

Properties of Sintered Fe-Carbide Composites

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Abstract

Pure Fe powders were admixed with 5 wt. % of carbide powders, such as vanadium carbide (VC) and tungsten carbide (WC). Two carbide particle size fractions, namely < 20 μm and 20-32 μm , were used. The powder mixes were compacted into tensile test bars with green density of $6.43 \pm 0.05 \text{ g/cm}^3$. The green parts were then delubricated at 600 °C for 1 hour and followed by sintering at different temperatures (1100-1250 °C with 50 °C increment) for 45 minutes in vacuum. Carbide particle size and sintering temperature affected mechanical properties of the sintered Fe-carbide composites. Smaller carbide particles provided better mechanical properties. Tensile strengths and hardness of the sintered composites, which were inferior to those of the sintered Fe material, increased with increasing sintering temperature. In the sintering temperature range investigated, there were few evidences of carbide decomposition and reaction between Fe and decomposed carbide constituents

Keywords: Fe-base composites, vanadium carbide and tungsten carbide

1. Introduction

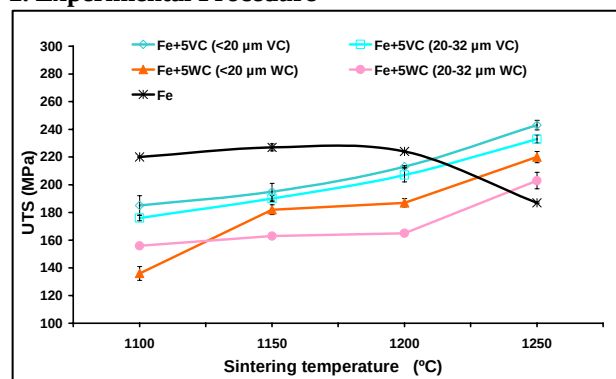
Ideally, introduction of hard particles into stainless steel matrix would generate a new material with high wear and corrosion resistance. This new material will be a competitor of a traditional tool steel. Two possible approaches for developing hard particle-reinforced stainless steels include ingot and powder metallurgical methods. 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 [1]. 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 (MMCs) [2]. Stainless steels and tools steels

were reinforced with particulate reinforcements such as Al_2O_3 , TiC, Cr_2C_3 and TiN [3]. 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 [4]. 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 [5]. In previous works, incorporation of carbide particles (SiC and TiC) into stainless steel 316L has been investigated [6, 7]. Varied amounts of carbides (1.5 and 4.0 wt.%) were added during powder mixing step. Sintered composite materials exhibited lower sintered density than that of the sintered 316L. The sintered 316L+carbide materials showed improved yield strength and hardness. Addition of SiC improved strain at break of sintered materials. In contrast, addition of TiC caused ductility reduction. It was observed that sintering of 316L+SiC mixes could be performed at temperatures ≤ 1200 °C. Sintering of these powder mixes at temperatures beyond 1200 °C resulted in material melting [8].

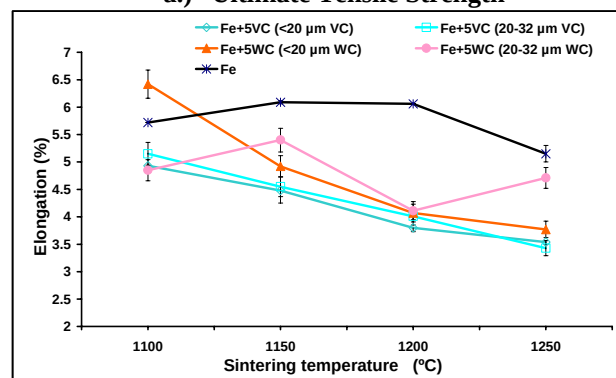
In recent works [9, 10], non-reactive Al_2O_3 and reactive SiC particles were added to iron (Fe) powders for producing Fe-base composites. Addition of Al_2O_3 particles caused reduction of sintered density and mechanical properties of the sintered Fe- Al_2O_3 materials. The presence of Al_2O_3 particles 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_2O_3 materials. However, tensile strengths and hardness, except elongation, of the sintered Fe-SiC

composites were significantly improved. Sintered Fe-SiC and Fe-TiC composites have been investigated recently [11]. It was found that SiC particles decomposed during sintering process. The decomposed Si and C atoms diffused into Fe particles resulting in formation of solid solution of Si and C in Fe during sintering. During cooling, the solid solution of C in Fe decomposed to pearlite structure (ferrite and cementite (Fe_3C) lamellar structure). In contrast, in the sintered Fe-TiC composites, no evidence of TiC decomposition at the investigated sintering temperatures was observed. Because of the reaction between SiC and Fe, tensile strength and hardness of the sintered Fe-SiC composites were higher than those of the sintered Fe. Experimental results showed that strength and hardness of the sintered Fe-SiC composites increased with increasing sintering temperature and with decreasing SiC particle size. In contrast, mechanical properties of the sintered Fe-TiC composites were inferior to those of the sintered Fe. The reason of poor mechanical properties may be attributed to poor bonding between Fe and TiC particles. For the sintered Fe-carbide composites, decomposition of carbide and reaction between Fe and carbide particles show some effects on mechanical properties of the materials. Stability of the carbide particles under the sintering conditions is the prime factor controlling carbide decomposition and reaction between metal matrix and the reinforcements. Because of importance of carbide stability, investigation has been extended to examine microstructures and properties of sintered Fe-VC and Fe-WC composites

