

## Sintered Fe-Al<sub>2</sub>O<sub>3</sub> and Fe-SiC Composites

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### Abstract

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The presence of non-reactive (Al<sub>2</sub>O<sub>3</sub>) and reactive (SiC) hard particles affected properties of sintered Fe-base composites. With the same compacting and sintering conditions, addition of Al<sub>2</sub>O<sub>3</sub> particles caused reduction of sintered densities. Tensile strengths, elongation and hardness of the sintered Fe-Al<sub>2</sub>O<sub>3</sub> materials decreased with increasing Al<sub>2</sub>O<sub>3</sub> particle amounts. The presence of Al<sub>2</sub>O<sub>3</sub> particles prohibited compacting and sintering processes of the Fe powder. In contrast, addition of SiC particles resulted in reaction between Fe and SiC particles. Sintered density of the sintered Fe-SiC composites was significantly lower than that of the sintered Fe-Al<sub>2</sub>O<sub>3</sub> materials. However, tensile strengths and hardness, except elongation, of the sintered Fe-SiC composites were significantly improved.

**Key Words :** Sintering, Fe-base composites, sintered properties

### Introduction

In powder metallurgical processing, two steps are important, namely compacting and sintering. In the compacting process, a relationship between a compacting pressure and a green density (density of a compressed part) is one of the prerequisite pieces of information required by researchers and industrial press operators. In general, green density is increased with increasing compacting pressure.<sup>(1, 2)</sup> 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.<sup>(3)</sup> Most research papers are 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 powders. It has been shown that the impurity of the powders reduced their compressibility.<sup>(1)</sup>

Powder metallurgy (P/M) has some advantages for the 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 processing consists of simple steps, such as powder mixing, pressing, delubricating and sintering. Some works have been carried out to produce particulate-reinforced metal matrix composites (P-MMCs).<sup>(4)</sup> Stainless steels and tools steels were reinforced with particulate reinforcements such as Al<sub>2</sub>O<sub>3</sub>, TiC, Cr<sub>2</sub>C<sub>3</sub> and TiN.<sup>(5)</sup> 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 influence on properties of 316L matrix composites.<sup>(6)</sup> 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.<sup>(7)</sup>

In this investigation, foreign particles of non-reactive  $\text{Al}_2\text{O}_3$  particles and reactive SiC were added to pure iron powders and then the mixed powders were processed. This work aimed determine some basic behaviors of the sintered Fe- $\text{Al}_2\text{O}_3$  and Fe-SiC materials. In this article, all processing parameters including compacting, debinding and sintering conditions were fixed. Only particulate reinforcement content was varied. This work would be a foundation for further development of P-MMCs.

## Experimental Procedures

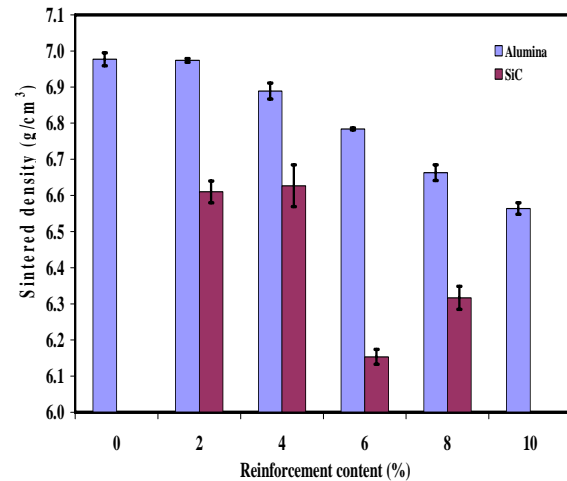
Pure iron powder (0.01% C) was mixed with varied amounts of particulate reinforcements ( $\text{Al}_2\text{O}_3$  or SiC powders) and 1 wt.% of zinc stearate lubricant. Experimental works were designed to determine two factors, namely particulate reinforcement content and reaction between particulate reinforcements and base metal powders. 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 delubricated at 600°C for 1 hour in argon atmosphere and then sintered at 1200°C for 45 minutes in pure hydrogen. Sintered densities of the 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.

