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COMPOSITES THEORY AND PRACTICE

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YIELD STRESS OF PM Al-10 wt.% SiC COMPOSITE AFTER EXTRUSION AND DRAWING

The yield and flow stress data for an Al-10% SiC composite and for its aluminium PM matrix after extrusion and drawing are reported. Preforms were manufactured by the cold pressing of RAl-1 aluminium powder and of its mixture with 10% SiC particles. They were extruded at 480ºC, with extrusion ratio λ = 4.2. No porosity was observed on longitudinal sections of the Al-SiC composite. The hardness and compressive mechanical properties of the materials were evaluated. The yield and compression strengths of the composite were higher than for the PM aluminium. After cold drawing with strain φ_r = 0.09, the yield stress of the extruded aluminium increases from the range of 74 to 80 MPa to the range of 115 to 118 MPa and at a 0.75 strain flow, the stress increases to 160 MPa. The average yield stress of the extruded composite is 93 MPa and drawing increased it to 135 MPa; at a 0.75 strain flow stress, it increased from 150 to 180 MPa. For both the aluminium and the composite, the critical compressive strains are higher than 0.75.

Keywords: **composites with an aluminium matrix, silicon carbide particles, extrusion, drawing, reinforcing, mechanical properties**

GRANICA PLASTYCZNOŚCI KOMPOZYTU Al-10% mas. SiC OTRZYMANEGO METODĄ METALURGII PROSZKÓW PRZEZ WYCISKANIE I CIĄGNIENIE

Przedstawiono wyniki badań wpływu odkształcenia kompozytu Al-10% mas. SiC w procesie ciągnienia na granicę plastyczności i naprężenie płynięcia oraz twardość. Porównawczo przeprowadzono również badania także dla aluminiowej osnowy. Materiał do badań otrzymano przez wyciskanie wyprasek z proszku aluminium RAl-1 oraz mieszanki tego proszku z proszkiem węglika krzemu SiC w ilości 10% mas. Wyciskanie realizowano w warunkach izotermicznych przy temperaturze 480ºC i ze współczynnikiem wyciskania λ = 4,2. Wyciskane próbki toczono ze średnicy 18 mm do średnicy 17,5 mm, a następnie przeciągano na średnicę 16 mm. Logarytmiczne odkształcenie obliczone ze zmiany średnicy wyrobu w wyniku ciągnienia wynosi φ_r = 0,09. Z wyciskanych i ciągnionych wyrobów pobrano próbki wzdłużne. Próbki ściskano z prędkością 0,15 mm/s. W wyniku ciągnienia nastąpiło umocnienie materiału zarówno próbek z aluminium, jak i z materiału kompozytowego Al-10%SiC. Granica plastyczności osnowy aluminiowej wzrosła o około 30 MPa, a naprężenie uplastyczniające z 160 do 180 MPa przy odkształceniu wynoszącym 0,75. Dla materiału kompozytowego efekt umocnienia jest większy: granica plastyczności wzrosła z 110 do 138 MPa, a naprężenie uplastyczniające, przy odkształceniu podczas ściskania wynoszącym 0,75, podwyższyło się z 150 do 180 MPa. Widoczne jest umocnienie osnowy aluminiowej w wyniku odkształcenia, a w kompozycie również wpływ obecności mikrometrycznych cząstek węglika krzemu na jej umocnienie. Własności wytrzymałościowe określone dla próbek pobranych na długości wyciskanych i ciągnionych wyrobów są porównywalne z wyjątkiem materiału w początkowej części wyrobów.

Słowa kluczowe: **materiały kompozytowe na osnowie aluminium, cząstki węglika krzemu, wyciskanie, ciągnienie, umocnienie, własności mechaniczne**

INTRODUCTION

To improve the stiffness, strength and useful properties such as wear resistance, composite materials reinforced with particles which do not react with the matrix are produced. For metallic matrix composites, MMCs, casting and the PM route are used. The hot forming of PM materials results in densification and also, after cold working of the matrix, strengthening due to the reinforcing particles, is in accordance with the Orowan rule. Processing using the forging and extrusion of composites obtained using the PM route are described in [1-3]. The effects of extruding Al-X% SiC on the density and mechanical properties have been reported [4]. Extruded products were densified to nearly theoretical density, but, to obtain better strengthening of the composites, cold processing is needed. The research concentrated on designing the chemical composition, structure and properties [4-6]. The increase in the yield stress of light materials gives a new possibility to develop them as construction materials. The influence of cold drawing on the yield stress of the extruded Al-10%

SiC composite is presented in this paper. The aim of the investigation was to obtain a light material with increased yield stress in comparison to the matrix. Hot extruded PM specimens were used for cold drawing. The compression test was used to obtain information about material strength.

