

STRENGTHING OF COMPOSITE TOOL STEELS BY SELF-SYNTHESIZED TiC

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Introduction

Metal matrix composites (MMCs) provide good combinations of metal properties and ceramic characteristics[1]. Among MMCs, TiC reinforced ferrous composites are characterized for being chemically stable. TiC greatly improve hardness and wear-resistant properties of tool steels and MMCs[2].

In present study, Composite tool steels containing TiC are produced by a novel process which combines in-situ and powder metallurgy techniques. The TiC strengthening particles are synthesized via mechanical alloying (MA) [3]. These TiC and tool steel powders are then sintered by combining two powder metallurgy routes[4], vacuum sintering and hot isostatic pressing (HIP). Up to 44 vol.% of TiC is added to study the effects of MA parameters and TiC volume fractions on properties of MMCs.

Experimental

Elemental Ti (10 μ m, purity 99.9%) and nano-carbon powders (30 nm, purity 99.8%) were used as raw materials and mixed to give composition of Ti₅₀C₅₀. Commercial tool steel powders (40 μ m) with compositions of 1.7C-8Si-0.3Mn-18Cr-1Mo (in wt%) were used as matrix. The milling process for TiC was carried out at room temperature using high-energy planetary ball mill. The ball-to-powder weight ratio was 10:1. The materials were milled at 100~400rpm for 0~16hrs. X-ray diffraction (XRD) with CuK α radiation was used to identify the phases of powders after ball milling. Raman spectroscopy was applied to further confirm TiC formation.

Tool steel powders were milled for 2hrs at 450 rpm. Composite powders containing 0 to 44 vol.% TiC were then prepared using TiC powders milled at 400rpm for 8hrs. Densification processes included vacuum sintering (1543 $^{\circ}$ K, 1hr) and HIPping (1523 $^{\circ}$ K, 120MPa, 4hrs) after vacuum sintering. Heat treatments were performed by austenitizing the specimens at 1373 $^{\circ}$ K for 1 hr, quenching in water, tempering twice at 480 $^{\circ}$ C for 3 hrs, and furnace cooled. Microstructure of composites was observed by optical microscope and SEM. The bulk density of the composites was determined by Archimedes' principle. The hardness test was performed according to ASTM E18-08b.

Results and Discussion

TiC Synthesizing Processes

For all Ti and C powders milled at 100-300rpm for 16 hrs, only Ti and C peaks are observed. As rotation speed increases to 400 rpm, Ti and C peaks disappear and TiC peaks emerge.

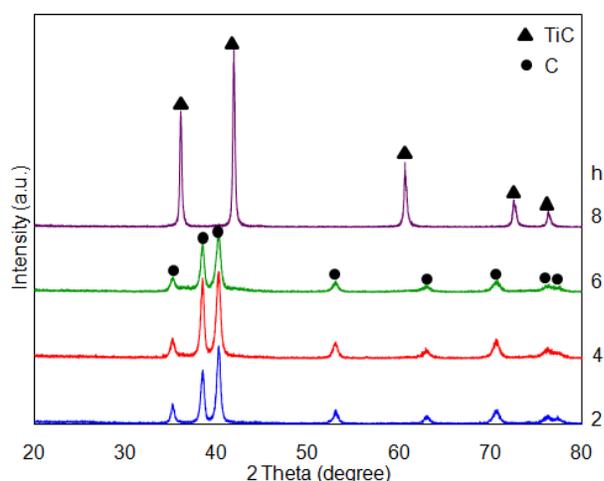


Fig.1 XRD spectra of Ti and C powder mixtures milled for varied milling time at 400rpm.

By fixing the rotation speed at 400rpm, the effects of milling time are further studied. Fig.1 shows the XRD spectra of 400rpm ball milled Ti₅₀C₅₀ powders with varied MA durations. Within the first six hours, only Ti peaks are observed. When milling time further increases to 8 hrs, Ti peaks disappear and only TiC peaks exist. TiC formation reaction occurs very rapidly by high energy milling. It undergoes a mechanically induced self-propagating reaction (MSR)[5]. The Raman spectra of ball milled Ti-C mixtures also confirm that TiC is formed successfully[6]. SEM shows that the TiC powders made by milling >8hrs at 400rpm have size of ~1 μ m with spherical shape clustered by nanosize particles.