2. Experimental Procedure



a.) Ultimate Tensile Strength

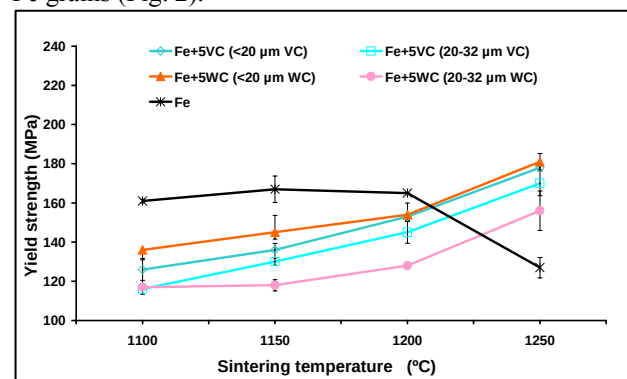


b.) Elongation

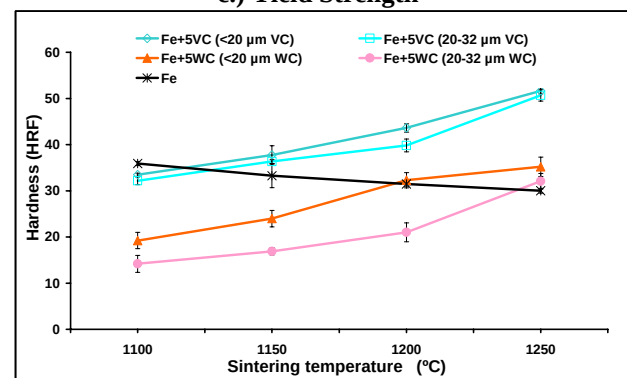
An iron powder was mixed with 5 wt. % of carbides (SiC and TiC) and 1 wt. % of zinc stearate lubricant. Two fractions of carbide particle sizes, i.e., < 20 μm and 20-32 μm, were used. The admixed powders were compacted, using a uniaxial press into tensile test bars (TTBs) with green density of $6.43 \pm 0.05 \text{ g/cm}^3$. The green TTBs were sintered at 3 different temperatures, 1100, 1150 1200 and 1250 °C for 45 minutes in a vacuum furnace. 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. A hardness tester (Rockwell scale F) was employed to measure hardness of the sintered materials. Microstructural observation was performed by using optical microscopy (OM).

3. Results and Discussion

Mechanical properties of the sintered composites (Fe-VC and Fe-WC) depended on three parameters, namely carbide type, carbide particle size and sintering temperature (Fig. 1). The sintered composites reinforced by different carbides showed different mechanical properties. Experimental results, given in Fig. 1, seemingly indicate that the Fe-VC composites exhibit better properties than those of the Fe-WC ones. However, addition of both VC and WC to Fe powders caused properties of the sintered Fe-carbide composites be inferior to those of the sintered Fe material. This was attributed to the fact that both VC and WC particles prohibited sintering between Fe powder particles. Sintering prohibition was evidenced by the necklace form of carbide particles plus pores along grain boundaries of Fe grains (Fig. 2).