EXPERIMENTAL PROCEDURES AND SIMULATION

Extrusion of PM Al and Al-10% SiC preforms

Preforms from aluminum powder RAl-1 and a mixture of its powder with 10% SiC particles were cold pressed at 80 MPa. The mass of the preforms was 75 g, diameter of 35.5 mm and their density ~1.95 g/cm^3. Extrusion of the preforms was carried out at 480°C on a hydraulic press, with a 90° die angle and 18 mm diameter. After heating at 480°C for 10 minutes, the specimens were extruded in isothermal conditions at the ratio of 4.2. The diameter of the extruded products was 18 mm. The shape of the extrusion die is shown in Figure 1. Changes in the force vs punch displacement for the Al and Al-10% SiC preforms during extrusion are shown in Figure 2.

The chemical composition of the preforms influenced the force-punch displacement relationship and the value of the extrusion force. The force during the extrusion of Al-10% SiC at a steady state of flow is ca. 30% higher than for PM aluminium. The microstructures of the extruded products were observed on longitudinal sections. The observation sites are shown in Figure 3a. Elongation of the aluminium grains appears in the sizing zone, and the flow line is visible. SiC particles are located on the grain boundary of the aluminium matrix and oriented along the flow line. After the flow of the material through the sizing zone of the die, the grains are oriented in the flow direction (Figs. 3c, d).

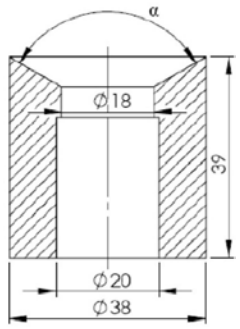

Fig.1. Extrusion die with ratio 4.2

Rys. 1. Matryca do wyciskania ze współczynnikiem 4.2

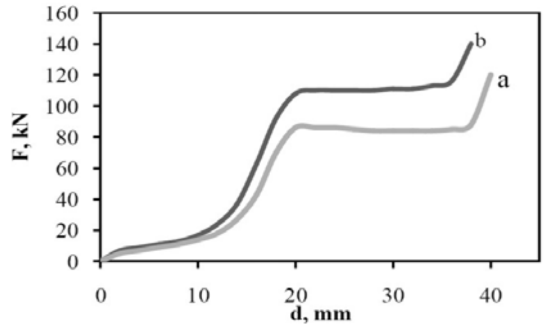

Fig. 2. Force F vs. punch displacement d during extrusion of preforms at 480°C with ratio λ = 4.2 for: a) RAl-1 PM, b) powder mixture Al-10% SiC

Rys. 2. Siła F w zależności od przemieszczenia stempla podczas wyciskania w temperaturze 480°C ze współczynnikiem λ = 4,2: a) wypraska RAl-1, b) wypraska z mieszanki proszków Al-10% SiC