Composite Densification

Microstructures of the vacuum sintered + HIPped composites containing 15-44vol.% TiC are shown in Fig.2. It is found that the fine TiC particles distribute uniformly within the tool steel matrix.

The relative density (97.9 to 95.3%) decreases with increasing TiC content in vacuum sintered composites. After HIPping, the relative density increases with TiC content (98.7 to 99.9%). The apparent porosity of vacuum sintered composites is lower than 1.8%, and that of

HIPped specimen is below 0.5%. It shows that TiC reinforcements hinder densification and increase the internal voids, while HIPping process reduces internal voids and improves densification effectively by closing up TiC-steel interfaces.

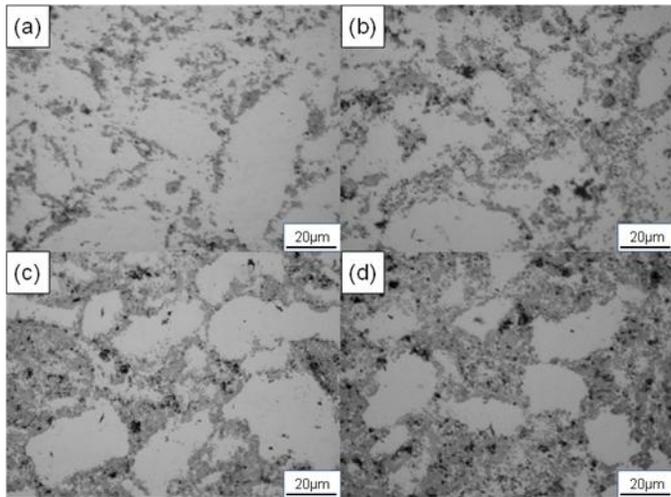


Fig.2 Microstructures of vacuum sintered plus HIPped composites containing (a)15 (b)26 (c)35 (d)44 vol% TiC (black areas are TiC partly removed during grinding).

Fig.3 shows that the hardness values of composites reinforced with synthesized TiC in current study are no less than those of commercial TiC containing composites sintered by encapsulated HIPping[7]. The hardness increases linearly with TiC content except at 0%TiC. In 0% TiC specimens, carbon concentration in matrix decreases due to chromium carbide formation which causes the hardness to drop to under 40HRc. Specimen with over 71HRc is achieved by adding 44 vol% TiC. The dual process combining vacuum sintering and HIPping gives slightly higher hardness than vacuum sintering. It indicates that HIPping is indeed effective in reducing internal voids as proposed. Hardness obtained by the two processes becomes almost the same when TiC vol% increases to over 40%. The effects of porosity on hardness are apparently less pronounced in composites containing great amount of TiC.

Conclusion

TiC powders are successfully synthesized by mechanical alloying elemental Ti and nano-carbon for over 8hrs at 400 rpm. TiC forms at an instant via a mechanically induced self-propagating reaction. Vacuum sintering and HIPping are applied to consolidate the composite compacts. Up to 99.9% sintering density is achieved without encapsulation. The composites strengthened by synthesized TiC bear mechanical properties comparable to those strengthened by

commercial TiC. HIPping is beneficial in reducing internal voids of vacuum sintered composites and thus increases composite hardness. The benefits of HIPping appear to weaken as TiC content increases over 44 vol%. Composite hardness as high as 71 HRc are achieved.

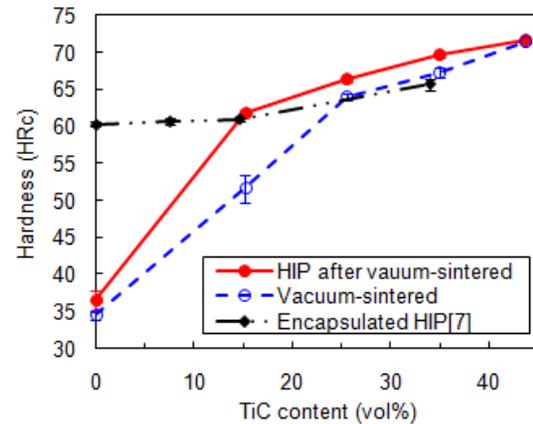


Fig.3 Variation of composite hardness with TiC content sintered by different processes in comparison with encapsulated HIPping using commercial TiC powders[7].

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