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Influence of Cold Working on Mechanical Properties of Al-SiC Composites

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Abstract. The main objective of this research was a study on the simultaneous influence of cold working and particle reinforcement on the mechanical properties of aluminum. The model composites were fabricated by cold pressing of RAl-1 aluminum and 5 % and 10 % SiC powders and hot extrusion with extrusion ratio 3.8 in isothermal conditions at 480°C with 90° die angle to 18 mm diameter. Some specimens were then cold drawn with a linear velocity of 1 m/min to 16 % area reduction, and one specimen in 3 passes to 51 % reduction in area. Mechanical properties of the near fully dense composites were determined by axial compression, bending tests and hardness measurement and their microstructure examined, showing near homogenous distribution of SiC particles in the aluminium matrix. The increase in Young's modulus (E) was from 67 to 74 GPa and to 82 GPa for 5 % and 10 % reinforcement, respectively. Drawing increased average yield strength from 70 to 100 MPa for Al, and from 74 to 110 MPa and from 80 to 115 MPa, for 5 and 10 % reinforcement, respectively. The results indicate that there is a significant increase in E, in accordance with the law of mixtures, through incorporation of SiC and a synergistic effect of SiC and plastic deformation during drawing on strength. An attempt is made to identify the various contributions to overall strengthening of Al by considering also Al-8.8Cu-6.3%Si-0.7Mg alloy. It appears that alloying and age-hardening have the greatest effect, but that contributions from hot, warm and cold working are not significant. As powder metallurgy processing is an important fabrication method, their incorporation into the processing schedule merits consideration.

Introduction

Silicon carbide particulate reinforcement of aluminium and its alloys is used generally to increase Young's modulus and wear resistance. Techniques employed include cold pressing and sintering [1], hot isostatic pressing HIP [2], stir casting and rheo-casting [3], vacuum hot pressing [4], spray forming [5], thixoforming [6] and other [9]. Strengthening in hot and warm forged and extruded composites has received special attention [7,8,10]. Closed-die forged Al-5%SiC and hot extruded Al-8.8Cu-6.3%Si-0.7Mg alloy were investigated. To obtain more precise input for the individual compositional and microstructural contributions to the overall strength, it is now reported about the influence of a further postextrusion operation, cold drawing, using model systems for Al-5 and 10% SiC particles.

Composites fabrication. Powders of aluminium RAl-1 (99.7 wt.-% of Al) with 5 and 10 weight-% SiC, with particles grit size 250 μm, were ground in a ball mill for 1 hour. Preforms were cold unilaterally pressed on a hydraulic press ZD100, at ambient temperature under 80 MPa with die diameter 35.3 mm. The preforms were heated at 480°C before hot extrusion, with the extrusion ratio (defined by starting cross-sectional area divided by the final cross-sectional area) 3.8 to a diameter 18 mm. Some specimens were turned to 17.5 mm diameter before drawing. Drawing was done on a carriage drawing machine at linear speed of 1 m/min with a 16 mm diameter drawing die to 16.4 % reduction in area. Figure 1 shows the shape of specimens during processing (with one step drawing) of aluminium material from powder. The microstructure and properties by means of hardness, compression and bend tests were examined of extruded and drawn materials.

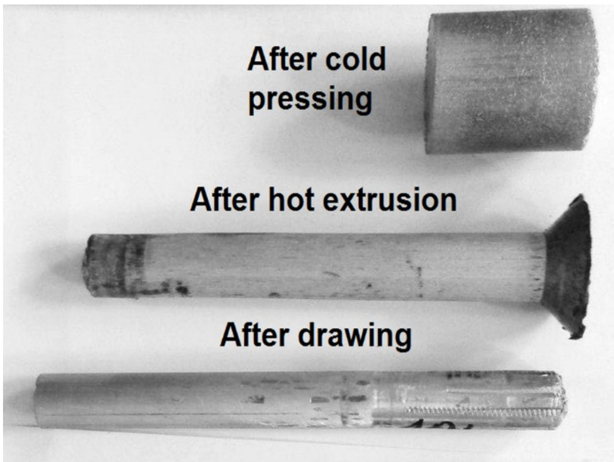


Fig. 1. Processing steps of aluminium

Microtructural examinations. Metallographic studies using optical microscopy, Leica DM4000M and Zeiss Axio Imager M1m, and scanning electron microscopy, Hitachi S-3500N, were carried out on as-fabricated and fractured specimens.

