Deformation behavior of high speed steel/low Carbon steel composite with harmonic structure by MM/SPS process

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Abstract. The harmonic-structured composite that consists of a network fine grain region with a high speed steel and a dispersed coarse grain region with a low carbon steel was fabricated prepared using a mechanical milling, which is one of the severe plastic deformation method, and spark plasma sintering process. The microstructure and mechanical properties harmonic-structured composite compact were evaluated by a scaning electron microscope and a tensile test, respectively. The harmonic-structured composite exhibited high strength and enough ductility compared with a conventional particle-dispersed composite with the same weight ratio of high speed steel/low carbon steel. The microstructure observation of harmonic-structured composite revieals that the superior elongation of the harmonic-structured composite is attributed to the plastic deformation around the cracks which initiate at the network area.

1. Introduction

Grain refinement is well known to improve the mechanical properties of metallic materials. The nano grain structure materials show very high strength but a limited ductility because of the early plastic instability [1]. The harmonic-structured materials with fine and coarse grains exhibit high strength and enough ductility, simultaneously [2]. The harmonic microstructure consists of fine-grained network structure and dispersed coarse grain parts. The fine grain network region, in which the grain size is less than 1 μm, has role of strength and the dispersed coarse grain parts has role of ductility [2]. In previous study, the harmonic-structured composite with the dispersed area having coarse grained low carbon steel (LCS) and the network area having fine grained high speed steel (HSS) exhibited high strength and enough ductility [3]. However, the mechanism of enough ductility is not clear yet. Then, the deformation behavior of a harmonic-structured composite with HSS network structure and dispersed LCS region is investigated in detail.

2. Experimental Procedure

The harmonic-structured composite with HSS and LCS is fabricated by mechanical milling (MM), which is one of the severe plastic deformation method, and spark plasma sintering (SPS) process. The HSS powder with an average particle size of 35 μm and LCS powder with an average particle size of 142 μm were used as initial powders. The HSS powder (C: 1.298, Si: 0.29, Mn: 0.37, P: 0.016, S: 0.011, Cr: 4.28, Mo: 4.87, V: 2.84, W: 5.89, Fe: bal. (mass%)) and LCS powder (C: 0.27, Si: 0.19, Mn: 0.48, P: 0.014, S: 0.015, Cu: 0.02, Ni: 0.02, Cr: 0.12, Fe: bal. (mass%)) were mechanically milled by a planetary ball mill equipment with an SKD11 vial and SUJ2 balls in Ar atmosphere at room temperature. First, HSS powder was milled for 90 ks at 300 rpm with ball-to-powder weight ratio of 43:1. Obtained fine MM powder of HSS and initial LCS powder were milled for 90 ks at 100 rpm with ball-to-powder weight ratio of 7.2:1. Subsequently, this composite MM powder was sintered at 1173 K to 1073 K at 50MPa in a vacuum (10Pa) by SPS equipment. The microstructure of SPS compacts was used by a scanning electron microscope (SEM). The mechanical properties of SPS compacts were examined by tensile test. The tensile test was carried out by initial strain rate of 5.5×10^{-4} s^{-1}

IOP Conf. Series: Materials Science and Engineering **63** (2014) 012029 doi:10.1088/1757-899X/63/1/012029

and were performed on specimens with 3 mm in gauge length, 1 mm in width, and 1 mm in thickness.

3. Result and Discussion

3.1 Microstructure of the Harmonic-Structured Composite with HSS and LCS

Figure 1 shows an SEM micrograph of the harmonic-structured composite with HSS and LCS. Areas with a bright and dark contrast are observed in Fig. 1. The bright contrast area with the HSS is the network structure and the dark contrast area with the LCS is dispersed among the network. This microstructure with the network structure and the dispersed area is referred to as a “harmonic structure”. Figs. 2 (a) and (b) show enlargements of the network area and the dispersed area shown in Fig. 1, respectively. In the network area with HSS, the grain size is less than 1 μm as shown in Fig. 2 (a). On the other hand, a ferrite and pearlite structure with the grain size of approximately 25 μm is observed in Fig. 2 (b).

