. This work should provide basic information for further development of particulate-reinforced metal matrix composites (P-MMCs). Selection of non-reactive particles to be admixed with pure iron powders may exclude some effects resulting from reaction between particles.

Powder metallurgy (P/M) has some advantages for fabrication of particulate-reinforced metal matrix composites. This is because P/M offers materials and energy saving, near net-shape parts fabrication, high productivity as well as parts dimensional accuracy. Furthermore, P/M consists of

*Corresponding author.
Email address: thanyy@mtec.or.th

simple steps, such as powder mixing, pressing, delubricating and sintering. Some works have been carried out to produce P-MMCs (Upadhyaya, 2000). Stainless steels and tool steels were reinforced with particulate reinforcements such as Al_2O_3, TiC, Cr_2C_3 and TiN (Pagounis and Lindroos, 1998). The hot isostatically hipped materials showed that the incorporation of a relatively low volume fraction of ceramic particulate reinforcements significantly increased the wear resistance of the steel matrices, without deteriorating the corrosion properties. However, the material exhibited reductions in the tensile strength, ductility and toughness. Reinforcement type and amount and sintering atmosphere showed the influence on properties of 316L matrix composites (Abenojar *et al.*, 2003). Yttria alumina garnet (YAG) reinforced 316L matrix composites, prepared by either solid-state sintering or supersolidus sintering, improved hardness compared to that of sintered 316L material (Jain *et al.*, 2004).

2. Experimental procedure

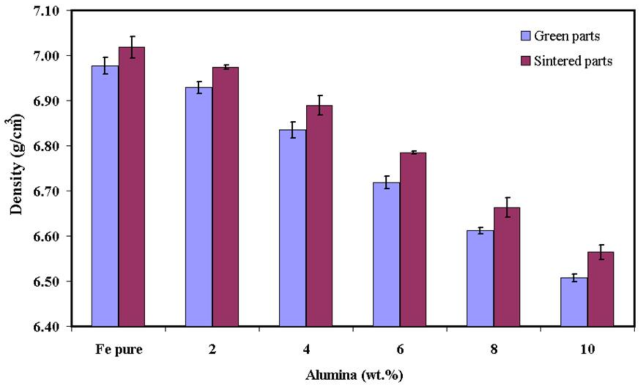
An iron powder size 45-150 micron was mixed with a non-reactive Al_2O_3 powder and 1 wt. % of zinc stearate lubricant. Experimental works were designed to determine the effect of two factors, namely Al_2O_3 powder content and particle size. To explore the effect of Al_2O_3 powder content varied amounts (in wt. %) of Al_2O_3 powder particles, with particle size of between 32-45 micron, were admixed with pure iron powders. For the effect of Al_2O_3 powder particle sizes, sieved fractions, i.e., 20-32, 32-45, 45-60, 60-93 and 93-106 micron, of the Al_2O_3 powder were mixed with the iron powder with a fixed ceramic content of 4 wt. %. The admixed powders were compacted, using a uniaxial press, into tensile test bars (TTBs) with a constant pressure of 300 MPa. The green TTBs were then sintered at 1200°C for 45 minutes in pure hydrogen. Dimensional changes after compacting and sintering of the TTBs were measured along a length of TTBs. Densities of green and sintered samples were determined using the Archimedes method. A universal testing machine (Instron model 8801) was employed to measure mechanical properties of the sintered TTBs. Hardness of the sintered TTBs was determined using a hardness tester (Rockwell scale F). Microstructures were also observed using optical microscopy.

3. Results and Discussion

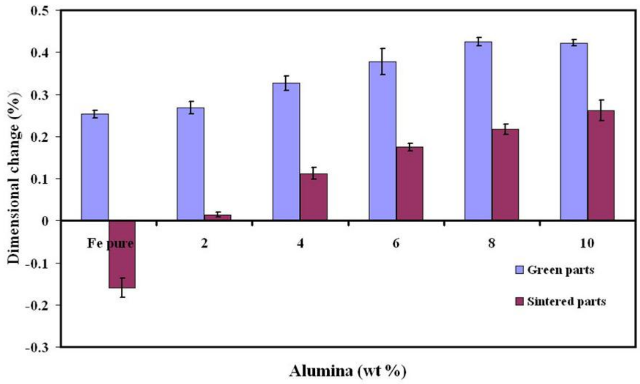
3.1 Effect of Al_2O_3 powder content

3.1.1 Density and dimensional change

All sintered materials showed higher final or sintered density higher than green density. This indicates that all compacts were sintered under the sintering conditions stated in an experimental procedure. It was observed that the presence of Al_2O_3 powder particles caused a reduction in