Compression and bend tests. Compression and bend tests were conducted on an Instron 1196 machine with a traverse speed of 5 mm/min. Axial compression was performed on specimens with height 16 mm and diameter 16 mm. For bend testing the span was 60 mm for 16 mm diameter specimens.

Hardness testing. Brinell hardness was measured with a force of 153.2 N.

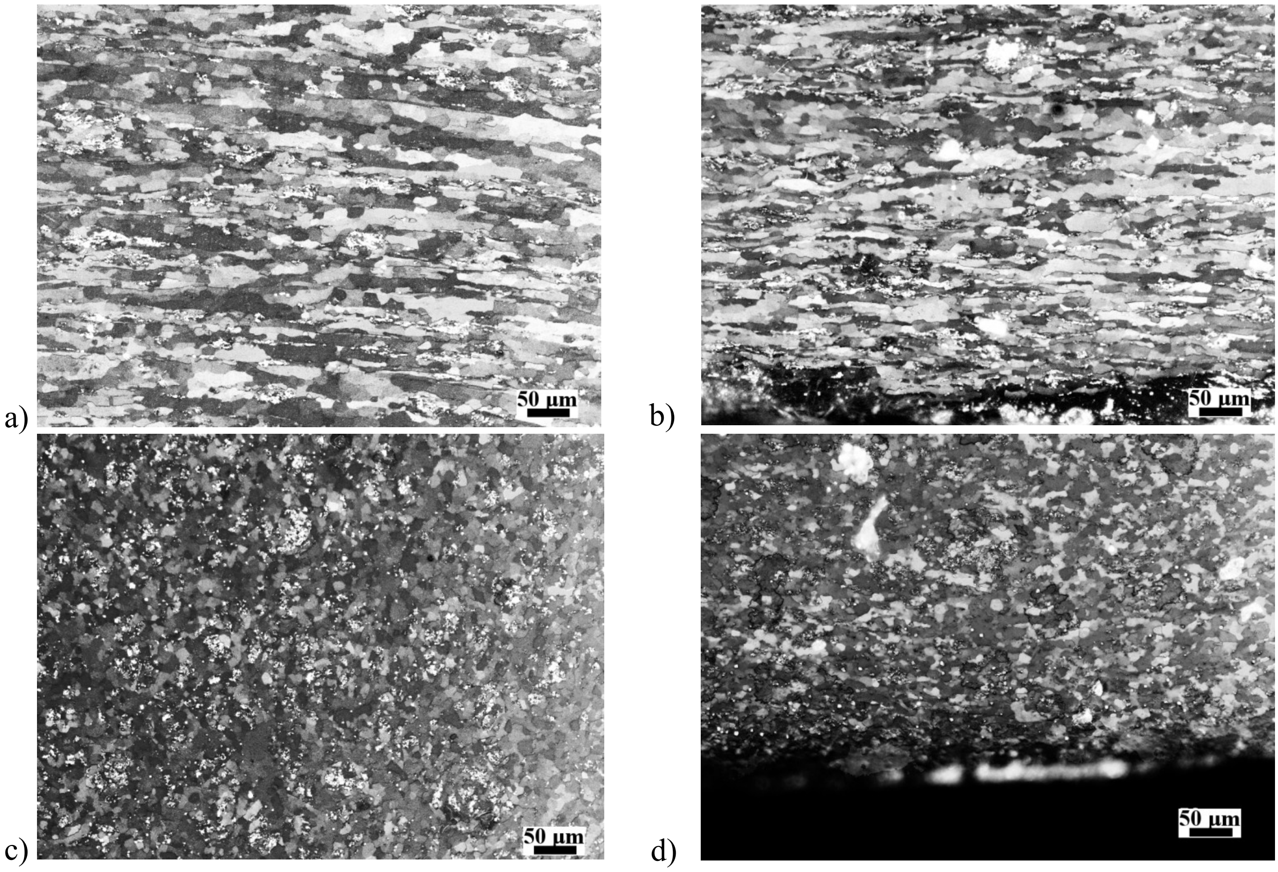


Fig. 2. Microstructures of hot extruded aluminium (at 480°C, extrusion ratio 3.8) on the: a), b) longitudinal section; c), d) cross section. Magnification: a), c) 100x, b), d) 200x. Zeiss microscope, etched. Observation sites: a), c) – 0.5 mm from outer surface; b), c) - near outer surface

Results

Microstructures of Al and Al-SiC composites. Examples of metallographic observations, as revealed by Barker reagent, on Zeiss Axio Imager M1m microscope using polarized light are presented in Fig. 2. As a result of extrusion the grains became elongated in the direction of material flow (Fig. 2a, 2b). The microstructure observed on cross section on Figures 2c and 2d is formed of small, nearly globular shaped grains. Fig. 3 shows the unetched microstructure of composite materials observed on the Leica microscope. Uniform distribution of pockets of SiC particles (dark regular shape), fine oxides and small porosity in the aluminium matrix are visible. More uniform distribution of SiC particle appears in Al-10%SiC structure.

