Evaluation of mechanical properties of Al7075/SiC Nanocomposite Fabricated by Hot Uniaxial Pressing

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Abstract: Fabrication and characterization of Al7075 reinforced by SiC nano particles are investigated in this paper. Al7075 micron sized powder and different amounts of SiC nano sized particles are mechanically milled and then consolidated using hot quasi-static and uniaxial pressing. Microstructural and mechanical behaviour of the samples applying optical microscopy, scanning electron microscopy (SEM), density, micro-hardness, and compressive test are carried out to have a comprehensive investigation. Compressive behaviour of the samples is also examined for both the low and high strain rate loadings. The results show a reduction of relative density as the nano phase content increases. Furthermore, incorporating nano phase could enhance the ultimate strength and micro-hardness of the Al7075 mono phase samples about 15% and 10%, respectively.

Keywords: Nanocomposite; Al7075; Silicon Carbide; Uniaxial Pressing

Introduction
Aluminium alloys like Al7xxx series are widely used in different industries specially aerospace, automotive, sport, and military due to their fairly high strength-to-weight ratio. Reinforcing Al7xxx series, which have the highest strength-to-weight ratio among other Al alloys, using ceramic nano particles and producing a metal matrix nano composite (MMNC) have attracted many attentions [1]. It is reported in different studies that incorporation of ceramic particles such as SiC, Al2O3, B4C, TiB2, TiC, and WC to an Al alloy using powder metallurgy techniques can enhance the strength, toughness, wear, and temperature resistance of the monolithic Al alloy [2-4]. It must be added that nano particles due to their small size have superior properties to micron sized particles when applied in metal matrices as reinforcement. The reasons of this superiority are also discussed briefly in Result and Discussion section. Despite of all of advantages of nano particles, these light weight particles have strong tendencies to cluster due to Vander Waals forces and so they cannot be distributed uniformly in the metallic matrices. In order to overcome this phenomena, ultrasonic of the composite powder suspension and controlling the temperature rise during the fabrication may be carried out [5].

Hot uniaxial pressing is one of the powder metallurgy processes which can be used to consolidate the powders and make a bulk nanocomposite. This process can be followed by other processes like hot extrusion, hot rolling, and hot forging to reach the full sintering and densification of the powder [1, 3, 6, 7].

Mohammad Sharifi et al. [3] used hot pressing to mechanically milled Al-B4C powder to produce bulk nanocomposite samples. They reported a significant increase of compressive strength and wear resistance of pure Al after adding B4C nano phase. Gu [7] also used the same processing route. He applied a pressure of 100 MPa and temperature of 723–873 K to fabricate Al/SiC nanocomposite. It was shown that higher temperature, 873 K, led to agglomeration of nano particles while using low temperature of 723 K could obtain a uniform distribution of SiC nano particles. In this research work, the processing of Al7075 nanocomposite having different amounts of nano phase, i.e 5 vol% and 10 vol%, using hot pressing technique is investigated. To characterize the bulk nanocomposite samples, micro-hardness, quasi-static and dynamic compressive tests were also carried out altogether with microstructural studies.

Materials and method
The as-received materials were SiC (average 50 nm, purity>99.0%, spherical morphology, specific surface area>90 m²/g, Pasargad Novin Co., Tehran) and Al7075 (-100 μm, gas atomized, irregular morphology, Khorasan Powder Metallurgy Co., Mashhad). Fig.1 shows the SEM micrograph of these materials. Proper amounts of each powder to have Al7075-5 vol% SiC and Al7075-10 vol% SiC were selected and manually mixed. Then, ethanol was added to the mixed and the resultant suspension was placed in ultrasonic bath for 30 minutes. The sonicated suspension was dried at furnace and then mechanically milled for 2 h under argon atmosphere and room temperature. The milling media consisted of twenty-two 10 mm diameter hard chromium steel balls embedded in a 125 ml volume steel vial. About 30 g of the powder mixture, to have ball-to-powder mass ratio 3:1, was milled at a rotation speed of 300 rpm. 0.5 wt.% of stearic acid was also added as process control agent (PCA).
To conduct the uniaxial pressing experiments, the 1.2344 heat-treated hot-work steel die and a 15 mm diameter 1.2542 shock-resisting steel punch were used. 5 gr of the nanocomposite powder with tap density of about 55% of the theoretical density was poured into the die hole. Then, the uniaxial pressure with 5 mm/min loading rate was applied using a 600kN INSTRON universal testing machine. To minimize frictional force of the die and to improve the surface quality of the samples a MoS₂ high-temperature die wall lubricant was also used. The temperature for the compaction tests was adjusted to 425°C and was selected how to minimize the agglomeration of nano particles [7]. To obtain the best conditions of process parameters, magnitude and duration of applied pressure, a parametric study was performed. As Table 1 illustrates, 500 MPa pressure for 30 minutes can lead to highest density. Therefore, these values for pressure and time were adjusted to fabricate main samples with 0-10 vol% nano SiC. In order to avoid pore formation, the pressure on specimen was released after cooling down from 425°C to 300°C [2]

Table2: Different process conditions.