(a) Density as a function of Al_2O_3 powder content



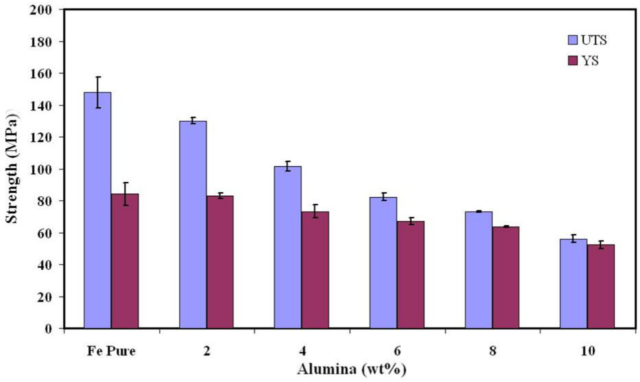
(b) Change of TTB lengths as a function of Al_2O_3 powder content

Figure 1. Density and dimensional change as functions of Al_2O_3 powder content.

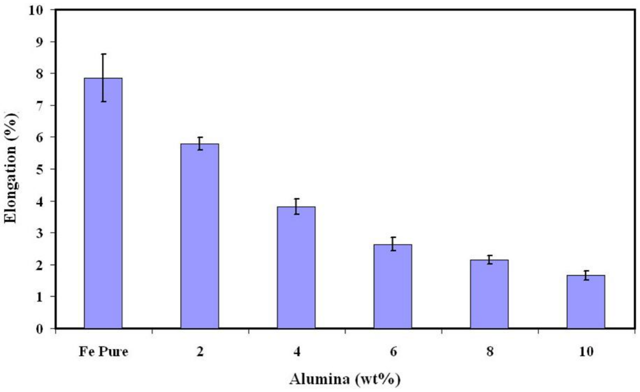
both green and sintered densities (Figure 1(a)). This indicates that non-reactive hard Al_2O_3 particles prohibited densification of the Fe- Al_2O_3 materials. Dimensional changes, or changes of TTB lengths of green and sintered specimens (Figure (1 (b)), decreased with increasing Al_2O_3 powder content. Normally, dimensional changes of the TTBs are closely related to shrinkage of the sintered TTBs. The results shown in Figure 1(b)) indicate that the presence of Al_2O_3 powder particles prohibited shrinkage or, in other words, densification of the sintered Fe- Al_2O_3 TTBs.

3.1.2 Mechanical properties

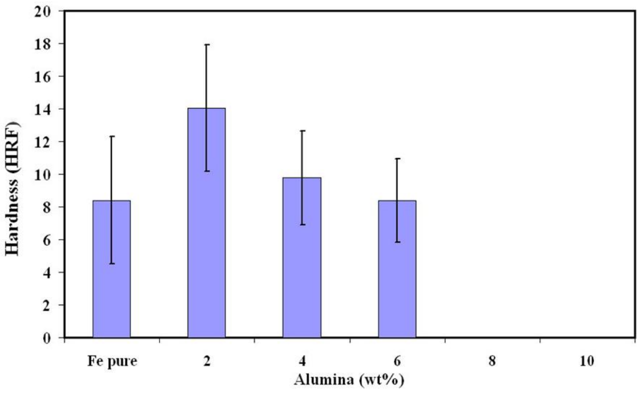
Tensile properties (UTS, yield and elongation) of the sintered Fe-Al_2O_3 materials were lower than those the sintered Fe material (Figure 2(a) and (b)). In contrast, hardness of the sintered Fe-Al_2O_3 materials was higher than that of the sintered Fe material except the case of non-sintered Fe-Al_2O_3 materials (Figure 2(c)). In general, tensile property of sintered materials is controlled by both quantity (number and size) and quality of sintered necks. A lower number and poor sintered necks between Fe particles are supposed to result from sintering inhibition by the presence Al_2O_3 powder particles. The sintering is prohibited due to poor wettability



(a) Tensile strength



(b) Elongation



(c) Hardness

Figure 2. Mechanical properties of sintered Fe-Al_2O_3 materials with varied Al_2O_3 powder contents.

of Fe on Al_2O_3 powder particles.

