Pearlitic ductile iron-like sintered Fe-Cr-Mo-Si-C alloys

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Abstract. Sintered Fe-Cr-Mo-Si-C alloys, produced from two different pre-alloyed powders with compositions of Fe-3.0Cr-0.5Mo and Fe-1.5Cr-0.2Mo, showed a microstructure similar to that of a fully pearlitic ductile cast iron (DCI EN GJS700-2). The two sintered alloys exhibited close values of area fractions of a black particle (7 % of area fraction for the sintered Fe-1.5Cr-0.2Mo-inherited alloy or sintered CrL alloy and 6 % for the sintered Fe-3.0Cr-0.5Mo-inherited alloy or sintered CrM alloy) and a pearlitic matrix (93 % for the sintered CrL alloy and 94 % for the sintered CrM alloy). The absence of a ferrite shell surrounding a black particle in these alloys was influenced by the alloying chromium. Despite similar microstructural feature, the two sintered alloys showed different tensile properties. With higher alloying element content, the sintered CrM alloy showed inferior tensile strength and elongation. The reason for lower tensile strength of the sintered CrM alloy could not be given by microstructural feature differentiation. Further investigation has been being carried out.

1. Introduction

Silicon carbide (SiC) is a non-oxide ceramic that exhibits a range of properties that make it suitable for a myriad of advanced technology applications [1]. It shows excellent thermal stability and thermal shock resistance, superb mechanical properties in terms of hardness and wear resistance, as well as high chemical stability. Although it has such excellent properties, its stability degrades at temperatures of ~1100 °C when it is in contact with iron (Fe) or Fe-base materials [2]. In the reactions between Fe or Fe-base powders with SiC powder, the evidences of SiC decomposition and diffusions of Si and C atoms into Fe matrix are already proved [3-5]. Due to such reaction, the SiC particles (≤ 1.5 wt.%) was employed 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 [6]. Addition of higher SiC powder content (4.0 wt.%) to pre-alloyed Fe-0.85Mo powder and processing the powder mixture via ‘press and sinter’ technique [7], the sintered materials showed microstructure similar to that of a ductile cast iron (DCI).

It is thus interesting to explore the interaction between SiC and iron powders with different compositions. In this work, two sintered alloys produced, via the ‘press and sinter’ process, from powder mixtures made of fixed 4 wt.% SiC with pre-alloyed Fe-1.5Cr-0.2Mo powder (designated as sintered CrL alloy) and Fe-3.0Cr-0.5Mo powder (designated as sintered CrM alloy) were investigated.
2. Experimental procedure
Two pre-alloyed steel powders with different compositions, e.g., Fe-1.5Cr-0.2Mo and Fe-3.0Cr-0.5Mo were admixed with 4.0 wt.% SiC and processed via the ‘press and sinter’ process to produce sintered alloys, such as CrL (Fe-1.5Cr-0.2Mo powder + 4.0 wt.% SiC) and CrM (Fe-3.0Cr-0.5Mo 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/cm³. The green tensile test bars were sintered at 1250 °C 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 scanning electron microscopy (SEM).

3. Results and Discussion

3.1. Microstructure
Microstructures of sintered CrL and CrM alloys exhibited a feature similar to that of a fully pearlitic DCI or DCI EN GJS700-2, i.e., a black particle enveloped by the matrix with fully pearlitic structure or full pearlite (P) as given in figure 1a and b. The black particle showed core-shell structure consisting of a solid core (the SEM images showed no core due to detachment during specimen preparation) enveloped with a graphite shell. The sintered CrM alloy showed some P colonies with short rods (figure 1c). The area fractions of black particle and pearlitic matrix in both sintered alloys figure 2) showed close values.

Microstructures of the sintered CrL and CrM alloys are different from those of sintered Fe-Mo-Si-C alloys [6]. It is worth noting here that the sintered CrL and CrM alloys are produced from powder mixtures of different pre-alloyed powders with fixed 4.0 wt.% SiC powder, but they both show full P in their matrices. The effects of alloying element content difference (under this investigation) on the formation of full P can be neglected. The possible causes of full P formation are given below.

Full P (lamellar structure of ferrite (α) and cementite (θ)) can be obtained with a eutectoid composition (around 0.65-0.76 wt.% C [8]). In both sintered alloys, the nominal C content is 1.2wt.%.

The presence of black particles indicates that not all C atoms contribute to the matrix microstructure development. However, the larger area fraction of the matrix (figure 2) suggests that majority of C atoms exist in the matrix.

The matrix C content is possibly equal to or higher than the common Fe-C eutectoid composition. Moreover, in case the matrix C content is lower than 0.65 wt.%, the eutectoid compositions still possibly exists in the sintered CrL and CrM alloys. According to theoretical calculation, the eutectoid point for Fe-3.0Cr-0.5Mo-C alloy is characterized by the temperature of 786 °C and C content of 0.35 wt.% C [9]. This calculated eutectoid C content is close to that of Fe-3.0Cr-C alloy [10]. For the Fe-1.0Cr-C alloy, the eutectoid C content is also lower than 0.6 wt%. Thus, the influence of alloying Cr on lowering the eutectoid C content can be the cause of full P formation. Consideration on the influence of cooling rate after sintering is also discussed here. A full P can also be obtained from austenite (γ) → P transformation at the temperature lower than the equilibrium eutectoid even in low carbon or hyper-eutectoid steel, which is known as the Hultgren extrapolation region, identified by extending the (γ + γ/θ) or (α+ γ/θ) phase boundaries to temperatures below the eutectoid [11-12]. In such cases, the cooling rates employed must be fast enough to eliminate free α and to get full P. However, the cooling rate after sintering CrL and CrM alloys is 0.1 °C/s, which is considered as a slow cooling. Thus the formation of full P inside the Hultgren extrapolation region can be considered as the second choice to the transformation around the eutectoid composition.
3.2. Tensile properties

The ultimate tensile strengths of both sintered alloys showed close values. Yield strength of the sintered CrM alloy was higher than that of the sintered CrL alloy. Ductility of the sintered CrM alloy was quite poor, due to a crack at black particle/matrix interface (figure 1c). According to close values of area fractions of microstructural features given in figure 2, there should have other factors influencing the tensile properties. One of possible causes of higher yield strength in the sintered CrM alloy is higher alloying element concentration. In order to examine the effect of microstructural features on mechanical properties, further experiments should be conducted on sintered alloys with different ratios of black particle to pearlitic matrix.
4. Conclusions
The sintered alloys, produced by sintering the powder compacts made of pre-alloyed Fe-Cr-Mo and SiC powders, have microstructural feature similar to that of a fully pearlitic DCI or DCI EN GJS700-2. Increase of Cr and Mo content results formation of the pearlite with short rods, which presumably contribute to higher yield strength. However, the relationship between microstructural features and the tensile properties will be further investigated.

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