Sintered Fe-Mo-Si-C alloys with ductile cast iron microstructure

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Abstract. Sintered Fe-Mo-Si-C alloys, produced by admixing 4.0 wt.% silicon carbide to two different pre-alloyed powders with compositions of Fe-0.85Mo and Fe-1.5Mo, sintering at 1250 °C for 45 minutes and cooling in a vacuum furnace, showed a microstructure similar to that of a ductile cast iron. The microstructure of the sintered alloys was characterized by the bull's eye structure consisting of a black particle surrounded by ferrite shell and harder shell of pearlite/bainite, respectively. With the influence of alloying element content in the pre-alloyed powders, the proportion of the harder shell, particularly the bainite fraction, increased with increasing molybdenum content. Due to the matrix hardenability via bainite formation by the molybdenum influence, tensile strength of the sintered alloys increased but elongation decreased with increasing molybdenum content.

1. Introduction

It was reported previously that non-oxide silicon carbide (SiC) ceramic reacted with iron-based materials at high temperatures [1-3]. The reaction resulted in SiC decomposition and silicon (Si) and carbon (C) atom diffusion into the iron-based metal powder matrix. Small amounts of admixed SiC particles (≤ 1.5 wt.%) could be used as a source of Si and C alloying elements for making sintered Fe-Cr-Mo-Si-C steels from pre-alloyed Fe-3.0Cr-0.5Mo powder [4]. The microstructures of sintered Fe-Cr-Mo-Si-C steels were similar to those of sintered Fe-Cr-Mo-C steels [5] under the same processing conditions (C content and cooling rate). Recently, sintered Fe-Mo-Si-C materials were prepared from pre-alloyed Fe-0.85Mo powder added with fixed 4wt.% silicon carbide powder and varied graphite powder contents [6]. It was found that the general microstructure of the sintered materials was similar to that of a ductile cast iron (DCI). Since molybdenum (Mo) has strong effect on hardenability via phase transformation in modern high-performance steels [7] it is interesting to explore whether its effect still exist in sintered alloys with high Si and C. In this work, the effect of Mo content on microstructure and mechanical properties has been investigated.

2. Experimental procedure

Two pre-alloyed steel powders with different Mo contents were admixed with 4.0 wt.% SiC and processed via the 'press and sinter' process to produce sintered alloys, such as Alloy 1 (Fe-0.85Mo powder + 4.0 wt.% SiC) and Alloy 2 (Fe-1.50Mo powder + 4.0 wt.% SiC). The mixed powders were compacted into tensile test bars (MPIF standard 10, ASTM B783) with green density of 6.50 ± 0.05 g/cm^3. The green tensile test bars were sintered at 1250 ºC for 45 minutes in a vacuum furnace. The sintered specimens were cooled at the rate of 0.1 °C/s. Universal testing machine (Instron model 8801) was employed to measure tensile properties of the specimens. Microstructural observation was performed by using optical microscopy (OM) and scanning electron microscopy (SEM).

3. Results and Discussion

Both sintered alloys exhibited microstructural feature similar to that of a DCI, particularly the ferritic-pearlitic DCI. The bull's eye structure consisting of black particle surrounded with ferrite and pearlite /bainite shells is shown in Fig. 1. Higher area fraction of bainitic ferrite was observed in Alloy 2. This would suggest that Mo promotes bainitic transformation in the sintered Alloy 2 (with 1.5 wt.% Mo). In [7], the Mo addition of 0.17 wt.% cannot noticeably alter the transformation behavior; conversely, when the Mo addition is up to 0.38 wt.%, the transformation behavior can be significantly altered. The polygonal ferrite (PF) and granular ferrite (GF) transformation fields are reduced with the increase of Mo content; whereas, the BF and martensite transformation fields are expanded.

