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Synthesis and characterization of Al-SiO_2 composites

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In this paper, aluminum matrix composites are successfully synthesized by melting of Al scrap at 850 °C. The reinforcements were then added gradually for 10 minutes to the molten aluminum with different amounts weight ratios (10, and 20) wt.% of SiO_2. Mixtures were stirred with 450 rpm for 10 minutes after the additions of SiO_2. The mixture was poured into previously prepared sand mold. The uniaxial tensile, cupping, and biaxial tensile tests were conducted by Gant Universal test machine, and local designed biaxial tensile machine. Al-SiO_2 composites presented good resistance to both uniaxial and biaxial tensile tests. It was observed that the ultimate tensile strength for Al- SiO_2 composites with 0, 10, and 20 wt% of SiO_2 were 25 MPa, 62 MPa, and 65 MPa and respectively. The Al- 20 % wt of SiO_2 composite presents good resistance to biaxial tensile test, and both of composites present a lower deformation ratio. The cupping results were promising for the composite with a ratio of 10 % wt it was deformed without failure until the depth d = 1.8 mm, whereas many cracks have been observed with 20 %wt of SiO_2 at small forming depth. Experimental and a finite-element simulation for biaxial and cupping test gave very closed results.

Key words: Recycled Al-SiO_2 composite, Biaxial tensile test, Cupping test, FE simulation.

Introduction

The strength and lightweight of the Aluminum make it so much attractive for several industrial applications such as aircraft, automobile, and aerospace industries. The addition of hard and rigid particles in the Aluminum matrices improves the modulus behavior and strength properties in the metallic matrices [1-3]. For instance, reinforcing aluminum metal with silica particulate yields a material that displays a combination of physical and mechanical properties of both the metal matrix and the silica [4-6]. The recycling of the aluminum alloy is one of the most important ways to manage the material waste and get a material with low cost [7]. The expected behavior of the recycled composite material through the stir casting could be influenced by some parameters such as: casting conditions, ratios of reinforcements, and types of reinforcement particles [7-9]. The aluminum sheet forming is one of the most important processing in several industries such as automobile aircraft aerospace and packaging industries. In general, the sheet forming is typically accompanied by data that defines the behavior of the material when it is subjected to mechanical loading. This important data, which usually includes yield strength, tensile strength and works hardening exponent, is typically obtained from a standard uniaxial tensile test. Since most metals forming operations are carried out under biaxial states of stress, the stress-strain formability parameters obtained by uniaxial tensile testing are inadequate for the application to deformation induced under states of biaxial stress. Then, the biaxial testing mechanism can be utilized for evaluating an interaction coefficient of anisotropic or orthotropic materials like reinforced composites that can help in characterizing and predicting failure behavior [10]. The experimental results obtained by the biaxial mechanism are validated with several numerical models. Hyper elasticity model and the non-linear biaxial tensile behavior of PVC-coated polyester fabrics were studied by M. BRIEU and C. Galliot et al. [10, 11]. The resulting test data may not be applicable to multi-directional forming processes such as deep drawing and cupping test. Biaxial testing is also becoming increasingly important for testing of metals used in machine and structural components that may be typically loaded in more than one direction during service [12]. Test methods employing cruciform specimens can cause failure of the material at loads much less than that determined by ordinary tensile-testing methods [13]. In the present study, it was necessary to conduct uniaxial tensile, cupping, and biaxial tensile tests to obtain a complete data that could analyses the characterization of recycled Al-SiO_2 composites.

Experimental

Aluminum (Al) was used as matrix material whereas different ratios (10, and 20wt. %) of SiO_2 particles with size range (150-200 μm) were used as reinforcements

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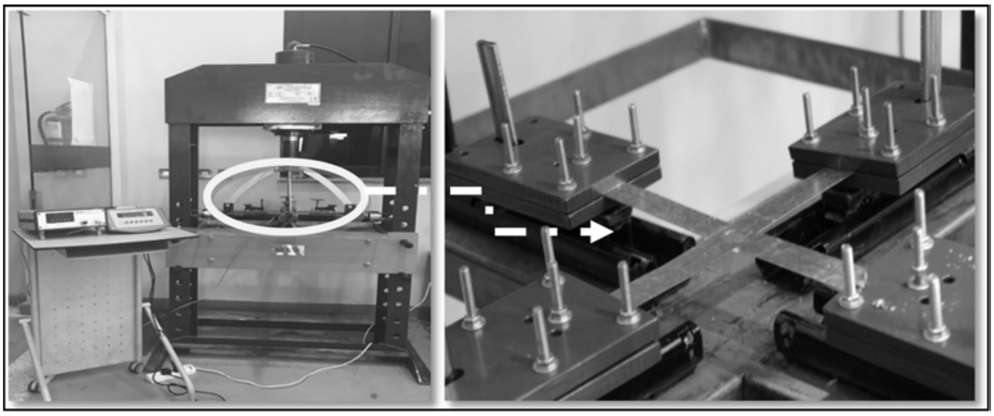