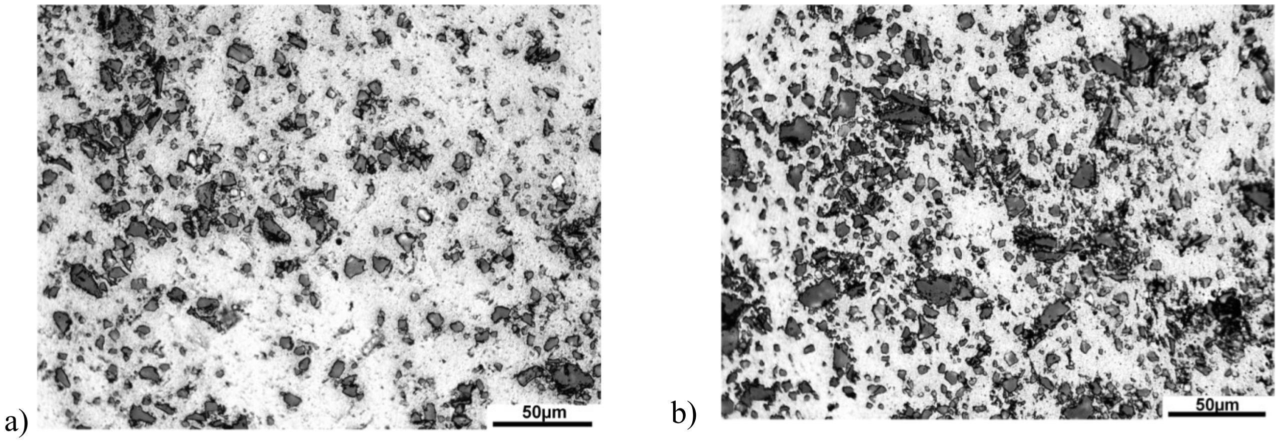


Fig. 3. Microstructures of hot extruded (at 480°C, extrusion ratio 3.8) and drawn (from diameter 17.5 to 16 mm) composites: a) Al-5%SiC, b) Al-10%SiC, Leica microscope, unetched, magnification 500x

