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Processing, Microstructure and Properties of 316L Stainless Steel-Tungsten Carbide Composites

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Tungsten carbide (WC) particles were added into 316L stainless steel matrix composites and were fabricated by conventional powder metallurgy route. The amount of WC powders was varied from 5 wt% to 15 wt%. The influence of processing parameters, i.e. tungsten carbide content, sintering temperature and holding time on microstructure and properties of the composites were investigated. The composite specimens were subjected to sintering at the temperature range of 1200 –1300 °C in H_2 atmosphere, using holding time between 30 - 60 minutes. The microstructure investigation was systematically carried out. The surfaces of specimens were successfully exposed after various sample preparation procedures. When using the etchants of glycerol, hydrochloric acid and nitric acid in the ratio of 3: 3: 1 etching for 7 minutes showed more effective reveal of the microstructure of the specimens. An addition of WC into the specimens generally increases the hardness of the specimens at all sintering temperatures and times. It was found that the shrinkage increased and the porosity decreased when the sintering temperatures were increased.

Keywords: powder metallurgy, metal matrix composite, microstructure

INTRODUCTION

Powder metallurgy (P/M) is a well-known process, which can produce materials that have high melting temperature as well as make small and complex-shaped components with precision in dimension and high productivity [1]. It also has advantages in materials and energy saving. The fabrication routes can be either a simply compacting or a, recently developed, metal injection moulding [2]. Stainless steels are extensively used as parts or devices in automobile and chemical industries as well as parts or devices for medical applications because of their ability of corrosion resistance. A variety of hard particles had been added into the stainless steel matrix in order to improve the mechanical properties, such as hardness or wear resistance of this material. Various hard particles, i.e. silicon carbide (SiC), Vanadium carbide (VC), aluminium chromide ($AlCr_2$), chromium titanide (Cr_2Ti) or yttria alumina garnet (YAG) [3-6] were added into the stainless steel matrix in order to improve the hardness and wear resistance of this material. The effects of types and contents of reinforcing materials and the sintering conditions were studied in the past decade. The present work aims to fabricate stainless steel composites reinforced with

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tungsten carbide particles by powder metallurgy route. The effect of processing parameters on the microstructure and properties of the composites will be investigated.

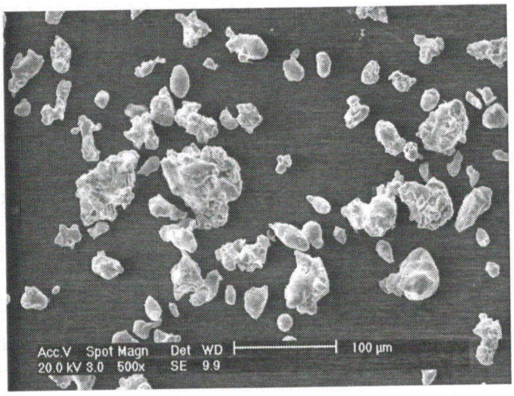
METHODS AND MATERIALS

The 316L Stainless steel (SS) powder and tungsten carbide (WC) powder were subjected to characterizations. Particle size distribution and powder morphology were observed by particle size analyzer and scanning electron microscopy, respectively. Stainless steel powders were mixed with various amounts of tungsten carbide (WC) powders (at 5%, 10% or 15% by weight), Afterwards, the powder mixtures were uniaxially compacted at 300 MPa. Specimens were sintered in hydrogen atmosphere, at 1200 °C, 1250 °C or 1300 °C with a holding time of either 30 or 60 minutes. Specimens of stainless steel powder without any WC addition were also fabricated with the same process. Sintered density of the composites were measured using Archimedes technique. Hardness testing was performed using Rockwell hardness equipment with the indenter of scale A, made of tungsten carbide in a shape of cone. A microstructural study was carried out using both optical microscope and scanning electron microscope. In metallographic sample preparation, all specimens were subjected to cutting, grinding and polishing. The precision cutting machine was used with a feed rate at 0.15 m/s and wheel speed at 3600 rpm. Grinding and polishing were carried out using SiC paper of 2500 and 4000 grit and diamond suspension of 3 and 1 micron, respectively. Both grinding and polishing were performed manually. The etchants used in this study were glycerol, hydrochloric acid and nitric acid in the ratio of 3: 3: 1. The etching was carried out at 7 minutes.