Fig. 1. Biaxial tensile machine.

in the Al-SiO_2 composites. Melting of Al scrap was carried out using a resistance box furnace at 850 ºC. The reinforcements were then added gradually for 10 minutes to the molten aluminum with different amounts weight ratios (10, and 20) wt.% of SiO_2. Mixtures were stirred with 450 rpm for 10 minutes after the additions of SiO_2. The liquid mixture was poured into previously prepared sand mold. However, at a temperature of 700 ºC the molten became in a semi-solid state, and the molten cannot be pouring into the mold because at this stage, its viscosity is high and fluidity is very low. Therefore, before pouring into the mold, it was necessary to re-melt it to a molten condition, and re-stir before pouring [14]. The obtained specimens were tested by both uniaxial and biaxial shown in Fig. 1.

Cruciform biaxial tests are increasingly becoming popular for testing the formability of sheet metals as they achieve frictionless. However, fracture of the samples during testing most possess large strain deformation which is necessary to the formability analysis. In this work, Biaxial tensile tests were conducted by local designed Biaxial Tensile Machine (BTM) as shown in Fig. 1. The efficiency of BTM was confirmed in various samples (aluminum, galvanized steel, and recycled Al-SiO_2 composites). The cupping test was done by universal test machine as shown in Fig. 3 for Al-SiO_2 composite according to standard ISO 20482:2013(E) [15].

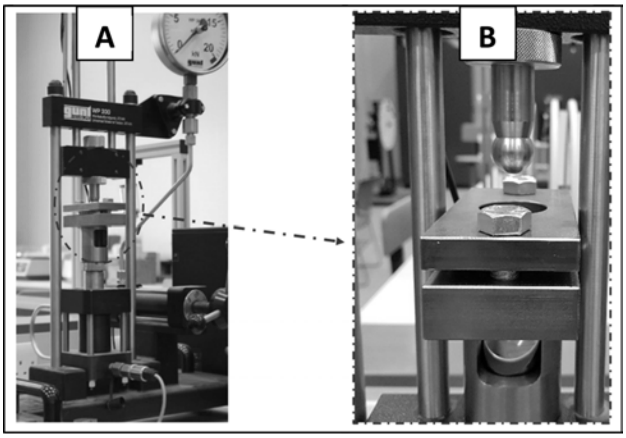

Fig. 2. (A) Universal test machine, and (B) Erichsen cupping device.

Results and Discussions

Mechanical characterization of recycled Al-SiO_2 composites

Recycled aluminum is considered as alloy with a composition around 90% of pure aluminum. The young modulus is around E = 66.1 GPa with density 2.8 g/cm^3 and poisson's ratio of 0.35. In addition, increasing weight percentages of SiO_2 (0 wt%, 10 wt%, and 20 wt%) led to increased tensile strength of Al-SiO_2

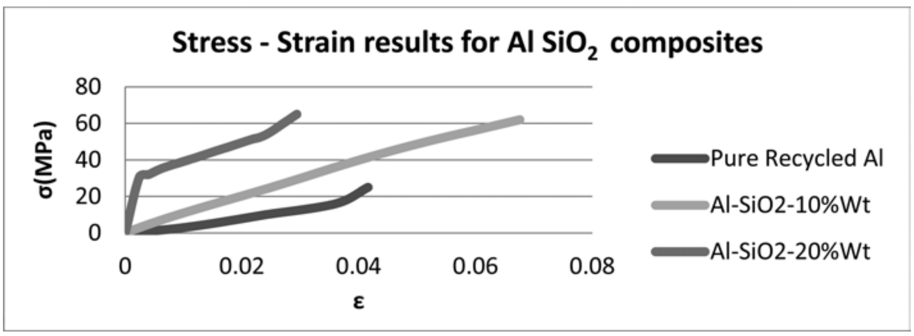

Fig. 3. Experimental results by biaxial tensile test.

composites from 84.13 MPa for 0 wt% to 120.24, and 140.24 MPa respectively. This indicates that the composite properties change from ductile to tough and brittle by good distribution of SiO_2 particles in the Al matrix. Fig. 3 shows the results of the biaxial tests for both recycled aluminum without reinforcement and recycled aluminum with 10 and 20 wt% of SiO_2. It is observed that the maximum strain for recycled aluminum with 0, 10, and 20 wt% of SiO_2 were 4.16 %, 6.76 %, and 2.94 %, respectively. The ultimate tensile strength with 0, 10, and 20 wt% of SiO_2 were 25 MPa, 62 MPa, and 65 MPa, respectively. The Al- 20 % wt of SiO_2 composite presents good resistance to biaxial tensile test, and both of composites present a lower deformation ratio.