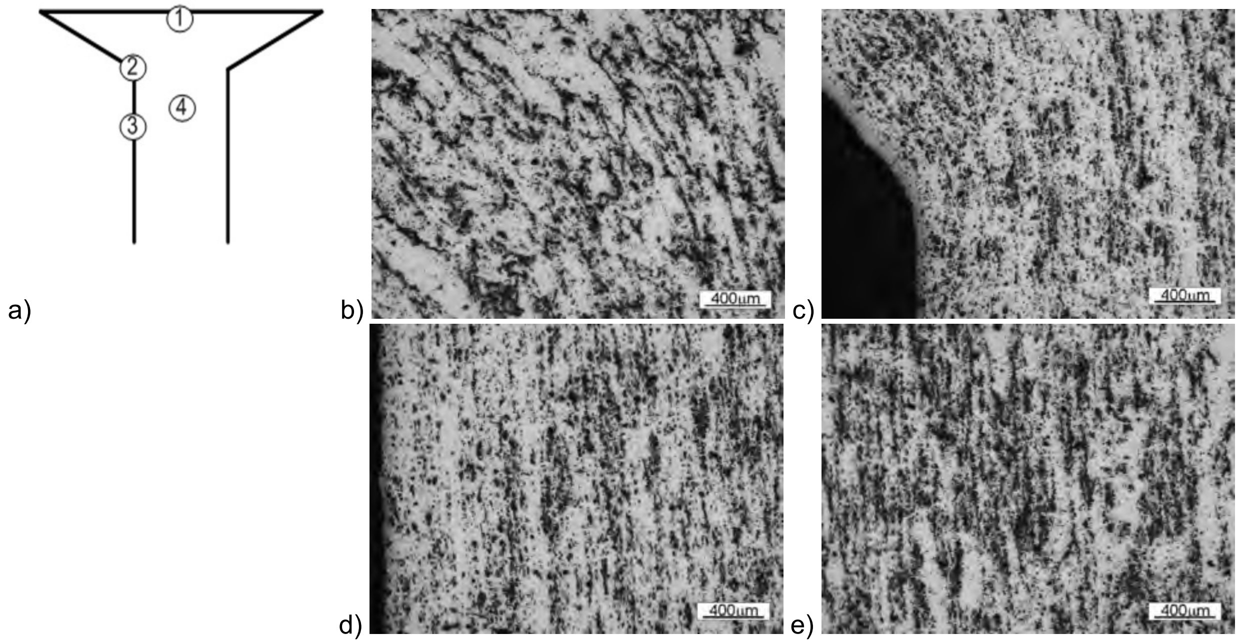

Fig. 3. Observation sites of micostructure on logitudinal sections of extruded Al-10%SiC material (at 480°C, extrusion ratio 4.2) (a), and the microstructures (b-e)

Rys. 3. Miejsca obserwacji mikrostruktury na przekroju wzdłużnym wyciskanego materiału Al-10% SiC (480°C, współczynnik wyciskania 4.2) (a), i mikrostruktura (b-e)

One part of the extruded samples was turned to a diameter of 16mm, and the second part to 17.5 mm and drawn to a diameter of 16 mm on a chain drawbench. In order to compare the material properties after extruding and extruding and drawing, the axial compression test was used.

Drawing of PM Al and Al-10% SiC extruded samples

The drawing of Al and Al-10% SiC specimens was performed on a drawing bench; the diameter of the drawing die was 16 mm (logarithmic strain φ_r was 0.09). The shape of the drawing die is shown in Figure 4. The force vs time during drawing is shown in Figure 5a for the PM aluminium and Figure 5b for the PM Al-10%SiC specimens, respectively. The drawing force is circa 3.5 kN higher for the Al-10% SiC specimens than for the specimens from aluminium.

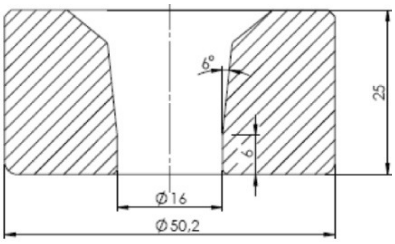

Fig. 4. Drawing die (17.5 mm->16 mm, λ = 0.09)

Rys. 4. Oczko do ciągnienia ze średnicy 17,5 na średnicę 16 mm (φ_r = 0,09)