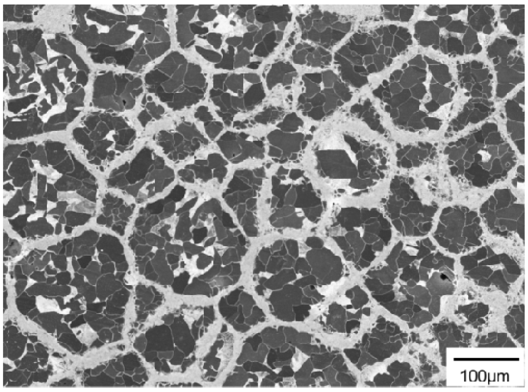

Fig.1 SEM image of the harmonic-structured composite material

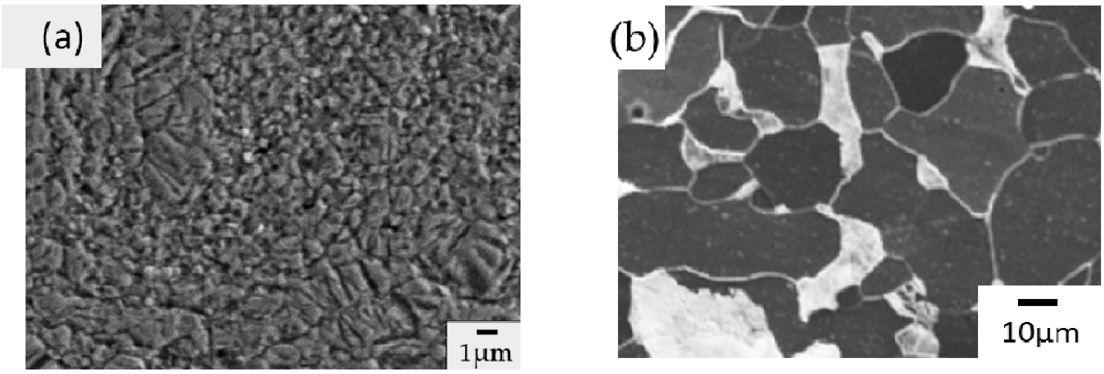

Fig.2 SEM images of (a) the network area and (b) the dispersed area of the harmonic-structured composite as shown in Fig.1.

3.2 Mechanical Properties of the Harmonic-Structured Composite with HSS and LCS

Figure 3 shows results of an ultimate tensile strength (UTS) and a uniform elongation (UE) of the harmonic-structured composite material and the conventional HSS dispersed composite with HSS volume fraction ranging from 11.5 to 18.5 %. Both the UTS and the UE of the harmonic-structured composite are mostly higher than the conventional HSS dispersed composite, because the harmonic-material has the fine grained network structure connected in the entire microstructure and the dispersed coarse grain area between its network. In the harmonic-structured composite, the UTS increases and UE decreases with increasing the HSS volume fraction.

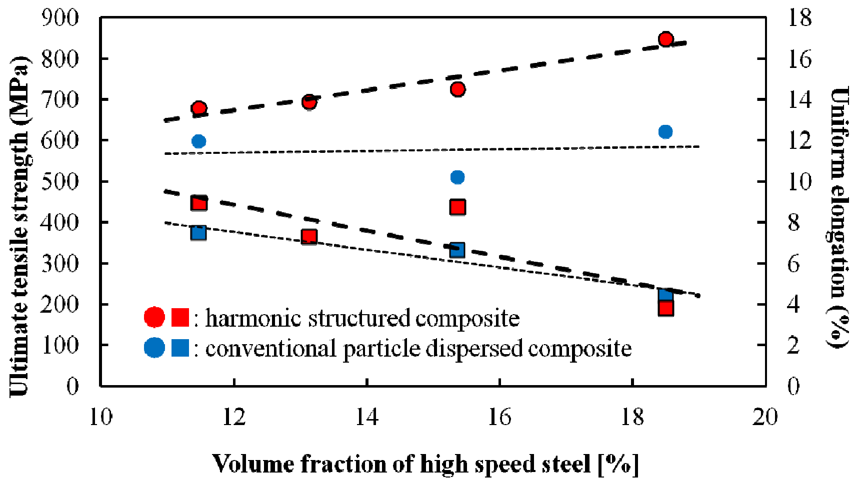

Fig.3 Relationship between the tensile test results and the HSS volume fraction of the harmonic-structured composite and the conventional HSS dispersed composite.

3.3 Deformation Behavior of Harmonic-Structured Composite with HSS and LCS

Figure 4 shows true stress–true strain curves and strain-hardening rate curves of the harmonic-structured composite and the conventional HSS dispersed composite with the HSS volume fraction of 15.4%. The strain-hardening rate of the harmonic-structured composite is larger than that of the conventional HSS dispersed composite. This tendency for the strain-hardening rate often observes in other harmonic-structured materials [4].