From Fig. 4. The maximum attainable force for forming recycled aluminum with 0, 10, and 20 wt% of SiO_2 were 3.37 kN 3.34 kN and 3.04 kN, respectively. By a progressive loading through cupping test, a ductile fracture was observed due to non-uniform distribution of SiO_2. Sheet microstructure revealed particles cracks, which were oriented in line to the crack growth as shown in Fig. 5. Erichsen test was in line with the results as observed in the literature.

Finite element simulation

To simulate the biaxial test and the forming operation, a commercial software "ABAQUS explicit" was used. The FEM was developed through estimating the composite reinforcements of SiO_2 as spheres, as shown in Fig. 6. The linear quadrilateral elements of type CPS4R were chosen to simulate the deformation of the Al-SiO_2 composites. The SiO_2 is considered as a rigid particle with a density of 2.17 Mg/m^3, Poisson's ratio of 0.15, Young Modulus of 66.3 GPa.

In cruciform biaxial tension testing, a collection of large stresses and strains is observed at centre of the specimen as shown in Fig. 7. In addition the maximum stress-strain is localized at the curved boundaries of the centre area in the specimen. The experimental and numerical investigation of the cruciform biaxial testing has a unique deformation mechanism which has large and uniform strains in the test region. That gives a first explanation of the formability of the composite without any friction. In the Al- 10 % wt of SiO_2 the deformation is quite heterogeneous and some cluster of SiO_2 grains

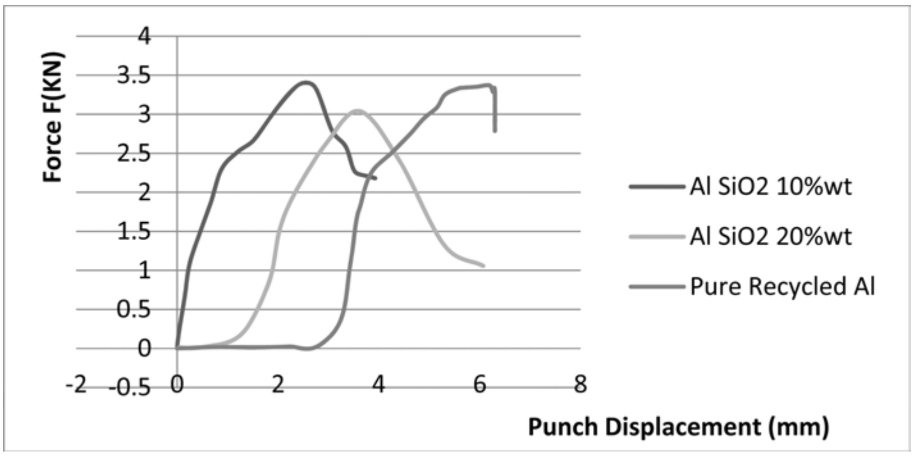

Fig. 4. Experimental results by Cupping test.

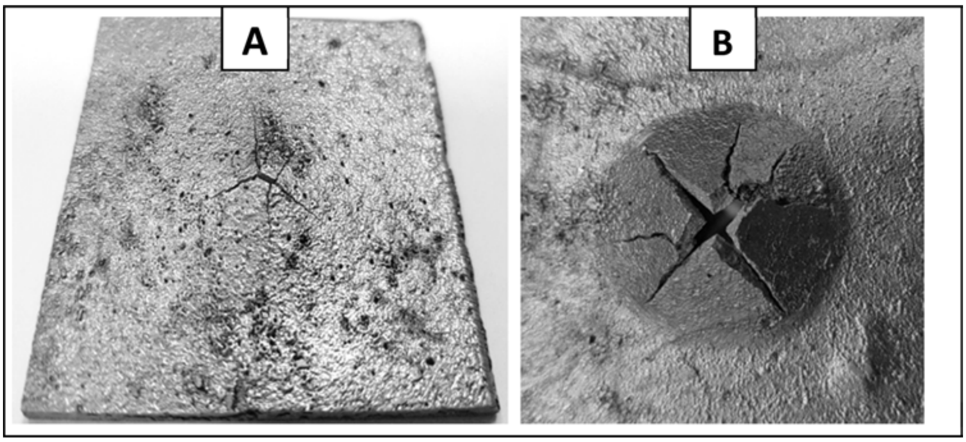

Fig. 5. Cupping test results for Al- 10 % wt.SiO_2 Composites: (A) Initial cracks at depth 2 mm, and (B) Propagation of cracks until depth 10 mm.