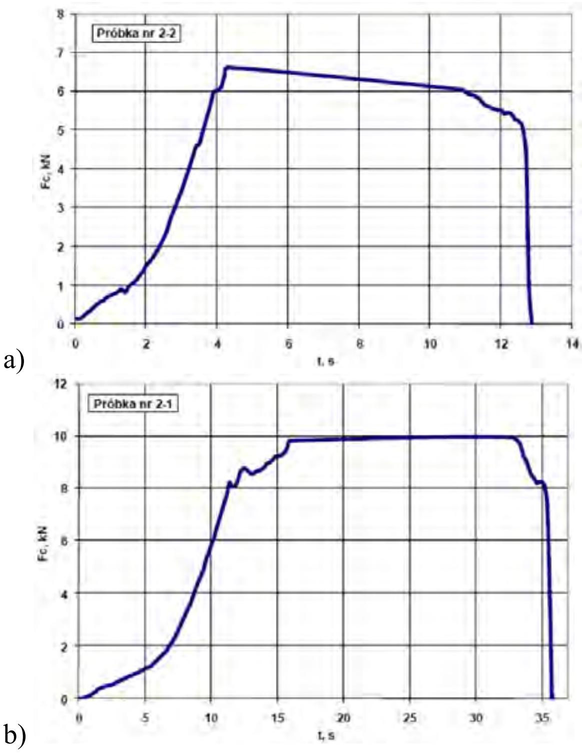

Fig. 5. Drawing force vs time for: a) Al specimen, b) Al-10% SiC specimen. Reduction of diameter from 17.5 to 16 mm (φ_r = 0.09)

Rys. 5. Siła podczas ciągnienia zmierzona dla: a) materiału Al, b) kompozytu Al-10% SiC. Zmniejszenie średnicy z 17,5 na 16 mm (φ_r = 0,09)

EXTRUSION SIMULATION

For the numerical simulation, the FEM program LARSTRAN Shape was used [7, 8]. The simulation was thermo-mechanical. The stress-strain relationship for aluminium was defined by the Hensel-Spittel equation [9]. The boundary conditions for the die were: punch velocity 0.17 mm/s, die and material temperature 480°C, friction coefficient between the die and the material 0.2. The calculated distribution of the equivalent strain and equivalent stress on longitudinal sections of the extruded product from PM aluminium is shown in Figure 6. In the deformation zone during extrusion, the equivalent strain value is in the range of 0.6 to 1.2 and the equivalent stress is in the range of 31 to 36 MPa.

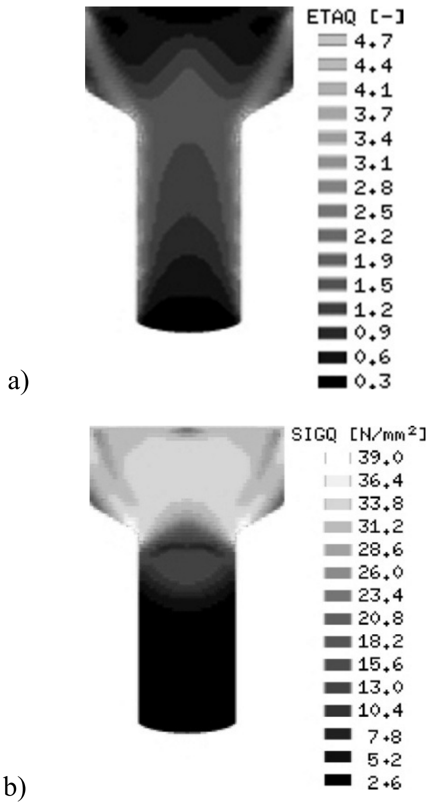

Fig. 6. Distribution of simulated: a) equivalent strain, b) equivalent stress in half time of calculation for extrusion products from PM aluminum at 480°C with extrusion ratio λ = 4.2

Fig. 6. Obliczony rozkład: a) intensywności odkształcenia i b) intensywności naprężenia w połowie symulacji wyciskania aluminium w temperaturze 480°C ze współczynnikiem λ = 4,2

DRAWING SIMULATION

The simulation was mechanical. The stress-strain relationships for the aluminium and Al-10% SiC composites were taken from the compression tests. The boundary conditions were: punch velocity 1 mm/s, die and material temperature 20°C, friction coefficient between the die and the material 0.05. The diameter was reduced from 17.5 to 16 mm. The distribution of the calculated equivalent strain on the longitudinal section of the specimens after drawing is shown in Figure 7.