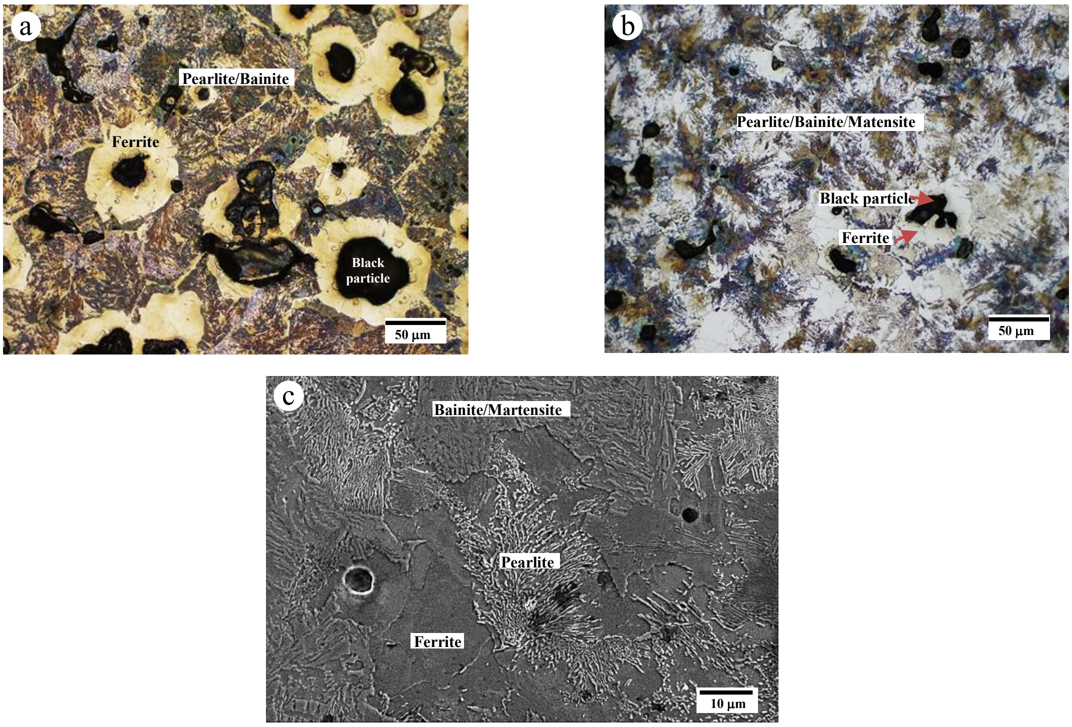

Fig. 1 Microstructures of sintered alloys. (a) Alloy 1 (b-c) Alloy 2.

The black particle was not totally composed of graphite but it showed solid Si-based (Si-C-Fe-Mo) core enveloped with graphite (Fig. 2). A crack was frequently observed along the boundary between the Si-based core and graphite shell. Such crack is similar to that forms as a failure nucleation during tension test of a ferritic or ferritic-pearlitic DCIs [8, 9]. The nucleation and propagation of a crack in the graphite shell coming from the reduced carbon solubility in γ phase is defined as "onion-like" mechanism.

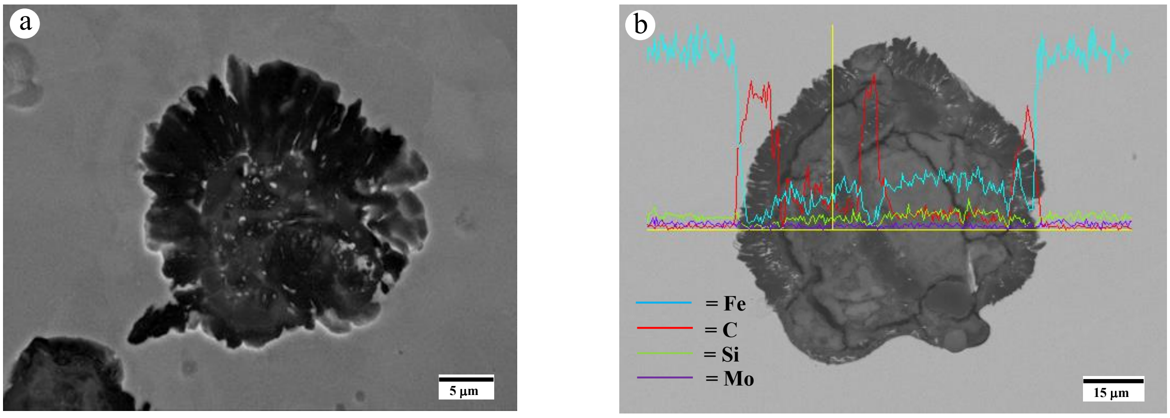

Fig. 2 SEM micrographs of black particle. (a) Si-based core enveloped with graphite (b) Cracks along Si-based core and graphite.

