INVESTIGATION OF TRIBOLOGICAL CHARACTERISTICS OF AL/NANO SiO_2 NANOCOMPOSITES PRODUCED BY ACCUMULATIVE ROLL BONDING (ARB) PROCESS

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Abstract: *Accumulative roll-bonding process (ARB) is an important severe plastic deformation technique for production of the ultrafine grained, nanostructured and nanocomposite materials in the form of plates and sheets. In the present work, this process used for manufacturing Al/SiO_2 nanocomposites by using Aluminum 1050 alloy sheets and nano sized SiO_2 particles, at ambient temperature. After 8 cycles of ARB process, the tribological properties and wear resistance of produced nanocomposites were investigated. The wear tests by abrasion were performed in a pin-on-disc tribometer. Results show that by increasing ARB cycles and the amount of nano powders, the friction coefficient of produced nanocomposites decreases.*

Keywords: *Nanocomposite, Nanoparticles, Severe plastic deformation (SPD) process, Accumulative roll bonding (ARB), Tribological properties.*

1. INTRODUCTION

Numerous research studies are being attended to replace heavy steel body constructions with lighter aluminum ones in order to reach stronger energy consumption and environmental standards to produce high performance materials. One of the most important technical difficulty in achieving this aim is the inferior ductility properties of most aluminum sheet alloys. It has been expressed that control of the grain size, microstructure and the texture of materials is necessary for improvement of their mechanical properties, especially in nanocomposites form [1]. Also reducing the grain size of polycrystalline metallic materials to the nanosize ($d < 100$ nm, nanocrystalline) or submicron levels (100 nm$< d <$1μm, ultra-fine grain) is a useful and relatively economic method of raising mechanical properties such as strength, toughness, wear resistance and corrosion resistance of composite materials [2-4]. In addition, various studies are focused on the nanoparticles and their effects in materials and their properties [5, 6].

It has been shown that these nanocomposite materials can be obtained by severe plastic deformation (SPD) through several noble techniques in different metals and alloys [7-10]. By now, various SPD processes such as accumulative roll bonding (ARB) [11-13], cyclic expansion-extrusion (CEE) [14], high pressure torsion (HPT) [15], and equal channel angular pressing (ECAP) [16] have been proposed for various materials. Among these processes, the ARB process has been applied to different kinds of bulk metallic materials. This process consists of repeating of cutting, stacking, and rolling of sheets. The first goal of ARB is to impose an extremely high plastic strain on the material, which leads to strength increase and structural refinement without changing sample dimensions. So this process is suitable for manufacturing ultrafine grained and nanocrystalline plates and sheets, which are the most widely used material shapes in the industrial and commercial fields.

It is reported that ARB processing results in the formation of a lamellar structure at high strains [4], and that the conversion of low-angle to high-angle boundaries dominates over grain refinement [3]. Several researchers have worked on microstructural evolution, thermal stability and tensile properties of ARB-processed alloys to find out that they have high hardness, tensile strength, and limited ductility [8-10]. However some characteristics of ARB-processed alloys such as wear properties still need an in-depth study. The wear characteristic is an important material property that should be examined for practical use of the UFG (ultra-fine grain) and nanomaterials [17]. In this study, tribological properties and wear behavior of produced nanocomposite samples were investigated. The wear tests by abrasion were performed with a pin- on-disc tribometer.

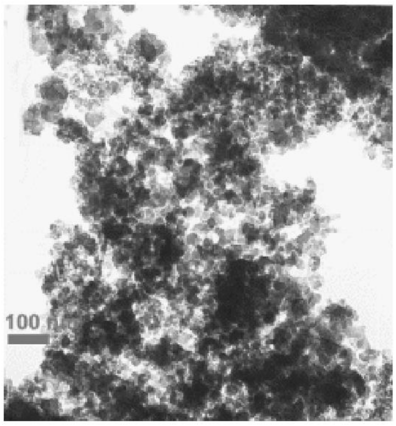

Fig. 1. The TEM image of the SiO_2 nanoparticles were used in this research.

2. EXPERIMENTAL PROCEDURES

2. 1. Materials

Strips of 1050-aluminum alloy with the length of 250mm,width of 40mm, and thickness of 0.4mm that were annealed at 400K in ambient atmosphere for 30 minutes and analytical grade of SiO_2 nano powder with an average size of 80 nm, were used as raw materials. Table 1 lists the chemical composition of the Al strips that used in this research. Fig. 1 and Fig. 2 show the TEM image and X-Ray diffraction pattern of the SiO_2 nanoparticles were used in this study, respectively.