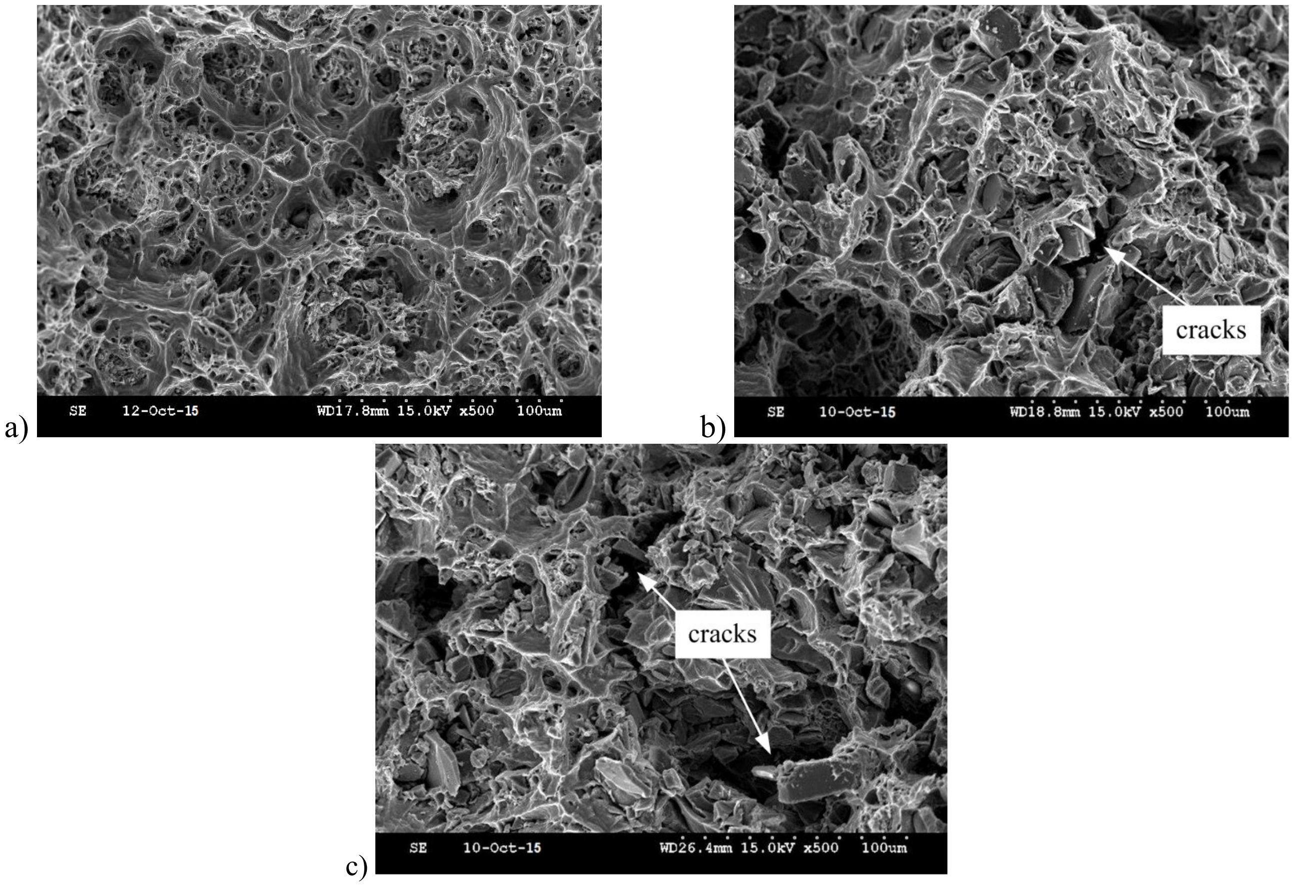


Fig. 4. SEM fractures: a) Al, b) Al-5%SiC, c) Al-10%SiC after hot extrusion at 480°C with 4.2 ratio

Small particles of SiC were observed on fracture images of failed bend specimens acting as stress concentrators for cracking (Fig. 4b, c). Al matrix fracture surfaces were ductile. In fractures of Al-10%SiC composite small brittle sites around the SiC particles appeared.

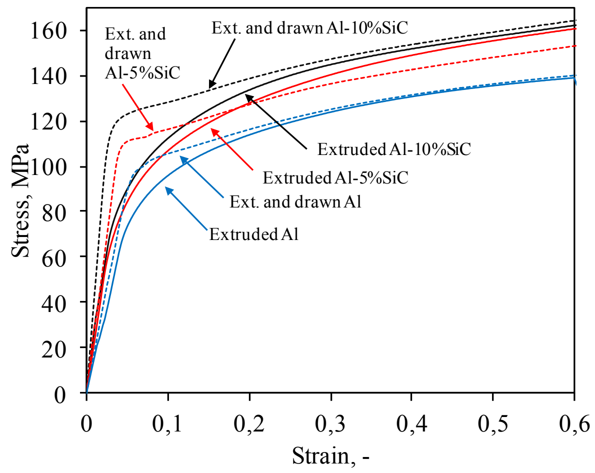
Properties. The density of hot extruded specimens was 2.65 g/cm^3 for aluminium and 2.67 g/cm^3 for Al-SiC composites. Young's modulus, yield stress and hardness data are summarised in Table 1. Almost 30 % increases in hardness were obtained as a result of one pass drawing. Young's modulus increased with SiC content in accordance with the law of mixtures. Yield strength increased with SiC content, extrusion and drawing (Table 2). For extruded materials the reinforcing SiC particles have only a small influence on the yield stress. Fig. 5 shows the compressive stress - logarithmic strain and Fig. 6 the bending moment vs displacement plots.