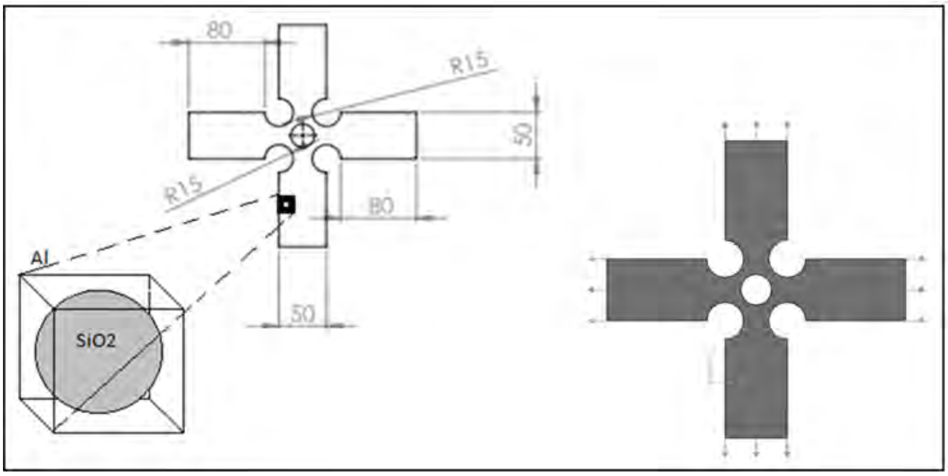

Fig. 6. Dimensions of Cruciform Sample (in mm); Model for biaxial FE simulation of Al- SiO_2 composites

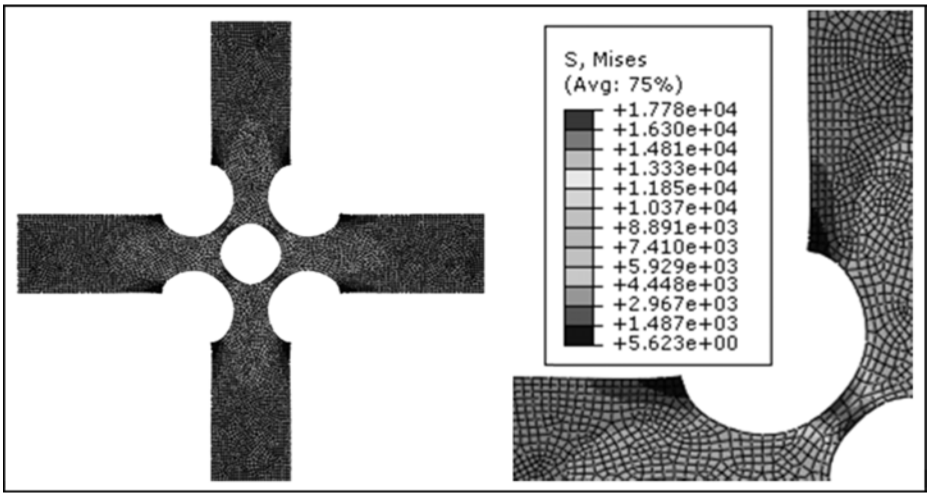

Fig. 7. Results in biaxial FE simulation for Al- 10 % wt of SiO_2 composites.

