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Investigation of the Microstructural and Compression Properties of Al-SiO_2 Nanocomposites Produced by Ultrasound and Stir Casting

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1- Introduction

Metal matrix nanomposites are widely used and investigated for different applications such as aerospace and military industries. Usually ceramic micro-particles are used to increase the yield and ultimate strength of metals, but it has been shown that they decrease the ductility of the composites. Thus, efforts have been done to use ceramic nano-particles for strengthening metal matrices. Dispersion of nanoparticles using an ultrasound process based on melt route has been recently introduced. It is believed that high intensity ultrasonic waves generate strong cavitation and acoustic streaming effects. Acoustic cavitation involves the formation, growth, pulsation, and collapse of micro-bubbles in the melt under cyclic high intensity ultrasonic waves. Transient cavitation can produce an implosive impact force strong enough to break up the clustered fine particles and disperse them more uniformly in liquids and the melt.

Based on the literature survey done by the authors, there is no evidence of using ultrasound to produce Al-SiO_2 nanocomposites. For this purpose the aim of the current research was to produce aluminum nanocomposites reinforced with different amounts of SiO_2 nanoparticles using ultrasonic and stir casting techniques. The microstructure, hardness and compressive characteristics of the samples have also been investigated.

2- Experimental procedure

The chemical composition of the aluminum alloy which was used as the matrix is presented in Table 1. Silicon dioxide powder with a particle size ranging from 40 to 80 nm was selected as reinforcement material because of its good wettability with aluminum alloys.

Table 1. The chemical composition of the aluminum alloy

Element	Si	Zn	Fe	Cu	Mg	Pb	Mn	Ni	Ti	Al
wt%	8.62	1.46	1.16	0.83	0.23	0.15	0.14	0.09	0.03	Remaining

Al-SiO_2 nanocomposites were fabricated with the addition of 0.25, 0.5, 0.75 and 1.0 wt% SiO_2 nanoparticles. For this purpose, the aluminum alloy was melted in the furnace and silicon dioxide powder was added to the molten aluminum at 680±10 °C and stirred at 700 rpm for 20 min. Then, an ultrasonic probe was immersed into the melt and flustered at 20 kHz for 10–15 min to improve the wettability and distribution of the nanoparticles. The produced nanocomposites were evaluated using standard techniques of metallographic preparation and observation with scanning electron microscope (SEM) to view the distribution of SiO_2 nanoparticles. Uniaxial compression tests were performed at 3.1 mm/min cross head speed.

3- Results and discussion

Fig. 1 shows optical micrographs of the Al-alloy after melting in the furnace and Al-0.5 wt.% SiO_2 nanocomposite. As it can be seen from Fig. 1, the processing of the nanocomposite causes changes in the metal matrix microstructure. Liu and Ji showed that different intermetallic compounds can form, if Al–Si alloys containing iron re-melt close to the formation temperature of the iron-rich intermetallic phase. Fig. 2 shows the SEM image of Al–0.5 wt.% SiO_2 nanocomposite. As it can be seen from this figure, SiO_2 nanoparticles are well dispersed, although a few clusters of nanoparticles were observed in the matrix.

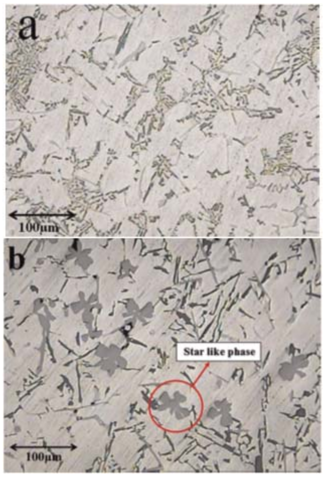

Fig. 1 Microstructure of (a) aluminum alloy; (b) Al–0.5 wt.% SiO_2

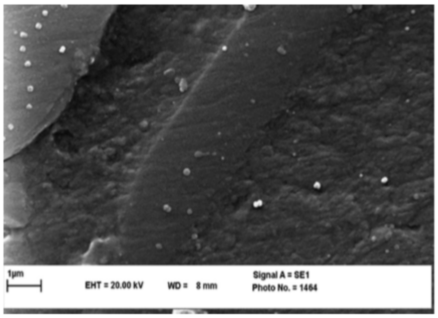

Fig. 2 SEM image of the Al–0.5 wt.% SiO_2 nanocomposite

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As was reported by Li et al., using ultrasonic agitations results in transient cavitation that can break up the clustered nanoparticles and disperse them in the melt. Strong impacts coupled with locally high temperatures could also enhance the wettability between the matrix and the reinforcements.

Compressive stress–strain curves and work hardening results of the as received aluminum alloy and the nanocomposite samples are shown in Fig. 3 and table 2, respectively. All the nanocomposite specimens have a higher strength than the aluminum specimen.

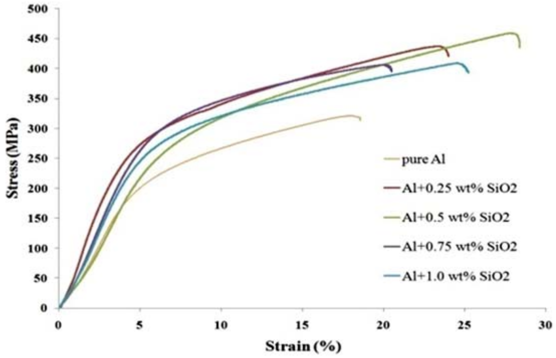

Fig. 3 Compressive stress–strain curves for pure aluminum and Al–SiO_2 nanocomposites

Table. 2 Compression and work hardening results

Sample	**Wt % SiO_2**	**Compressive strength (MPa)**	**Work hardening exponent**
1	0	321	0.3392
2	0.25	437	0.2944
3	0.5	453	0.2462
4	0.75	405	0.2568
5	1.0	403	0.2691

The data in Table 2 indicate that work hardening will increase by adding nanoparticles up to 0.5 wt.%, and then decrease. This increment is expected because nanoparticles act as a barrier to dislocation movement. It was also shown that Orowan strengthening mechanism is quite significant, especially when the reinforcing particle size is less than 100 nm.

4- Conclusions

1. Stir casting and ultrasonic techniques led to well-dispersed SiO_2 nanoparticles in the matrix.
2. Adding 0.5 wt.% SiO_2 nanoparticles increases the compressive strength up to 41% in comparison to the as-received sample.
3. The specimen reinforced with 1.0 wt.% SiO_2 nanoparticles has 11% less strength in comparison to the specimen reinforced with 0.5 wt.% SiO_2 due to the agglomeration of the nanoparticles.