Tensile properties varied with alloy composition and microstructure. Yield strength increased but elongation decreased with increasing Mo content (Fig. 3). Variation of tensile properties is attributed to fractions of microstructural components (Fig. 4). The decrease of black particle area fraction in Alloy 2 indicates the decrease of the crack as the failure nucleation. Moreover, the increase of harder structures like pearlite and bainite in Alloy 2 also contributes the strength to the sintered alloy. The pearlitic fraction influence on tensile properties of ferritic-pearlitic DCIs shows that the strength increases with increasing pearlitic structure percentage [9]. Similarly, the study on tensile properties indicated that yield and tensile strengths were increased with increasing pearlite content [10].

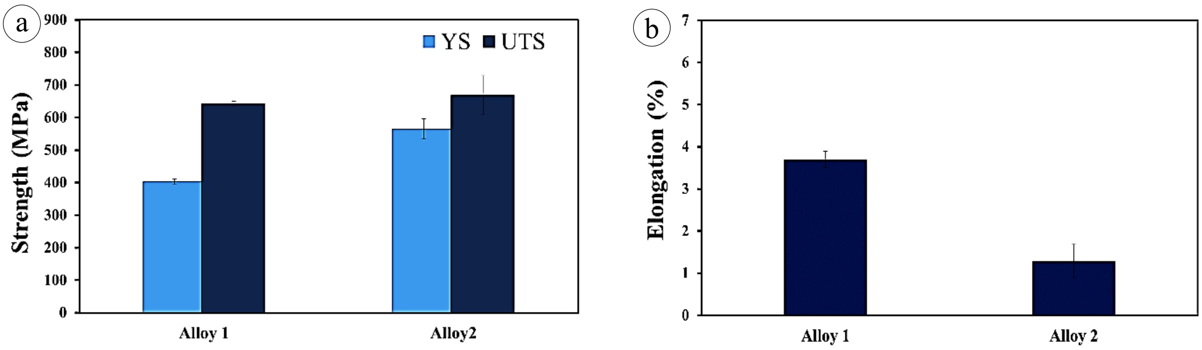

Fig. 3 Tensile properties of the sintered alloys (a) Strength and (b) Elongation.

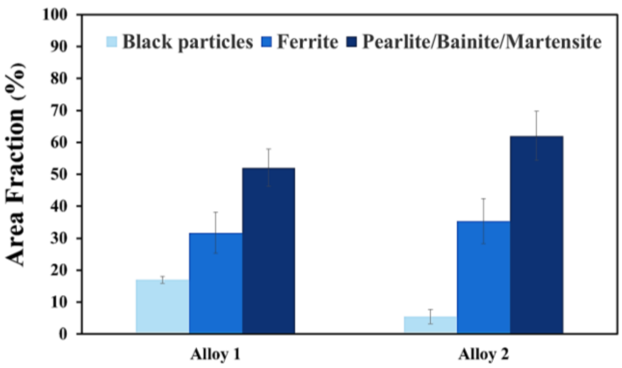

Fig. 4 Fractions of microstructural components of sintered alloys.

4. Conclusions

The sintered alloys, produced by sintering the powder compacts made of pre-alloyed Fe-Mo and SiC powders, have microstructural feature similar to that of a ferritic-pearlitic DCI. Increase of Mo content results in lower fraction of black particle but higher fraction of matrix (ferrite, pearlite and bainite). The presence of bainite in Alloy 2 indicates that Mo promote bainitic transformation. The microstructural components provide contribution to the alloy tensile properties.

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