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Pressure (MPa)</th>
<th>Time (min)</th>
<th>Relative Density (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>250</td>
<td>15</td>
<td>96.60</td>
</tr>
<tr>
<td>2</td>
<td>250</td>
<td>30</td>
<td>96.72</td>
</tr>
<tr>
<td>3</td>
<td>500</td>
<td>15</td>
<td>97.50</td>
</tr>
<tr>
<td>4</td>
<td>500</td>
<td>30</td>
<td>97.84</td>
</tr>
</tbody>
</table>

Results and Discussion

In order to evaluate the crystallite size of Al matrix, XRD analysis was carried out using a PHILIPS X'PERT PW3040 diffractometer (40 kV/30 mA) with Cu Kα radiation (λ = 0.154059 nm). Since, strain in the crystal lattice also contributes to broadening of the XRD peaks, the approach of Williamson–Hall (W-H) was used to separate the effects of crystallite size and strain from each other [8]. Crystallite size of Al matrix in 2h milled powder using W-H analysis has an increase from 50 nm for monophase Al7075 to 275 nm for Al7075-5 vol% SiC and finally to 690 nm for Al7075-10 vol% SiC. This behavior can be explained due to SiC effect in milling efficiency. Since the SiC has low density, it occupies big volume of milling vial and act as a barricade to efficient milling process. The crystallite sizes of consolidated samples are also 70, 115, and 80 nm for Al7075-0 vol% SiC, Al7075-5 vol% SiC, and Al7075-10 vol% SiC, respectively. The grain growth of Al matrix in Al7075-0 vol% SiC from 50 nm to 70 nm is attributed to exposing the samples under process temperature of 425°C. While for samples having 5 and 10 vol% SiC, being under 500 MPa pressure for 30 minutes is probably the main reason of grain refinement. Density is one of the parameter which expresses well the consolidation quality. As Fig.2 indicates, relative density of the samples which was measured using Archimedes principal, decreases when volume percentage of nano particles increases. This behavior is may be due to presence of hard and non-deformable particles in a ductile matrix which reduces the pressability.

![Fig.1: SEM micrograph of as received Al7075 (top), and SiC (bottom)](image)

Fig.1: SEM micrograph of as received Al7075 (top), and SiC (bottom)

Compressive strength of the nanocomposite samples for low and high strain rate regimes were also evaluated using quasi static compressive test (strain rate about 10⁻² /s) and split Hopkinson pressure bar (SHPB) (strain rate about 10¹ /s), respectively. Fig.3 and Fig.4 expresses the stress-strain curve for both of these tests. It is clear in both of curves that elongation is reduced in specimens having nano reinforcement. This means that nanocomposite samples have fairly a brittle behavior.
Moreover, reinforcing nano phase could improve the ultimate strength of monolithic Al7075 about 25% and 60% for quasi-static and dynamic curves, respectively. As can be seen in Fig.4, elongation of samples are reduced compared with Fig.3 which is well known due to this fact that materials under high strain rates loadings show brittle behavior.

The variations of Vickers micro-hardness is also depicted in Fig.5. Hardness and strength have usually a direct relation. As can be seen, micro-hardness has increased about 10% as nano phase content increases. This increase is also in agreement with strength improvement of these samples.

**Conclusions**

1. By adding hard ceramic nano particles densification of the powder can be reduced. These hard and non-deformable particles act as hinders against full densification.
2. Reinforcing of Al7075 with SiC nano particles can improve the compressive strength up to 60%.
3. Vickers micro-hardness of the nanocomposite samples increases about 10% with respect to Al7075 mono-phase samples.
4. Compressive behaviour of samples under high strain rates loading is fairly brittle.

5. No considerable increase is obtained in compressive strength under dynamic loading compared to strength under quasi-static loading.

**Fig.6: Variations of Vickers Micro-hardness**

**References**


