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Comparison of microparticles and nanoparticles effects on the microstructure and mechanical properties of steel-based composite and nanocomposite fabricated via accumulative roll bonding process

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ABSTRACT

In the present work, a comparison of microparticles and nanoparticles effects on the microstructure and mechanical properties of steel-based composite and nanocomposite fabricated via accumulative roll bonding (ARB) process was studied. The microstructure of the fabricated composite and nanocomposite after fourth cycle of the ARB process exhibited an excellent distribution of SiC micro/nano particles in the IF steel matrix without any porosity. Unlike the nanocomposite, the particle breaking (cracking) was one of the most important phenomena that occurred during ARB process of composite. The findings revealed that with increasing the number of ARB cycles, the tensile strength of the ARB-processed composite and especially nanocomposite improved, but their elongation decreased at first step and then increased at second step. In addition, the ARB-processed composite and especially nanocomposite exhibited a higher hardness than the annealed IF steel so that the hardness values of the composite and nanocomposite were 4.18 and 4.44 times higher than that of the annealed IF steel, respectively.

1. Introduction

The attractive mechanical properties that can be obtained with metal matrix composites and nanocomposites such as high strength and thermal stability have been reported previously [1]. The composites and nanocomposites have higher strength in shear and compression and higher temperature capability because they are a combination of metallic properties and ceramic properties [2]. Interest in composites and nanocomposites for aerospace, automobiles and other structural applications has grown over the last few years, as a result of availability of relatively inexpensive reinforcement as well as the development of new processing routes [3].

Interstitial free (IF) is a recently developed steel product with a very low free carbon and nitrogen level [4,5]. This steel is used widely in the automotive industry because of its excellent formability and high planar isotropy [6,7]. However, the IF steel in the coarse-grained (CG) condition possesses high ductility but low strength. Low strength in automotive body panel materials gives rise to the need for thicker sheets in order to maintain desired crash safety and panel rigidity, which cause heavier vehicles, and consequently higher fuel consumption [5,6]. In addition, low strength of IF steel limits its broader applications in conditions where high strength is needed in addition to high formability. Enhancing the strength with adequate ductility may increase the potential applications of IF steel sheets in new applications like those in aviation or defense industries [4,7]. Considering the single-phase ferritic microstructure of IF steel, strengthening methods to enhance its mechanical properties are limited [5,7]. Recently, the present authors have developed accumulative roll bonding (ARB) [8,9], continual annealing and roll bonding (CAR) [10,11], and cold roll bonding (CRB) [12,13] processes for fabrication of high strength metal matrix composite. Therefore, fabrication of metal matrix composites and nanocomposites via ARB process seems to be the suitable methods.

Recently, the ARB process has been used for fabrication of Al/Al_2O_3, Al/SiC, and Cu/Al_2O_3 composites with microparticles [8,9,14]. Up to now, any steel-based composites and nanocomposites have been produced by ARB process and no reports are available in the field of comparison between nanoparticles and microparticles on the microstructure and mechanical properties. The present study, to the best of our knowledge, is the first of its kind that focuses on the IF steel/SiC composite and nanocomposite fabricated by the ARB process. The aim of the present work is to fabricate IF steel/2 vol.% SiC composite and nanocomposite via ARB process and investigate

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the effect of the silicon carbide size on the microstructure and mechanical properties of produced materials.

2. Experimental procedure

The materials used in this study were fully annealed strips of interstitial free steel (specifications are given in Table 1) and SiC microparticles (50 μm) and nanoparticles (50 nm) (Fig. 1). Four strips of 150 mm × 50 mm × 0.7 mm were degreased via acetone and scratch brushed with a stainless steel wire brush 0.25 mm in diameter. For fabrication of steel-based composite (containing microparticles) and nanocomposite (containing nanoparticles), after the surface preparation, SiC micro/nano particles were uniformly dispersed between the four strips. To achieve a uniform dispersion of SiC particles between IF steel strips, an acetone-based suspension was prepared. After surface preparation, the SiC particles in acetone were sprayed between the four strips with an atomizer. Then, SiC particles were deposited and the acetone evaporated in air, so that the brushed surfaces of strips were uniformly covered with SiC particles. The strips were then stacked over each other and fastened at both ends by steel wires. Attention was also paid to proper alignment of the four strip surfaces prior to rolling. The roll bonding process was carried out with no lubrication and with an amount of thickness reduction equal to 75% corresponding to a von Mises equivalent strain e_{vM} of 1.6 per cycle (first step). Then, the roll bonded strips were cut into four pieces. Then, to achieve a uniform distribution of SiC particles in the IF steel matrix, the above procedure was repeated again up to fourth cycle without adding reinforcement particles (second step). The schematic illustrations of the ARB process for fabrication of steel-based composite and nanocomposite samples is shown in Fig. 2.