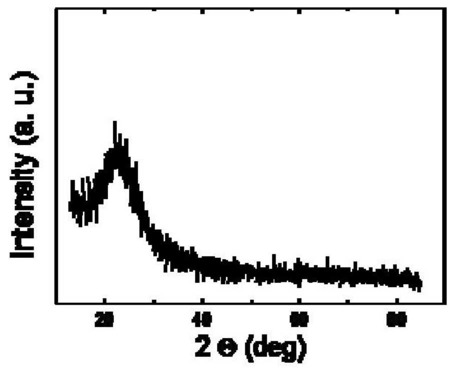

Fig. 2. The X-Ray diffraction pattern of the SiO_2 nanoparticles were used in ARB process

Table 1. Chemical composition of the 1050 Al alloy was used in this research.

Element	Wt (%)
Cu	0.05
Mg	0.05
Si	0.25
Fe	0.4
Mn	0.05
Zn	0.07
Ti	0.05
Al	99.5

2. 2. Accumulative Roll Bonding (ARB) Process

At first the strips were degreased in acetone and scratch brushed with a 90mm diameter stainless steel circumferential brush with 0.35mm wire diameter and surface speed of $14ms^{-1}$. Then these prepared strips were stacked over each other while 0.5, 1, 1.5 and 2 Wt.% SiO_2 nanoparticles were dispersed between each two layers. The stacked strips fastened at both end by steel wire to make it ready for the rolling process. The strip was roll-bonded with draft percentage of 66% reduction (VonMises equivalent strain of 1.245) in one cycle at ambient temperature. The reduction of 66% was used for creation of an appropriate bonding between the aluminum strips[18]. The well roll-bonded strip was cut into

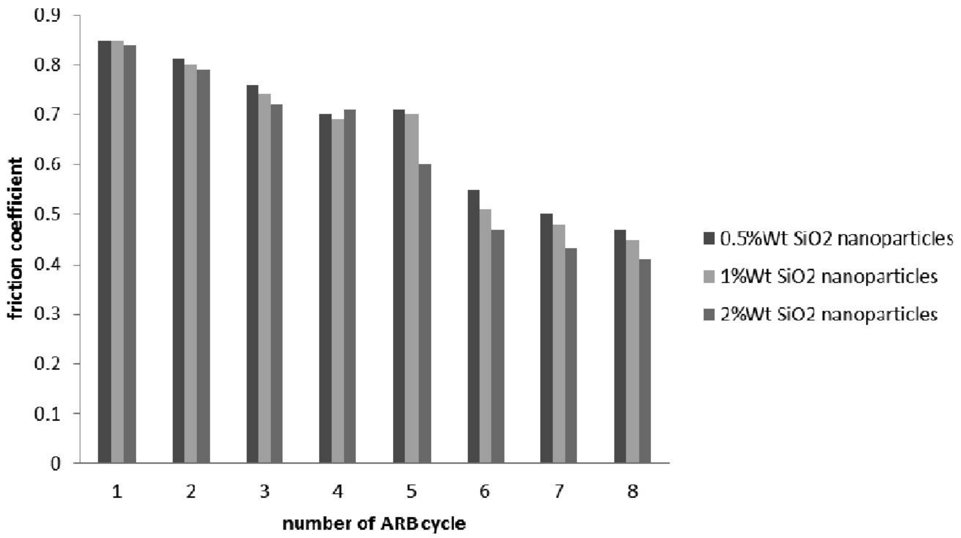

Fig. 3. The variation of friction coefficient of Al/nano SiO_2 nanocomposite with ARB cycles

two strips by a shearing. In the next step, the two roll-bonded strips degreased in acetone, scratch brushed again and after stacking over each other, without SiO_2 nanoparticles between them, was roll-bonded with draft percentage of 50% reduction (VonMises equivalent strain of 0.8). This last step of the process was repeated up to eight cycles. After eight accumulative roll-bonding cycles in total, the nanostructured Al matrix nanocomposite, including well dispersed nano SiO_2 reinforcements was produced. The ARB process were carried out, without lubricant, using a laboratory rolling mill with a loading capacity of 15 tons and roll diameter of 170mm.

2. 3. Microhardness Tests

Vickers microhardness (HV) test, using a load of 15 g for 15 s, was performed on the cross-section (RD–ND plane), rolling plane (RD–TD plane) and through the thickness of the ARB-processed nanocomposites. The mean value of ten separated measurements that taken at randomly selected points was reported.