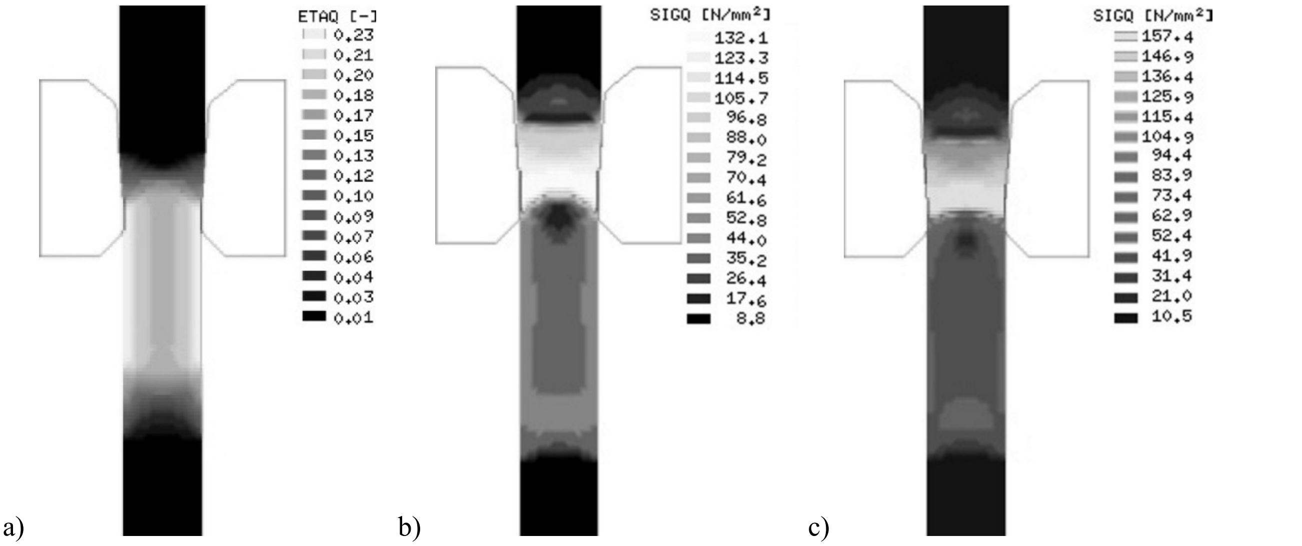

Fig. 7. Simulated distribution: a) of equivalent strain for drawing material and equivalent stress for: b) Al - material and c) Al-10% SiC material. Reduction of diameter from 17.5 to 16 mm

Fig. 7. Obliczony rozkład: a) intensywności odkształcenia w materiale ciągnionym i intensywności naprężenia: b) dla aluminium, c) dla kompozytu Al-10% SiC. Zmniejszenie średnicy z 17,5 na 16 mm

The equivalent strain after drawing was in the range of 0.19 to 0.24 in the zone from half the radius to the outer surface in both the Al and Al-10% SiC, and the equivalent stress has a value in the range of 106 to131 MPa and of 126 to 157 MPa, respectively.

COMPRESSION TESTING

The materials after extrusion and drawing were tested in uniaxial compression. The region from which the specimens were taken from the extruded products is shown in Figure 8. The slenderness ratio, h_0/d_0, was = 1. In the same way, specimens from the drawn materials were taken.

Fig. 8. Extruded sample with marked sites from which specimens were taken for compression testing

Fig. 8. Materiał wyciskany z zaznaczonymi miejscami do pobrania próbek do ściskania

The compression rate was 0.15 mm/s. The compressive yield stress was determined on specimens taken along the sample and is shown in Table 1.

The stress-strain relationships for the extruded material before and after drawing are shown in Figure 9 and in Figure 10. Comparison of the stress-strain curves for specimens taken from site 2 is shown in Figure 11.

TABLE 1. **Yield stress of extruded materials before and after drawing**

TABELA 1. **Granica plastyczności materiału wyciskanego i dodatkowo ciągnionego**

Material	Sample	Compresive yield stress, $\sigma_{0.02}$ [MPa]				
		Region from which the specimens were taken (see Fig. 8)				Average
		1	2	3	4	
Al extruded	I	76	76	72	72	77
	II	88	78	76	76	
Al+10% SiC extruded	I	102	102	98	98	93
	II	98	82	82	82	
Al extruded + drawing	I	119	119	117	X	115
	II	118	118	108	X	
Al+10% SiC extruded + drawing	I	140	136	116	X	135
	II	134	132	132	X	