c.) Yield Strength

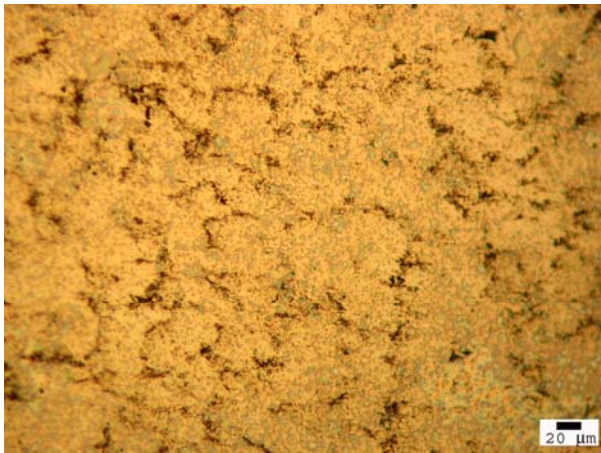


d.) Hardness

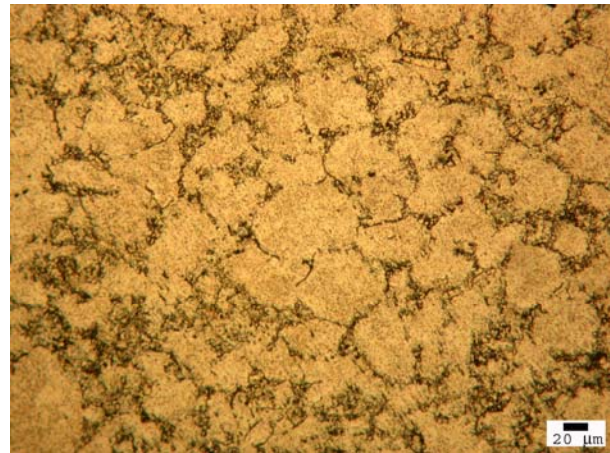
Fig. 1 Mechanical properties of the sintered Fe-carbide composites

With the same type of carbide, the sintered composites prepared by using smaller carbide particles ($< 20\ \mu\text{m}$) exhibited better strengths and hardness than those of the ones prepared from larger carbide particles (20-32

μm). It was observed that addition of larger carbide particles resulted in larger portion of carbide and pore necklaces around Fe grains (Fig. 3).



(a) VC, $< 20\ \mu\text{m}$



(b) VC, 20-32 μm

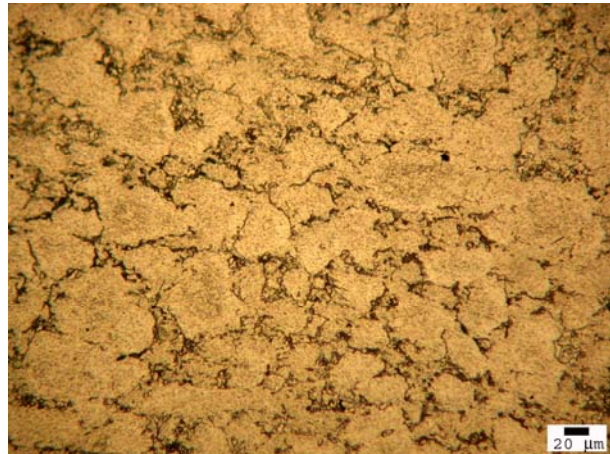
Fig. 2 Microstructures of Fe-VC materials sintered at 1100 °C

In theory, sintering is a thermally activated process [1]. Sintering of powder particles is controlled by material transport from a powder particle to a point or an area of contact. An important material transport mode for sintering is diffusion, which is promoted by heating. For the Fe powders sintered within the temperature range of 1100-1250 °C, properties of the sintered Fe were peak at 1150 °C. Sintering the Fe powders at temperatures above 1150 °C caused no increase of mechanical properties. For the Fe-carbide materials, increasing sintering temperatures resulted in increase of mechanical properties. Because of sintering prohibition by carbide particles as mentioned above, thermal activation was still required for promoting sintering process of Fe-carbide materials at temperatures above 1150 °C. Microstructures of the sintered Fe-VC material (Fig. 4) clearly shows that the carbide particle and pore necklaces are decreased with increasing temperatures.

In previous works [9, 10], it was shown that non-reactive Al_2O_3 and reactive SiC particles caused opposite effects on mechanical properties of the sintered Fe-base composites. Addition of Al_2O_3 particles caused reduction of mechanical properties of the sintered Fe- Al_2O_3 materials. In contrast, addition of SiC particles resulted in reaction between Fe and SiC particles at contacting areas between those particles. Tensile strengths and hardness, except elongation, of the sintered Fe-SiC composites were significantly improved. Investigation on reaction during sintering and cooling of the Fe-SiC and Fe-TiC composites [11] indicated that stability of TiC particles was higher than that of SiC particles when they were in contact with Fe powders at high temperatures. Experimental results in this work indicate that both VC and WC were also stable in the Fe-VC and Fe-WC systems. However, with increasing temperatures, their stability tends to be decreased.



(a) 1100 °C



(b) 1150 °C



(c) 1200 °C



(d) 1250 °C

Fig. 3 Microstructures of Fe-VC (20-32 μm) sintered at different temperatures

4. Conclusions

Mechanical properties of the sintered composites (Fe-VC and Fe-WC) depended on three parameters, namely carbide type, carbide particle size and sintering temperature. In the sintering temperature range investigated, there were few evidences of carbide decomposition and reaction between Fe and decomposed carbide constituents. Both VC and WC were stable in the Fe-VC and Fe-WC systems. However, with increasing temperatures, their stability tends to be decreased.

Acknowledgments

The authors would like to express their sincere gratitude to Materials Technology Division, School of Energy Environment and Materials, King Mongkut University of Technology Thonburi, Bangkok, Thailand, Thailand Graduate Institute of Science and Technology (TGIST) and National Metal and Materials Technology Center (MTEC), Pathum Thani, Thailand, for financial support.

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