Samples for scanning electron microscopy (SEM) observations were cut from the ARB-processed strips and these were mounted in bakelite. Then, these samples were polished using 80–4000 grit water-proof SiC paper. Finally, the polishing was finished on a cloth using alumina paste of 3 μm. Scanning electron microscopy PHILIPS XL30 was used for microstructural observation to investigate how well the SiC particles were distributed in the produced samples at different ARB cycles.

The tensile test samples were machined from the ARB-processed strips, according to the ASTM: E8 M tensile sample, oriented along the rolling direction. The gauge width and length of the tensile test samples were 6 and 25 mm, respectively. The tensile tests were conducted at room temperature on a Hounsfield H50KS testing machine at an initial strain rate of $1.67 \times 10^{-4}\ s^{-1}$. Total elongation of the samples was measured from the difference between the gauge lengths before and after testing.

Vickers hardness of the samples was measured in rolling direction–transverse direction (RD–TD) plane under a load of 30 kg. Hardness was measured randomly at 10 different points on the strips for each sample, the maximum and minimum results were disregarded, and the mean hardness value was calculated using the remaining eight values.

3. Results and discussion

3.1. Microstructural observations

The SEM images of RD–TD plane of the IF steel/2 vol.% SiC composite and nanocomposite fabricated by ARB process are shown in Figs. 3 and 4. From Fig. 3(a), it is clear that after the first ARB cycle, there are big agglomerated and clustered particles and porosity. The agglomerative nature of particles due to their high cohesive energy leads to an increase in the total surface area and increases their tendency to clump together forming big agglomerates and clusters. Therefore, the extent of agglomeration in the nanocomposite is higher than the composite (see Fig. 5). On the other hand, due to existence of big clusters in the both composite and

Table 1
Chemical composition of IF steel strip (in wt.%).

C	N	Si	Mn	Cu	Ni	Ti	Fe
0.002	0.004	0.01	0.14	0.01	0.018	0.055	Bal.

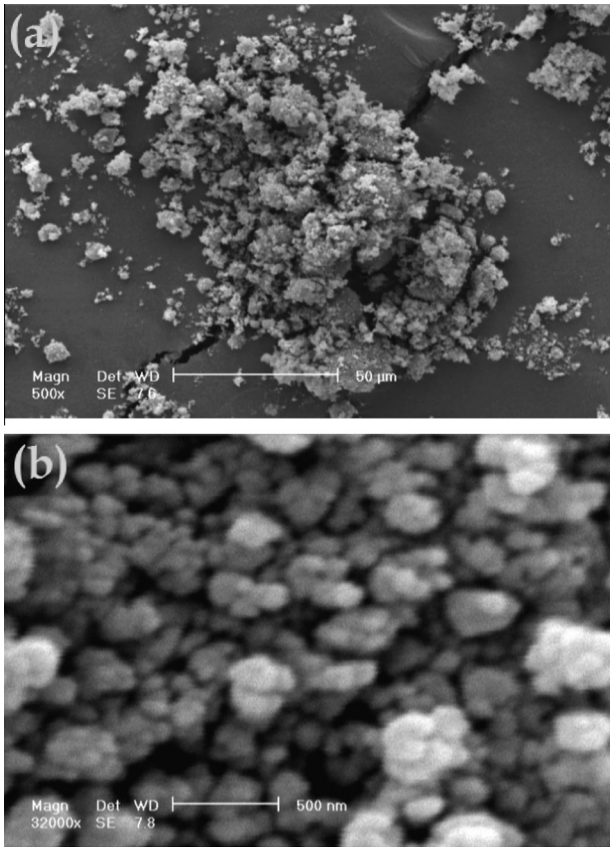

Fig. 1. SEM micrographs of the used SiC nanoparticles at two magnifications.

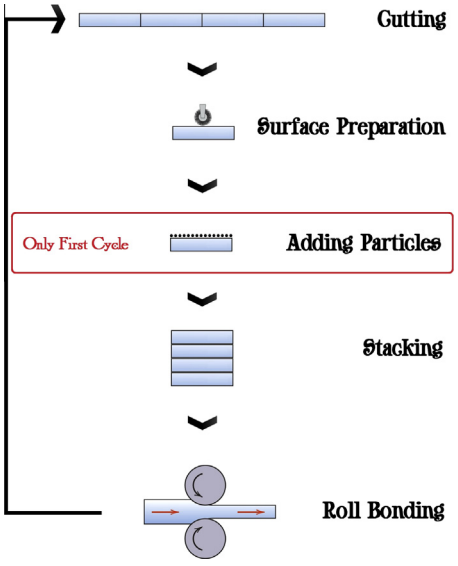

Fig. 2. Schematic illustration of ARB process for fabrication of steel-based composite and nanocomposite.