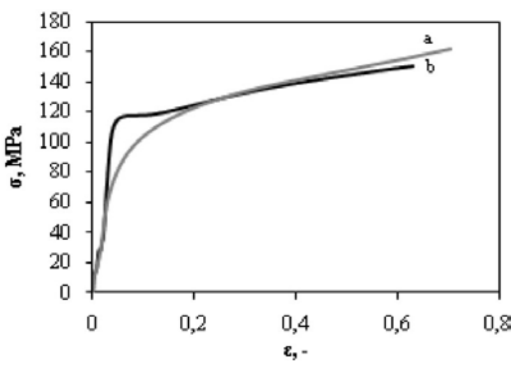

Fig. 9. Comparison of strain-stress relationships for PM aluminium: a) extruded, b) extruded and drawn ($\varphi_r = 0.09$) (Specimens taken from site 1, Fig. 8)

Fig. 9. Porównanie krzywych ściskania dla aluminium: a) po wyciskaniu, b) po wyciskaniu i ciągnieniu z odkształceniem $\varphi_r = 0{,}09$ (Próbki pobrano z miejsca 1, rys. 8)

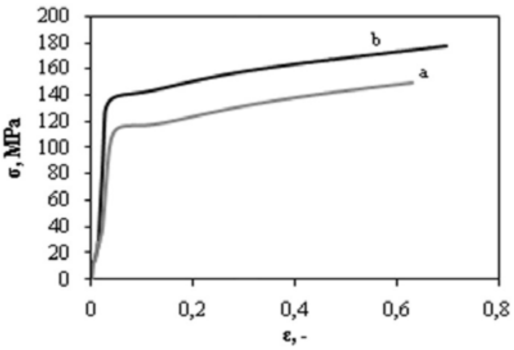

Fig. 10. Comparison of stress-strain relationships for Al-10% SiC material: a) after extrusion, b) after extrusion and drawn (φ_r = 0.09) (Specimens taken from site 1, Fig. 8)

Rys. 10. Porównanie krzywych ściskania kompozytu Al.-10% Si: a) po wyciskaniu, b) po wyciskaniu i ciągnieniu z odkształceniem φ_r = 0,09 (Próbki pobrano z miejsca 1, rys. 8)

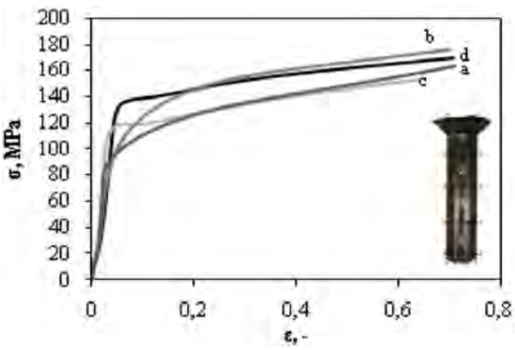

Fig. 11. Stress-strain relationships for extruded materials: a) Al, b) Al-10% SiC and extruded and drawn (φ_r = 0.09) c) Al, d) Al-10% SiC (Specimens taken from site 2, Fig. 8)

Fig.11. Zależność naprężenie-odkształcenie dla materiału wyciskanego: a) Al, b) Al-10% SiC i dodatkowo ciągnionego z odkształceniem φ_r = 0,09, c) Al, d - Al-10% SiC (Próbki pobrano z miejsca 2, rys. 8)

After extrusion, the yield stress for the Al PM material is in the range of 74 to 79 MPa and for the Al-10% SiC material in the range of 86 to 100 MPa. After drawing, it is higher and has a value of 114 to 118 MPa for the Al material and a value of 130 to 133 MPa for the Al-10% SiC composite.

CONCLUSIONS

Hot extrusion and drawing of Al and Al-10% SiC PM materials has shown a manufacturing possibility of obtaining products with nearly full density and useful strength properties.

These strengthening properties depend on the chemical composition of the preforms, the processing route and its parameters. As a result of cold drawing, sizing the product diameter and cold working of the matrix take place.

The value of the yield stress is nearly homogenous along the extruded products before and after drawing. The yield stress for the Al PM material is higher than of the extruded one by about 50% after drawing, and for Al-10% SiC by about 42%.

The distribution of simulated strain on longitudinal sections in the materials, calculated after drawing, confirms that cold working of the matrix appears in the zone near the outer surface.

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