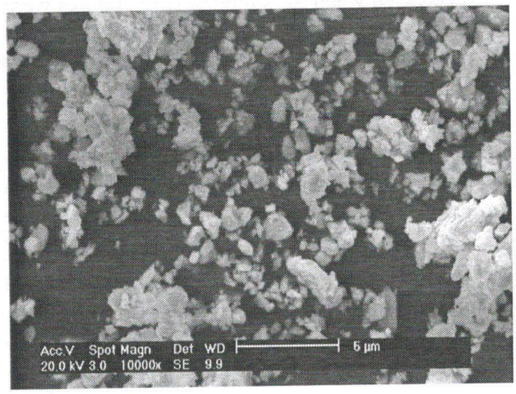
RESULTS AND DISCUSSION

Starting Materials

The particle size data, obtained from a laser particle size analyzer, showed that the stainless steel and tungsten carbide powders had a median size (D_{50}) of ~ 53 μm and ~ 3 μm, respectively. *Figs. 1(a)* and *(b)* correspondingly present scanning electron micrograph of SS and WC powders. The SS powders had irregular shape due to its fabrication route by water atomization technique. WC powders were agglomerated because they were very fine. It was thought that the finer particle size of WC could fill in the void between the stainless steel particles and resulting in an improvement of the powder packing behaviour.



(a)



(b)

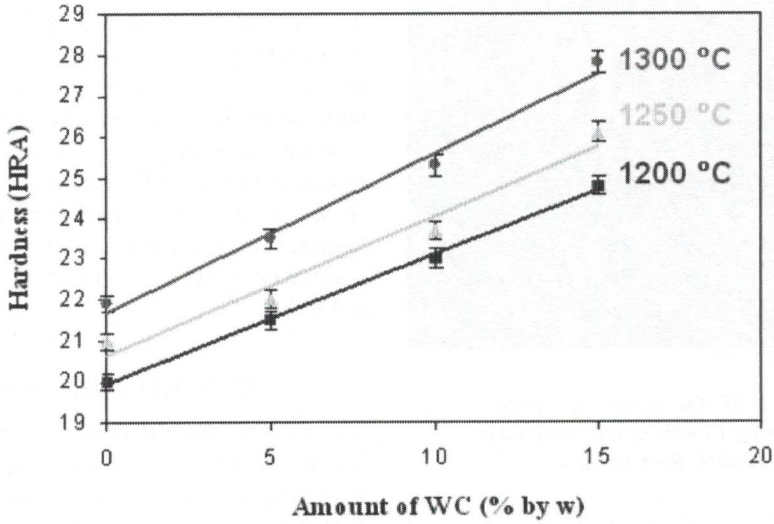
Fig. 1: SEM images of (a) SS powder (b) WC powder