Evidence of interparticle bonding formation between Al_2O_3 particles themselves and between 316L-Al_2O_3 particles, was hardly observed in the sintered 316L-Al_2O_3 materials (Coovattanachai *et al.*, 2006(B). No bonding between Al_2O_3 particles is due to a low temperature sintering process. No bonding between Al_2O_3-316L particles is attributed to poor wettability of metals on Al_2O_3 particles, since their electrons are tightly bound and their surfaces represent large discontinuities in charge (Pagounis and Lindroos, 1998).

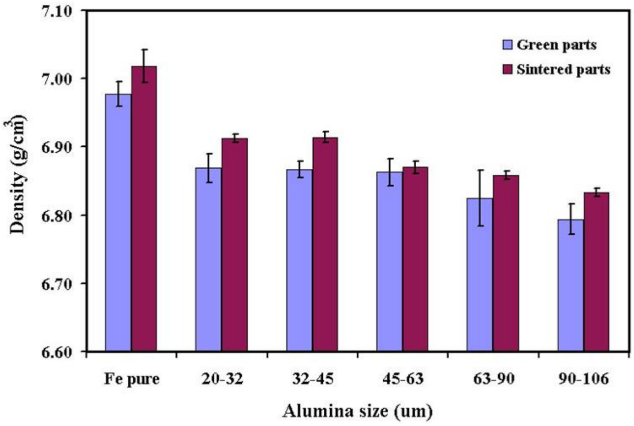
3.2 Effect of Al_2O_3 powder particle size

3.2.1 Density and dimensional change

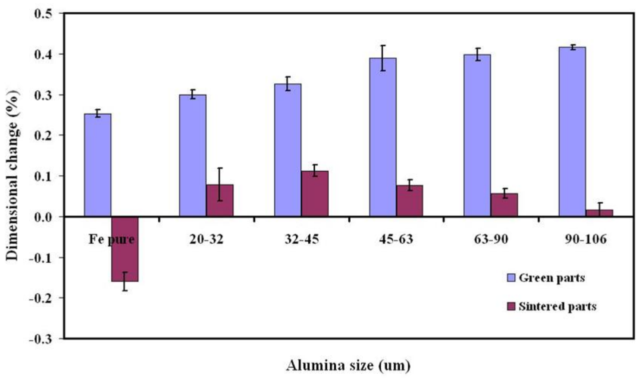
Density and dimensional change of the Fe-Al_2O_3 materials were less sensitive to Al_2O_3 powder particle size (Figure 3). This indicates that volume fraction occupied by the non-reactive Al_2O_3 powder particles, rather than the Al_2O_3 powder particle size itself, is the prime parameter controlling sintering of the Fe-Al_2O_3 materials. This is important basic information was obtained in this investigation.

3.2.2 Mechanical properties

Tensile properties and hardness (Figure 4) of the sintered Fe-Al_2O_3 materials consisting of different Al_2O_3 powder particle sizes showed no significantly difference.

