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Experimental Investigation of the Mechanical Properties of Aluminum Sheets Reinforced by Carbon Nanotubes Utilizing Accumulative Roll Bonding Process

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ABSTRACT: In this study, aluminum sheets reinforced by carbon nanotubes were fabricated using the Accumulative Roll Bonding method. The accumulative roll bonding process was chosen among the severe plastic deformation methods to strengthen metal sheets using carbon nanotubes owing to the enhanced microstructure and mechanical properties of final products. In order to evaluate the mechanical properties of the specimens, tensile tests were carried out and the strength of sheets made by accumulative roll bonding method was compared to single-layer pure aluminum and reinforced composite sheets. Microstructural changes of composite sheets were studied by optical microscopy after each cycle of rolling process. The results showed that spreading of (0.5 to 1.5) wt% of carbon nanotubes increased the ultimate strength of the composite sheets while by aggregating the carbon nanotubes more than 1.5 wt% a decreasing trend of the ultimate strength was observed. Furthermore, the composites fabricated from 7 cycle of rolling process had a homogeneous distribution of particles and strong bonding between particles and matrix without having any porosity. Also it was found that the tensile strength of composite sheets also increased as the number of cycles increased.

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1- Introduction

Nowadays, aluminum based laminate composites are used in various industries such as aerospace, automotive, etc. Their strength is low compared to other structural materials such as steels and titanium alloys. In recent years, numerous investigations have been done on the development of metallic nano-composites [1]. Because of excellent mechanical and physical properties including high modulus of elasticity and good strength to weight ratio, carbon nanotubes are used more increasingly in nano-composites [2-4]. Using carbon nanotubes in nano-composites results in and high improvement in mechanical properties such as tensile strength and hardness. The purpose of this investigation is to evaluate mechanical properties of fabricated fine-grained aluminum sheets via Accumulative Roll Bonding (ARB) process which reinforced with carbon nanotubes (with different weight percentages). Furthermore, variation of microstructure after different ARB process cycles, the effect of the weight percentage of carbon nanotube on the ultimate strength and modulus of elasticity of the composite sheets were studied [5, 6].

2- Experimental Process

In this study, firstly, carbon nanotube reinforced aluminum sheets were fabricated using accumulative roll bonding process, then mechanical properties of these sheets were measured using standard tests. The mechanical properties of aluminum sheet and carbon nanotube are presented in Table 1.

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3- Results and Discussion

3-1- Mechanical properties of ARB-ed sheets

The stress-strain curve of the 1200 aluminum sheet and the 1-7 cycles ARB-ed sheets are shown in Fig. 1.

In comparison to initial state the ultimate strength of

Table 1. Mechanical properties of 1200 aluminum alloy and carbon nanotube

Material	Ultimate MPa Strength,	Density g/cm^3	Modulus Elasticity GPa
Aluminum 1200	105	2.7	70
Carbon Nanotube	150000	2.6	1100

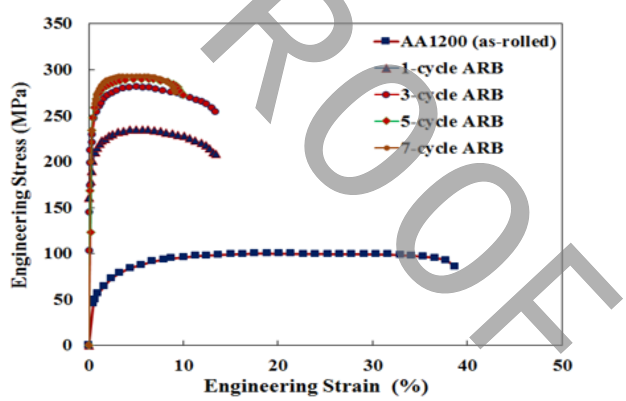

Fig. 1. Stress- Strain curve of initial 1200 aluminum and ARB-ed aluminum sheets

aluminum 1200 has been increased up to 2.7 times by 7-cycles ARB process.

3-2- Microstructure analysis of ARB-ed sheets

Fig. 2 shows the microstructure of ARB-ed samples after different cycles. As can be seen increase in ARB process causes to small grain size. In the initial cycles of ARB process, severe plastic deformation results in fine grain microstructure because of formation of grain boundary dislocations which in the next cycles leads to the formation of fine grains with stable boundaries.

Fig. 3 shows the grain size in different cycles of ARB process. As shown in Fig. 3, from the second cycle the intensity of grain size refinement is decreased and the grain size tends to be constant.

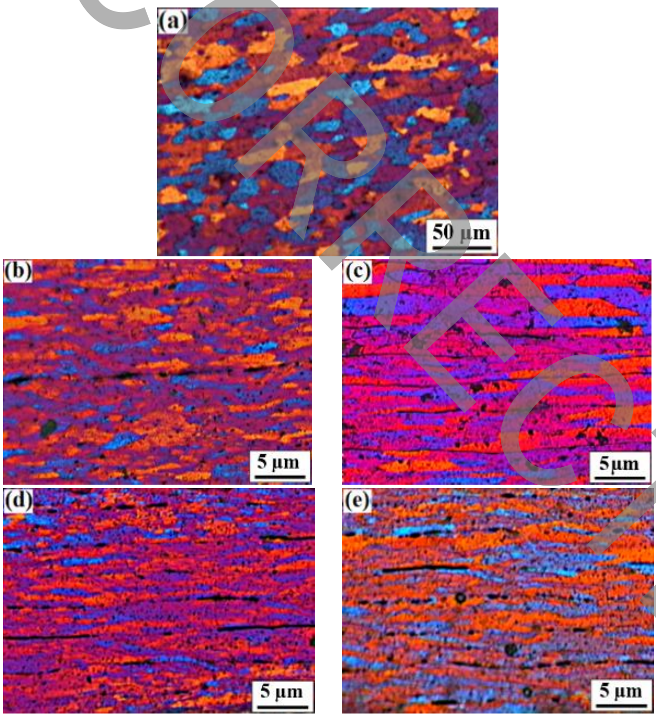

Fig. 2. Microstructure of ARB-ed sheets in different cycles (a: Al 1200, b: 1-cycle, c:2-cycle, d:3-cycle, e:4-cycle)