## Results and Discussion

### Sintered Density

It was observed that the presence of particulate reinforcements caused reduction of sintered densities (Figure. 1) For the sintered Fe- $\text{Al}_2\text{O}_3$  materials, the decrease of sintered density

may be attributed to densification prohibition by hard  $\text{Al}_2\text{O}_3$  particles and a low density of the  $\text{Al}_2\text{O}_3$  particles.<sup>(8-10)</sup> For the sintered Fe-SiC materials, decrease of sintered density may be attributed to only low density of the SiC particles.



**Figure 1.** Sintered densities of the sintered Fe-base composites (compared to that of the sintered Fe).

### Mechanical Property

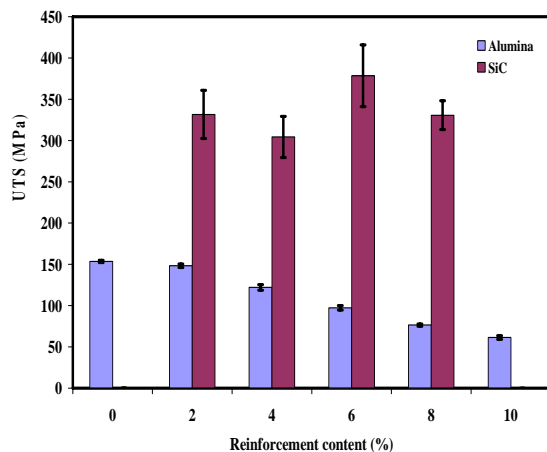
#### Sintered Fe- $\text{Al}_2\text{O}_3$ Composites

Tensile properties (UTS, yield and elongation) of the sintered Fe- $\text{Al}_2\text{O}_3$  materials were lower than those of the sintered Fe material (Figures. 2-4) In contrast, hardness of the sintered Fe- $\text{Al}_2\text{O}_3$  materials was higher than that of the sintered Fe material (Figure 5) In general, tensile property of sintered materials is controlled by both quantity (number and size) and quality of sintered necks. Less number and poor sintered necks between Fe particles are supposed to result from sintering prohibition by the presence of  $\text{Al}_2\text{O}_3$  powder particles. The sintering is limited due to poor wettability of Fe on  $\text{Al}_2\text{O}_3$  powder particles.

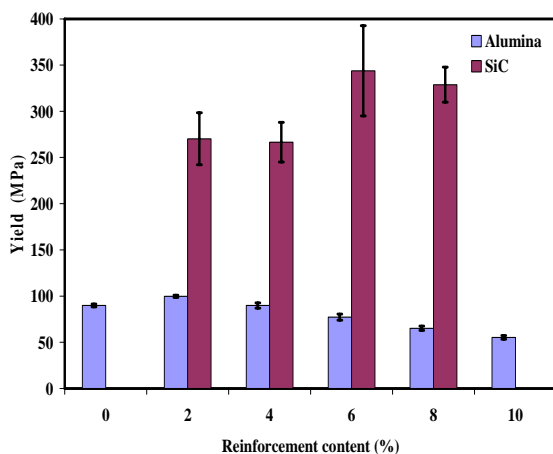
Evidence of interparticle bonding formation between  $\text{Al}_2\text{O}_3$  particles themselves and between 316L- $\text{Al}_2\text{O}_3$  particles was hardly observed in the sintered 316L- $\text{Al}_2\text{O}_3$  materials.<sup>(8)</sup> The lack of bonding between  $\text{Al}_2\text{O}_3$  particles is due to a low temperature sintering process. The lack of bonding between  $\text{Al}_2\text{O}_3$ -316L particles is attributed to poor wettability of metals on  $\text{Al}_2\text{O}_3$  particles since their electrons are tightly bound and their surfaces represent large discontinuities in charge.<sup>(5)</sup>