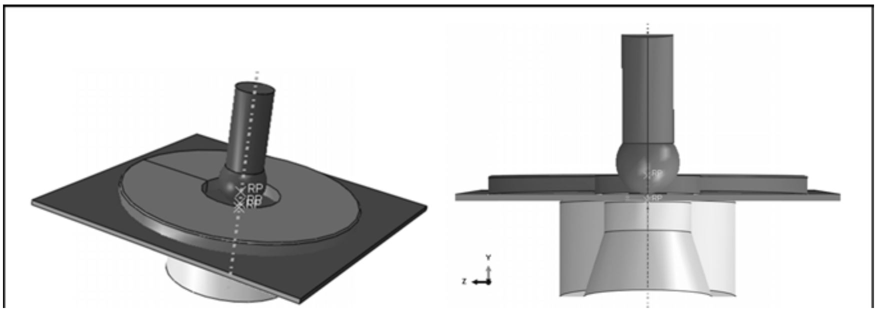

Fig. 8. Model for FE simulation for the cupping test.

remain unreformed during the test. For an anisotropic material such as Al-SiO_2 composite, deformation behavior is highly related to the grain size and distribution in the matrix. Limited deformation provided by slip or twin bands results in strain localizations and eventually cracks initiation. The punch enfacement was fixed to 4 mm to simulate the deformation of the sheet Al SiO_2 as shown in Fig. 8.

It was observed that the initiation of failure during cupping test starts at the top of the specimen as shown in Fig. 10.

Based on the comparative analysis, it may be concluded that the material forming behavior were determined with good accuracy and the finite element model offered similar results to those obtained experimentally.

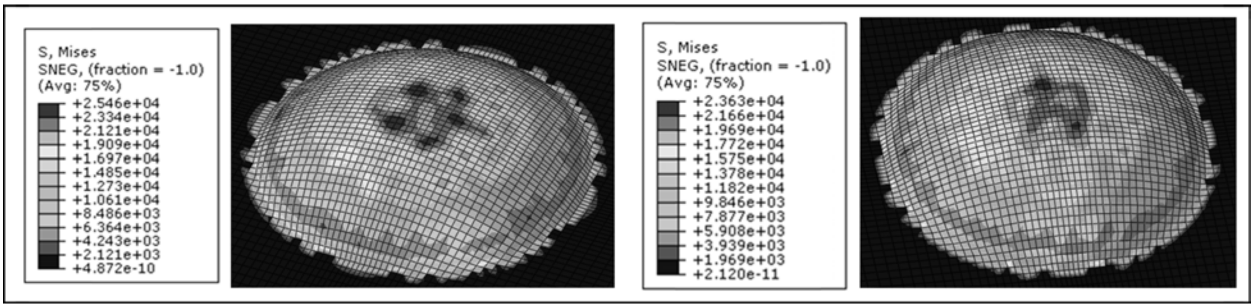

Fig. 9. FE Results in Cupping test for Al- 10% wt of SiO_2 Composites.

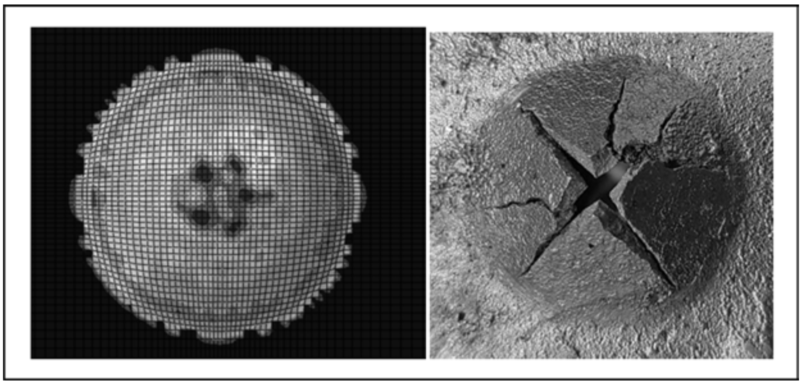

Fig. 10. (A) FE results, and (B) Experimental results for Cupping Test.

Conclusion

Al-SiO_2 composites are successfully synthesized by melting Al scrap at 850 °C and adding different amounts weight ratios (10, and 20) wt.% of SiO_2. The mixture was poured into previously prepared sand mold. The mechanical characterization of composites conducted through uniaxial and biaxial tensile tests. The biaxial tensile tests were conducted by local designed machine. The Al-SiO_2 composites showed a height resistance to both uniaxial and biaxial tensile tests. The Cupping test at room temperature was conducted for the composite at the different ratio of SiO_2. The results of cupping test for Al-10 % wt of SiO_2 was deformed without failure until the depth d = 1.8 mm. However, the composites with SiO_2 ratio more than 20 %wt demonstrated cracks at small forming depth. The experimental cupping and biaxial results were endorsed by a finite element simulation. It was demonstrated that the simulated variation of the sheet thickness showed relatively good agreement with the experimental results. It was observed that the experimental and numerical results were very close. The recycled Al- SiO_2 composite was very brittle, and it was necessary to improve the material formability by conduct a warm forming investigation and study the effect of worming temperature to the cupping.

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