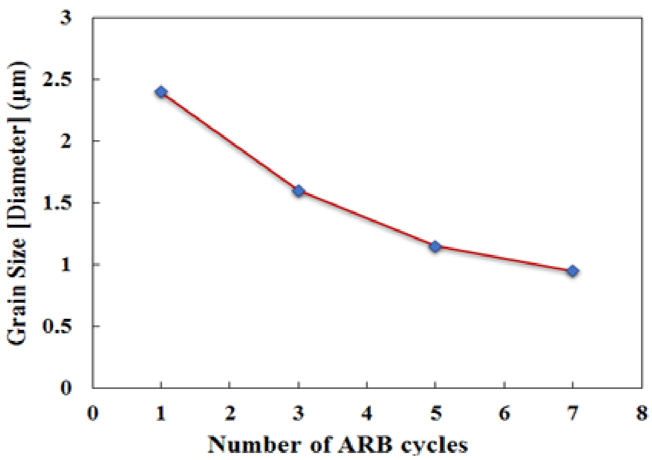

Fig. 3. Changes in grain size versus different cycles

3-3- The effect of carbon nanotube dispersion on the strength of samples

In the case of metallic composites reinforced by carbon nanotubes, the inappropriate dispersion of carbon nanotubes in the metallic matrix will have an adverse effect on the properties of the produced composite. The excessive increase in nanotubes percentage will result in agglomeration in the field, and the mechanical properties of the composite will be reduced. On the other hand, the small amount of carbon nanotubes will also have less effect on the reinforcement of aluminum composites. In this study, bi-layered aluminum sheets reinforced with a different percentage of carbon nanotubes. Fig. 4 shows that in 0.5 wt% added carbon nanotube, the strength of the composite sheet is improved 8% compared to the ARB-ed sheet, and by increasing the weight percentage of carbon nanotubes up to 1%, the increase in the strength of the composite sheet compared to the ARB-ed one is 10%.

3-4- Modulus of elasticity of reinforced samples with carbon nanotubes

Fig. 5 shows the variation in young's modulus of ARB-ed and carbon nanotube reinforced aluminum sheets with different cycles of rolling process.

In most studies, it has been shown that strain rates of less

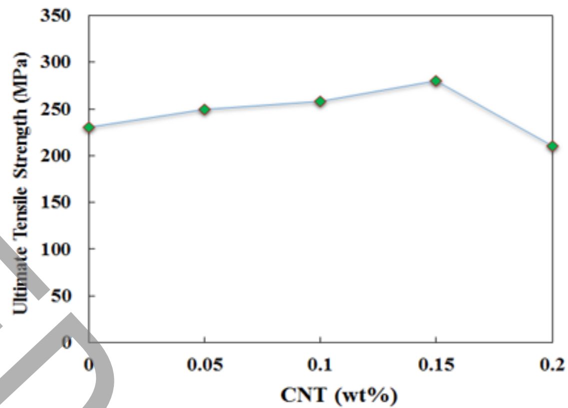

Fig. 4. Influence of carbon nanotube percentage on ultimate strength of ARB-ed sheets.

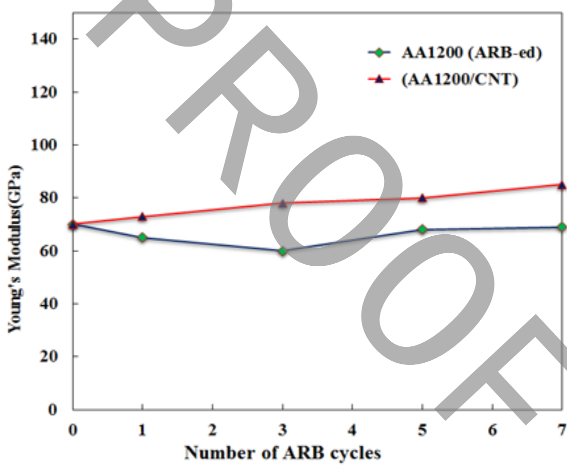

Fig. 5. The young's modulus variation of composite sheets AA1200 / CNT in different cycles of cumulative rolling process

than about 20-30 percent decrease in elastic coefficient and do not occur in strains above 50% variation in elasticity coefficient [7]. As shown in Fig. 5, there is a slight change in the elastic modulus in the ARB process, but in aluminum sheets reinforced with carbon nanotubes, the elastic coefficient of the initial cycles of the rolling process begins to increase.

4- Conclusions

The results show that adding (0.5-1.5) 1% by weight of carbon nanotubes increases the ultimate strength of the composite sheets, but adding more than 1.5% causes to decrease in ultimate strength.

In comparison to the 1200 and accumulative roll bonded aluminum sheets the ultimate strength of the carbon nanotube added ARB-ed composites increased up to 16 and 220% respectively, which shows significant improvement.

In total, the modulus of elasticity in ARB-ed sheets shows a slight decrease (about 10%), but increases in carbon nanotube-reinforced ones (about 20%).

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