## Sintered Fe-SiC Composites

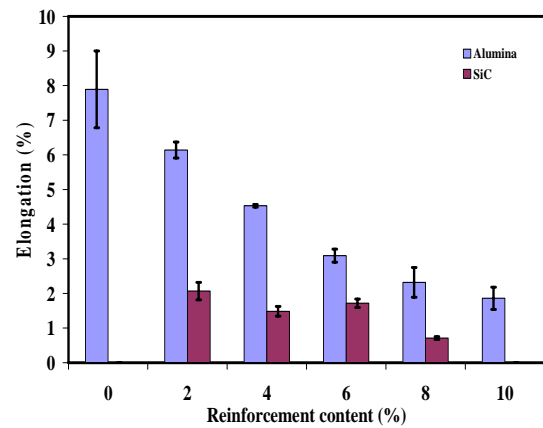
Tensile strengths (UTS and yield) and hardness, except elongation, of the sintered Fe-SiC materials were significantly higher than those of the sintered Fe and Fe-Al<sub>2</sub>O<sub>3</sub> materials (Figures. 2-5). Increase of tensile strengths and hardness in the sintered Fe-SiC materials was similar to the case of the sintered 316L-SiC composites.<sup>(9)</sup> This may be attributed to reaction during sintering process. Formation of a local functionally graded material (SiC-new phase-Fe) occurs. The new phase may help improving particle bonding between SiC and Fe particles. During sintering, some SiC molecules may decompose into Si and C atoms due to contacting with Fe particles. Both Si and C atoms can diffuse into the Fe particles. Reaction between Fe, Si and/or C atoms results in formation of new phase.



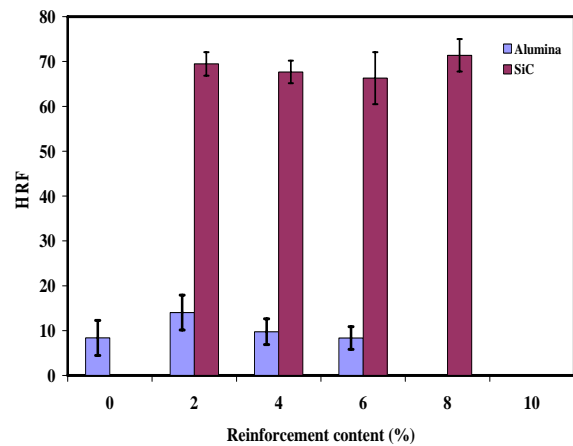
**Figure 2.** UTS of the sintered Fe-base composites (compared to that of the sintered Fe).



**Figure 3.** Yield of the sintered Fe-base composites (compared to that of the sintered Fe).



**Figure 4.** Elongation of the sintered Fe-base composites (compared to that of the sintered Fe).



**Figure 5.** Hardness of the sintered Fe-base composites (compared to that of the sintered Fe).

It was observed that addition of high SiC powder amounts ( $\geq 8$ wt. %) resulted in formation of liquid species during sintering. Although the melting point of SiC is much higher (2730°C) than the sintering temperature (1200°C), reaction between SiC and Fe particles at the sintering temperature resulted in formation of low melting point material. The similar situation was also observed when Fe-base powder compacts, in contact with graphite, were sintered. The Fe-base compacts could be melted at a temperature lower than the melting point of the base material.

Elongation of the sintered Fe-SiC composites tended to decrease with increasing SiC amount. This result conflicts with the case of the sintered 316L-SiC materials.<sup>(9)</sup> For the sintered 316L-SiC materials, elongation increase with increasing SiC content indicated good bonding between 316L