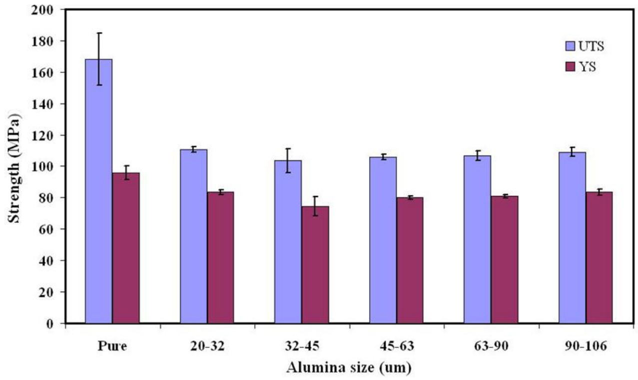


(a) Density of Fe- Al_2O_3 materials as a function of Al_2O_3 powder content

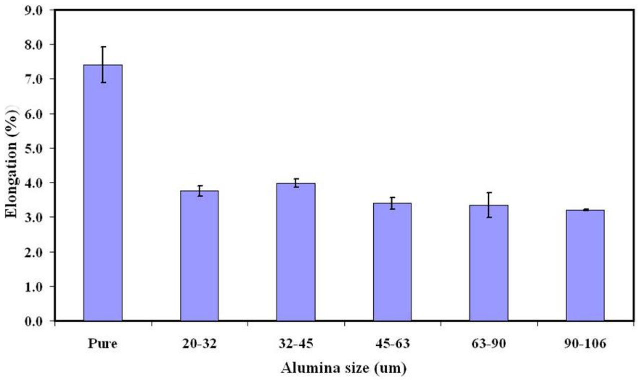


(b) Change of TTB length as a function of Al_2O_3 powder particle size

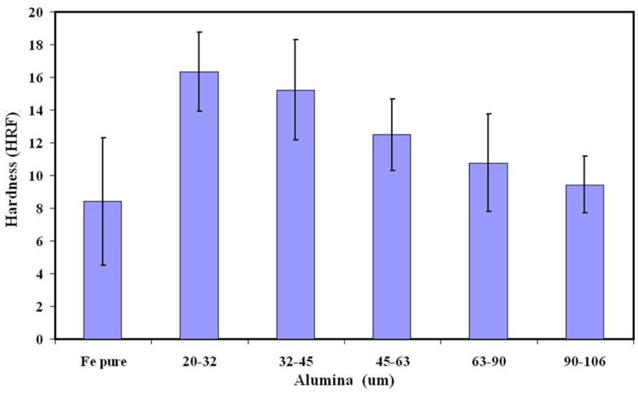
Figure 3. Densities and dimensional change as functions of Al_2O_3 powder particle size.



(a) Tensile strength

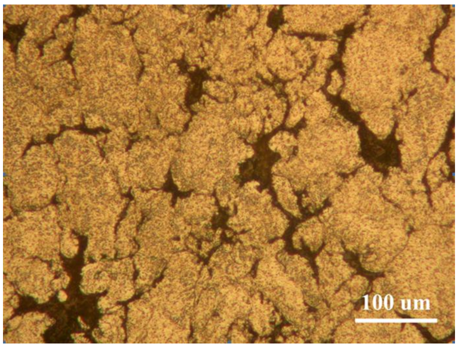


(b) Elongation

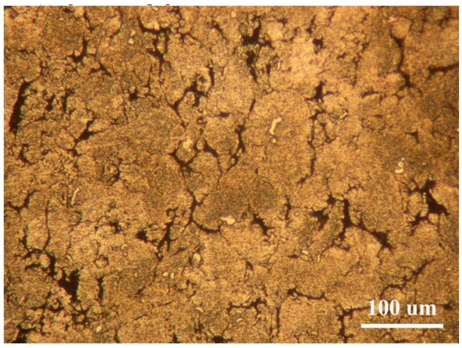


(c) Hardness

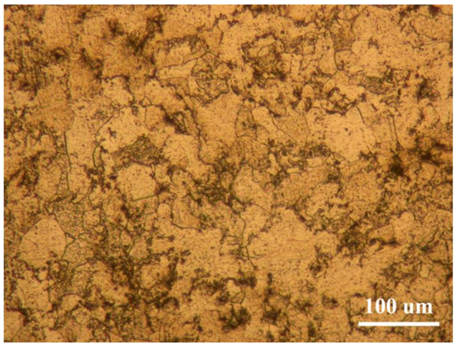
Figure 4. Mechanical properties of sintered Fe-Al_2O_3 materials with varied Al_2O_3 powder particle sizes.



(a) Optical micrograph of the sintered Fe-10% Al2O3 material



(b) Optical micrograph of the sintered Fe-4% Al_2O_3 material with ceramic particle sizes of 32-45 micron.



(c) Optical micrograph of the sintered Fe material

Figure 5. Microstructures of the sintered Fe-Al_2O_3 and Fe materials.