2. 4. Wear Tests

Wear tests of ARB-processed nanocomposites were performed by "pin on disk" wear Testing machine at ambient temperature and relative humidity of 10–20%. Rectangular sheets with dimensions of 0.4mm in thickness, 25mm in width, and 60mm in length were used to fit into the fixture of this testing machine. The pins were made of stainless steel with 5mm diameter, 50mm length and a hemispherical tip. The nanocomposites were weighted with an accuracy of 0.1mg before each wear test. The sheet rotation speed of 60 rpm and total 500m sliding distance were used for all wear tests that performed in this investigation. At specific sliding distances, the nanocomposites that cleaned out of debris were weighted. Wear properties of ARB-processed samples (1st cycle to 8th cycle) were studied and compared with each other.

3. RESULTS AND DISCUSSION

The variation of friction coefficient of the produced nanocomposite samples with different amount of nanoparticles were shown in Fig. 3. Regarding to thif figure, the friction coefficient decreased with increasing the amount of nano-sized SiO_2 particles. Also Results show that by increasing ARB cycles, the friction coefficient decreased.

Because of grain refinement of metals by ARB

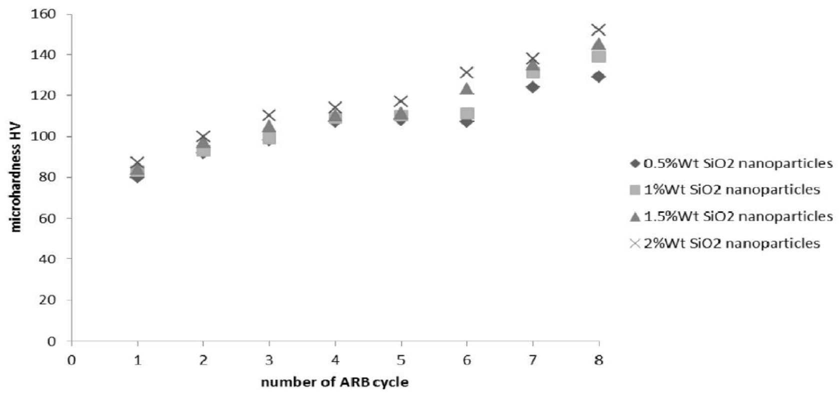

Fig. 4. The variation of microhardness of produced nanocomposite versus ARB cycles

process and presence of hard phase (ceramic reinforcement) in nanostructured metal matrix nanocomposite, the friction coefficient decreased in higher cycles of ARB and finally wear properties improved with increasing the amount of nanoparticles. Also in order to pin abrasion, the localized cold working increased the hardness of surface of nanocomposites and decreased the friction coefficient of them. As shown in Fig .4 the hardness of nanocomposites, increased with the increasing the amount of nano-sized SiO_2 and ARB cycles.

SEM images of abrasion surface of nanocomposites with 0.5, 1 and 2Wt% SiO_2 nanoparticles after 8th cycle were shown in Fig.5 . With attention to this figure the wear resistance of produced nanocomposite increased by increasing the amount of nanoparticles.