Hardness

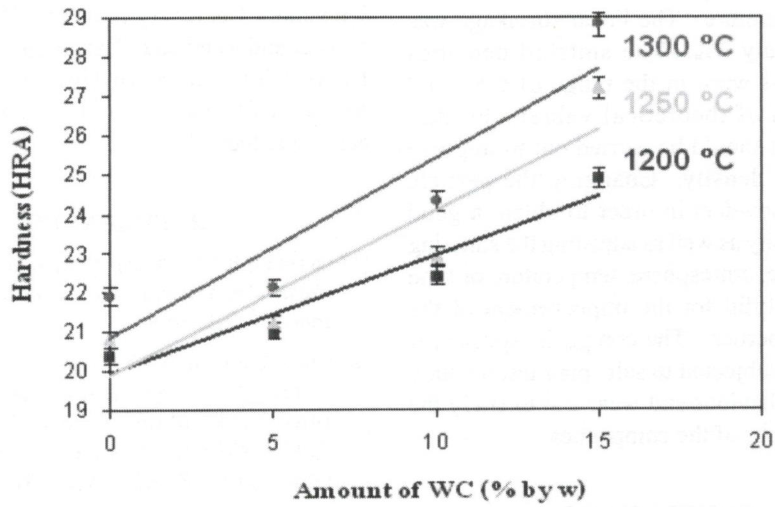
Increasing the WC content generally increased the hardness value of the specimens at all sintering temperatures and all times. *Figs. 3(a)* and *(b)* present the effect of WC content on hardness of specimens sintered at 1200 °C, 1250 °C and 1300 °C for 30 and 60 minutes, respectively. The higher sintering temperatures also led to higher hardness for all holding times. However, there is no statistically significant difference [7] on the hardness values of composite specimens sintered with various holding times.

Microstructure

From images of the composites surfaces after cutting, grinding and polishing, examined using an optical microscope, it was observed that the specimens had high porosity. Pores were generally distributed throughout the specimens. SEM micrograph of specimens prepared in this



(a)



(b)

Fig. 2: Hardness of specimens with various WC contents and sintering temperatures with holding times of (a) 30 minutes and (b) 60 minutes

study is also presented in *Fig. 3*. The grain boundary of stainless steel had clearly been seen after polishing and etching for 7 minute. It was found that too short etching time would not reveal the grain boundary properly. The brighter areas in the SEM micrograph represented the tungsten carbide powders, which were accumulated owing to their small particle size.

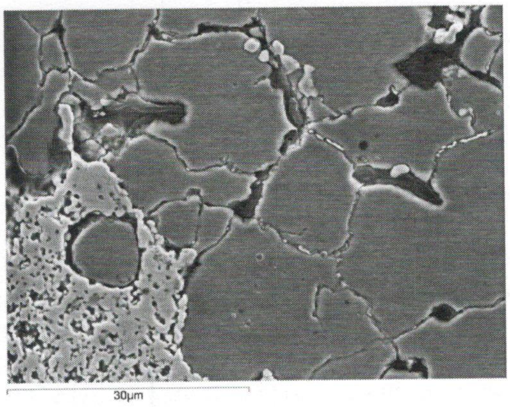


Fig. 3: SEM image of a specimen containing 15 wt% of WC, sintered at 1200 °C for 60 minutes

From the present work, it was observed that porosity decreased and sintering shrinkage increased when specimens were sintered at higher temperature. The linear shrinkage was approximately 3%. The sintered densities of specimens were in the range of 6.5 – 6.7 g/cm^3 (85% of theoretical value). Further investigation should be carried out to improve the sintered density. Changing the particle size of the powders in order to obtain a good packing density as well as adjusting the sintering conditions i.e. atmosphere, temperature or time might be helpful for the improvement of the sintered properties. The composite specimens will also be subjected to salt spray test to study corrosion behaviour and wear test to study the wear behaviour of the composites.

CONCLUSIONS

Powder metallurgy technique can be employed for a fabrication of stainless steel-tungsten carbide metal matrix composites. However, in this study, the composite specimens contained high porosity. The microstructure investigation of the composites was successfully carried out. The surfaces of specimens were exposed after various sample preparation procedures. When using the etchants of glycerol, hydrochloric acid and nitric acid in the ratio of 3: 3: 1, etching for 7 minutes showed more effective reveal of the microstructure of the specimens. Hardness was increased with increasing WC contents at all sintering temperatures and holding times conducted in the current study. Higher sintering temperature led to an increase in hardness and a reduction of porosity. However, the effect of holding time on the hardness value did not show any statistically significant difference. The highest value of hardness was achieved from the specimens, containing 15 wt% of WC, sintered at 1300 °C.

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