Table 1. Mechanical properties of aluminium and Al-SiC composites

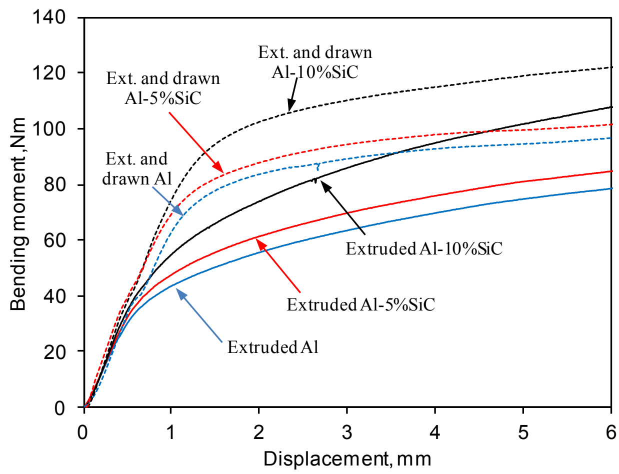
Material	Process	Young's modulus [GPa] Compression	Yield stress [MPa]		Hardness [HB]
			Compression	Bend	
Al	Extrusion	67±4	70±3	65±5	23±1
Al-5%SiC		74±4	74±3	73±5	27±1
Al-10%SiC		82±1	80±3	87±5	28±1
Al	Extrusion and drawing (1 pass)	67±2	100±3	104±5	31±1
Al-5%SiC		82±3	110±3	119±5	34±1
Al-10%SiC		95±3	117±3	126±5	36±1
Al-5%SiC	further 2 passes	-	150± 3	-	-

Table 2. Influence of SiC addition on yield stress and apparent bend strength for RAl-1, and for Al-8.8Cu-6.3%Si-0.7Mg alloy [10]

Material	Process	Yield stress [MPa]	Apparent bend strength [MPa]	SiC YS increase [MPa]	Drawing YS increase [MPa]
Al	Extrusion	70	221	-	-
Al-5%SiC		74	238	4	-
Al-10%SiC		83	267	13	-
Al	Extrusion and drawing	100	271	-	30
Al-5%SiC		115	285	15	31
Al-10t%SiC		122	309	22	39
Al-5%SiC	Further 2 passes	150	-	-	50
Alloy	Extrusion	220	675	-	-
Alloy-5%SiC		280	600	60	-
Alloy	Extrusion and age-hardening	380	926	-	-
Alloy-5%SiC		390	773	10	-



a)



b)

Fig. 5. a) Stress – compressive strain relationships and b) bending moment vs displacement diagram of extruded and extruded and drawn (1 pass) materials Al, Al-SiC composite (Ext- extruded)

Small particles of SiC were observed on fractures of failed bend specimens acting as stress concentrators for cracking (Fig. 4b, c). Al matrix fracture surfaces were ductile. Fractures of Al-10%SiC appeared more brittle than in Al-5%SiC. Near the surface layer of drawn materials a deformation zone appeared.

Discussion

The expected increase in Young's modulus of Al due to the much stiffer SiC particles was demonstrated. For every material almost 30 % improvement in hardness were obtained after drawing. Strengthening of the composite by drawing (one pass) after extrusion has clearly been shown (Table 2). Second subsequent passes resulted in further 35 MPa increase in the yield strength. Cold working of aluminium matrix influenced strengthening more than SiC particle content. Table 2 lists also some of our previous data in an attempt to identify the various contributions to overall strengthening of Al and Al-l8.8Cu-6.3%Si-0.7Mg alloy [10]. Some possible contributions to strengthening of aluminium are illustrated on Fig. 6.

It appears that alloying and age-hardening have the greatest effect. Possible contributions from hot, warm and cold working, however, are not insignificant. It is proposed that the higher stress values, up to 50 MPa, in drawn Al-SiC materials result from strain hardening of the aluminium matrix and dislocation blocking on particles. As powder metallurgy processing is an important fabrication method, their incorporation into the processing schedule merits consideration.

The hot extrusion and drawing of model Al and Al-X% SiC PM materials have shown manufacturing possibility of obtaining products with nearly full density and useful strength properties. The strengthening properties depend on the chemical composition of the preforms, the processing route and its parameters. As a result of cold drawing, sizing of the diameter of the product and cold working of the matrix take place.

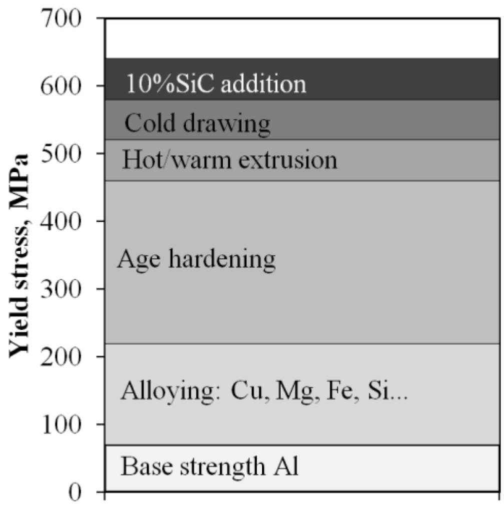


Fig. 6. Possible contributions to strengthening of aluminium

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