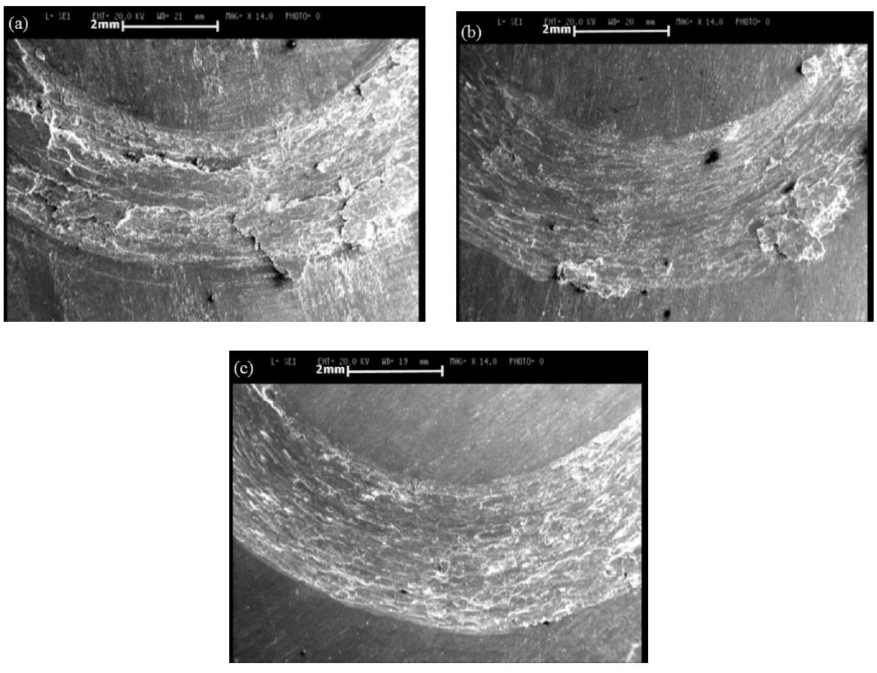

Fig. 5. The SEM images of the surface of worn nanocomposite with (a) 0.5, (b) 1 and (c) 2Wt% nano SiO_2 at 8th cycle of ARB process

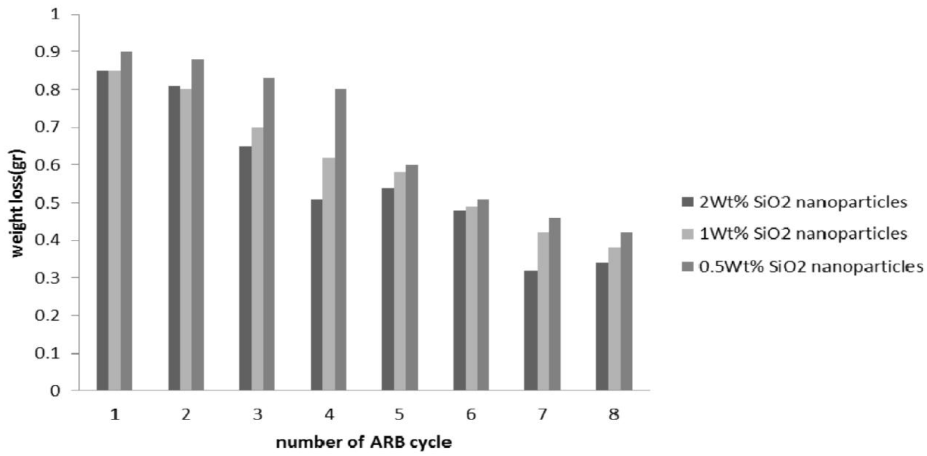

Fig. 6. The variation of weight loss of produced nanocomposites after wear test versus ARB cycles.

According to Fig. 6, it is clear that amount of weight loss decreased with increasing the number of ARB cycles and the amount of nanoparticles in the produced nanocomposites due to increasing the wear resistance.

Also Results show that different load forces have different effects on wear resistance of nanocomposite (Fig. 7). As shown in this figure, the friction coefficient of nanocomposites increased with increasing the number of ARB cycles and the wear forces. This is due to increasing the temperature of nanocomposites and more oxidation of them with increasing the load of the wear test.

4. CONCLUSIONS

1. The hardness and wear resistance of the ARB processed Al/nano SiO_2 increased with increasing the ARB cycles.
2. Increasing the amount of SiO_2 nanoparticles have significant effect on improvement of tribological properties of Al/nanoSiO_2 nanocomposites.
3. Because of grain refinement in different cycles of ARB process and presences of

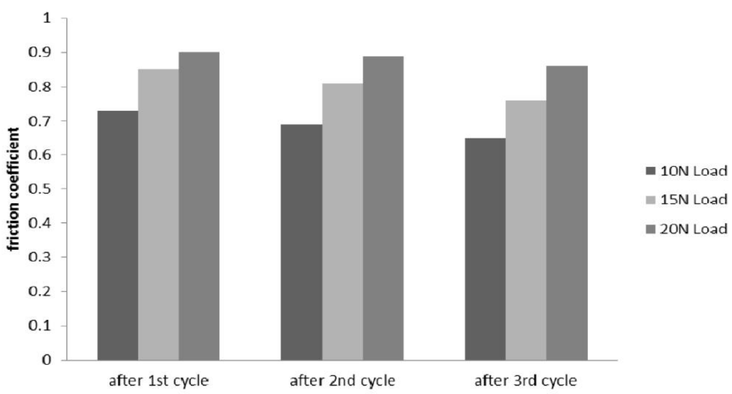

Fig. 7. The variation of friction coefficient versus load at different ARB cycles.

SiO_2 nanoparticles, the friction coefficient of Al/nano SiO_2 nanocomposites were decreased after eight cycles.

4. Because of thermal rising and oxide layers, in wear test with high load forces, the wear resistance of Al/nanoSiO_2 nanocomposites were improved.

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