These experimental results also confirm the statement that the volume fraction occupied by the non-reactive Al_2O_3 powder particles, rather than the Al_2O_3 powder particle size itself, is the prime parameter controlling sintering of the Fe-Al_2O_3 materials.

3.3 Microstructural observation

Microstructures of the sintered Fe-Al_2O_3 materials showed homogeneous distribution of Al_2O_3 particles in the Fe matrix (Figure 5(a) and (b)). Volume fraction occupied by the Al_2O_3 particles increased with increasing Al_2O_3 powder content. As mentioned above, the presence of the Al_2O_3 particles caused detrimental effects on both final density and mechanical property. The increase of Al_2O_3 particle volume fraction means inferior properties of the sintered Fe-Al_2O_3 materials are expected to be obtained.

The microstructure of the sintered Fe material showed a few pores (Figure 5(c)). Most Fe grains were bounded by grain boundaries, rather than pores. This type of microstructure indicates higher sintered density. It is not surprising to get this kind of microstructure because sintering of the Fe compacts is performed at high sintering temperature of 1200^{o}C, which is 50^{o}C higher than a normal sintering temperature (1150^{o}C) employed for sintering industrial Fe and steel powders.

4. Conclusions

The presence of Al_2O_3 particles causes some effects on P/M processing of Fe-Al_2O_3 materials. The content of Al_2O_3 particles caused reduction of green and sintered densities and tensile properties. The sintered Fe-Al_2O_3 material properties were less sensitive to the Al_2O_3 particle sizes. Tensile strengths, elongation and hardness of the sintered material were maximum when 2 wt. % of Al_2O_3 particles with particle size between 20-32 um was added. The presence of Al_2O_3 particles prohibited compacting and sintering processes of the Fe powder.

Acknowledgements

The authors would like to express their sincere gratitude to National Metal and Materials Technology Center (MTEC), Pathum Thani, Thailand, for financial support.

References

Abenojar, J., Velasco, F., Bautista, A., Campos, M., Bas, J.A. and Torralba, J.M. 2003. Atmosphere influence in sintering process of stainless steels matrix composites reinforced with hard particles, Composites Science and Technology. 63, 69-79.

Coovattanachai, O., Lasutta, P., Tosangthum, N., Krataitong, R., Morakotjinda, M., Daraphan, A., Vetayanugul, B. and Tongsri, R. 2006 (A). Analysis of compaction and sintering of stainless steel sowders, Chiang Mai Journal of Science. 33(2), 293-300.

Coovattanachai, O., Mima, S., Yodkaew, T., Krataitong, R., Morkotjinda, M., Daraphan, A., Tosangthum, N., Vetayanugul, B., Panumas, A., Poolthong, N., and Tongsri, R. 2006 (B). Effect of Admixed Ceramic Particles on Properties of Sintered 316L Stainless Steel, Advances in Powder Metallurgy and Particulate Materials, Metal Powder Industries Federation, Princeton, U.S.A., pp. (7-161) -(7-171).

German, R.M. 1994. Powder Metallurgy Science, Metal Powder Industries Federation, Princeton, U.S.A., pp. 191-240.

German, R.M.1998. Powder Metallurgy of Iron and Steel, John Wiley & Sons, New York, U.S.A., pp. 181-275.

Jain, J., Kar, A.M. and Upadhyaya, A. 2004. Effect of YAG addition on sintering of P/M 316L and 434L stainless steels, Materials Letters. 58, 2037-2040.

Pagounis, E. and Lindroos, V.K. 1998. Processing and properties of particulate reinforced steel matrix composites, Materials Science and Engineering A. 246, 221-234.

Panumas, A., Yotkaew, T., Krataitong, R., Morakotjinda, M., Daraphan, A., Tosangthum, N., Coovattanachai, O., Vetayanugul, B. and Tongsri, R. 2005. Preparation of 316L-Al_2O_3 composite", Proceeding of the 19th Conference of Mechanical Engineering Network of Thailand, Phuket, Thailand, October 19-21, 2005, 18.

Upadhyaya, G.S. 2000. Sintered Metallic and Ceramic Materials: Preparation, Properties and Applications, John Wiley & Sons, Chichester, U.K., 2000, pp. 189-191.