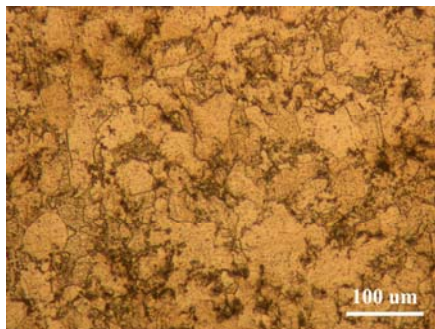
particles and the 316L-SiC phase. However, elongation improvement in the sintered 316L-SiC may be meaningless as sintering temperature is 1200 °C, which is lower than a normal sintering temperature (1300°C) for P/M 316L.<sup>(9)</sup>

### Microstructural Observation

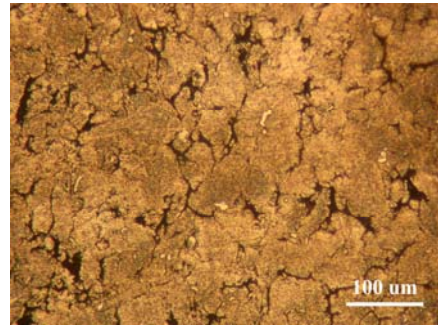
The microstructure of the sintered Fe material showed a few pores (Figure. 6(a)). This type of microstructure indicates higher sintered density. It is not surprised to get this kind of microstructure because sintering of the Fe compacts is performed at a high sintering temperature of 1200°C, which is 50°C higher than a normal sintering temperature (1150°C) employed for sintering industrial Fe and steels powders.

In the microstructure of the sintered Fe-Al<sub>2</sub>O<sub>3</sub> material (Figure. 6(b)), the Al<sub>2</sub>O<sub>3</sub> particles distributed unevenly along grain boundaries in the sintered Fe-Al<sub>2</sub>O<sub>3</sub> composites. The volume fraction occupied by the Al<sub>2</sub>O<sub>3</sub> particles increased with increasing Al<sub>2</sub>O<sub>3</sub> powder contents. As mentioned above, the presence of the Al<sub>2</sub>O<sub>3</sub> particles caused detrimental effects on both final density and mechanical property. The increase of Al<sub>2</sub>O<sub>3</sub> particle volume fraction means inferior properties of the sintered Fe-Al<sub>2</sub>O<sub>3</sub> materials are expected to be obtained.

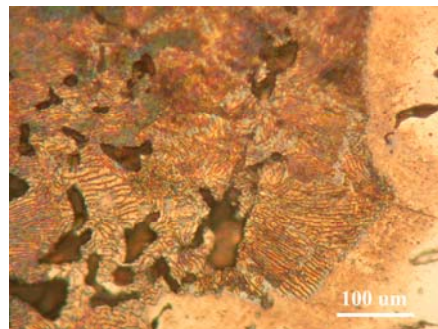
In the sintered Fe-SiC microstructure, there were some lighter Fe grains co-existing with some darker zones (Figure. 6(c)). In the darker zones, there were pearlite structures. During sintering, some SiC molecules may decompose into Si and C atoms due to contacting with Fe particles. Both Si and C atoms can diffuse into Fe particles. Decomposition of Fe-C solid solution results in formation of alternate ferrite and cementite layers.



(a) Optical micrograph of the sintered Fe material.



(b) Optical micrograph of the sintered Fe-4wt. % Al<sub>2</sub>O<sub>3</sub> material.



(c) Optical micrograph of the sintered Fe-4 wt. % SiC material.

**Figure 6.** Microstructures of the sintered Fe and Fe-base materials.

### Conclusions

Addition of Al<sub>2</sub>O<sub>3</sub> particles caused reduction of sintered density and mechanical properties of the sintered Fe-Al<sub>2</sub>O<sub>3</sub> materials. The presence of Al<sub>2</sub>O<sub>3</sub> particles prohibited compacting and sintering processes of the Fe powder. In contrast, addition of SiC particles resulted in reaction between Fe and SiC particles at contacting areas between those particles. Sintered density of the sintered Fe-SiC composites was significantly lower than that of the sintered Fe-Al<sub>2</sub>O<sub>3</sub> materials. However, tensile strengths and hardness, except elongation, of the sintered Fe-SiC composites were significantly improved.

### Acknowledgement

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