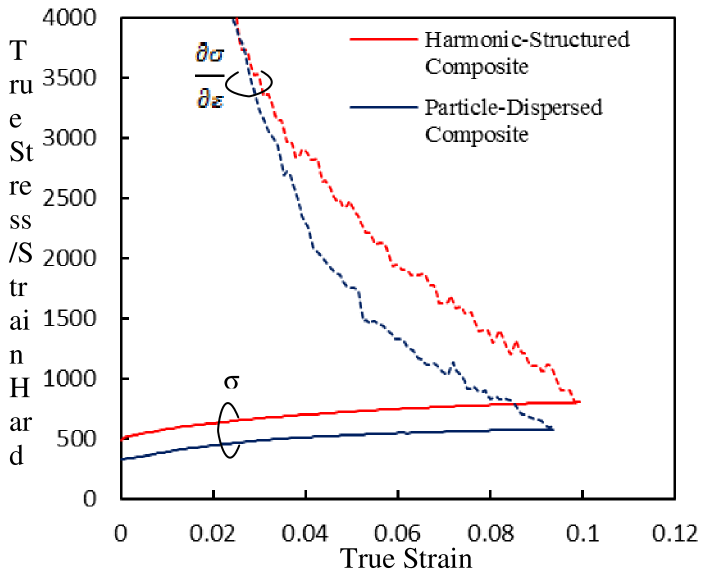

Fig.4 The true stress–true strain curves and the strain-hardening rate curves of the harmonic-structured composite and the conventional HSS dispersed composite.

Figure 5 shows an SEM micrograph of the harmonic-structured composite with engineering strain of 6.7 %. Tensile direction corresponds to the horizontal direction. The substantial change of the microstructure is not observed except a crack in the network area. A crack initiates at the fine-grained network area with hard materials in an early deformation stage.

Fig.6 shows an SEM micrograph in the vicinity of the fracture surface of the harmonic-structured composite with engineering strain of 8.8 %. Tensile direction corresponds to the horizontal direction. Some cracks are observed in the fine-grained network area and heavy plastic deformation around these cracks is also observed in Fig. 6. The dispersed area with soft materials acts as an obstacle for the propagation of the crack. Figs. 5 and 6 reveal that the superior elongation of the harmonic-structured composite is attributed to the plastic deformation around the cracks which initiate at network area.

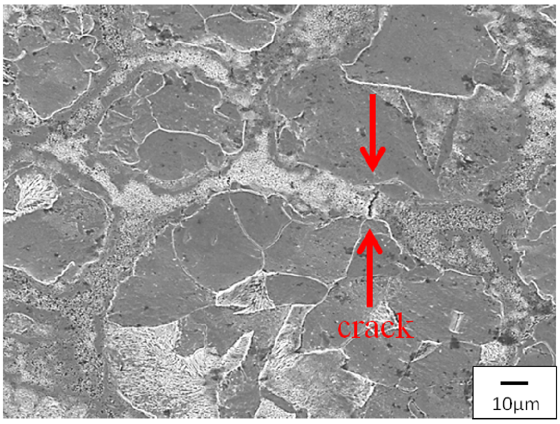

Fig.5 SEM micrograph of the harmonic-structured composite with engineering strain of 6.7 %.

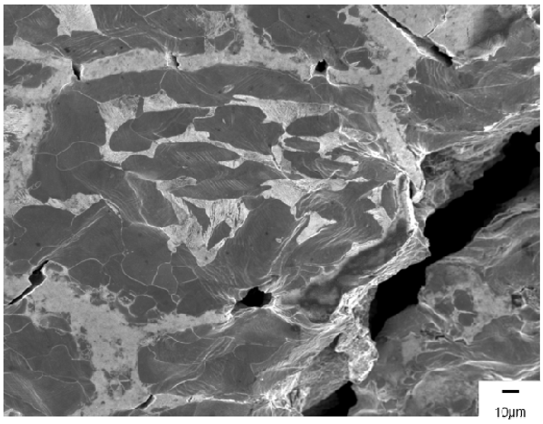

Fig.6 SEM micrograph in the vicinity of the fracture surface of the tensile specimen after the tensile test.

4. Conclusion

The high speed steel/low carbon steel harmonic-structured composite was fabricated by mechanical milling, which is one of the severe plastic deformation method, and spark plasma sintering process. The harmonic-structured composite exhibited superior mechanical properties compared to the conventional particle-dispersed composite. The strain-hardening rate of the harmonic-structured composite is larger than that of the conventional particle-dispersed composite. The superior elongation of the harmonic-structured composite is attributed to the plastic deformation around the cracks which initiate at the fine grained network area.

Acknowledgement

This work was financially supported by JSPS Grant-in-Aid for Scientific Research(c) (contact No. 23560847) and MEXT Supported Program for the Strategic Research Foundation at Private Universities (project No. S1311036), and these supports are gratefully appreciated.

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