HOT WORKABILITY AND MECHANICAL PROPERTIES OF AN ALUMINUM-SILICA COMPOSITE

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ABSTRACT: In this work a metal matrix composite was obtained by using aluminum powder and mineral silica fibers as reinforcement and a hot compression test was applied to evaluate the composite workability. The composite was obtained by hot extrusion of a previously pressed mixture of powder metal and fibers. In this method, the aluminum powder is mechanically mixed with 5% weight silica fibers and the aluminum/fibers mixture is conditioned in a protective aluminum shell. The hot extrusion of the shell in a 50:1 ratio enables the composite formation where the fibers are aligned with the extruded direction. The samples taken from the extruded bars were submitted to workability test and uniaxial tensile tests to evaluate their mechanical properties. SEM and optical microscopy were used to analyze the fracture surface induced by the tensile test and these results were compared with the microstructure deformation in the workability test, to define the fracture mechanisms.

KEYWORDS: aluminum matrix composite, mineral silica fiber, workability test, hot extrusion

1. INTRODUCTION

Very few works explored the use of silica as reinforcement element in aluminum or aluminum alloy matrix, due to the aggressive reactivity between these two materials [1]. Some previous works tried to use silica and aluminum without inducing interfacial reaction between them [2,3]. More recently, silica has been used as reinforcement in aluminum or aluminum alloys, but the reaction is intentionally induced until all the silica microstructure changes to an alumina composition interlaced with the metal phase [4,5,6].

The Powder Metallurgy process would just involve the stages of mixture, pressing and sintering of the materials. For the production of composites based on an aluminum matrix, this traditional form of process has not shown to be efficient, due to the oxide layer that covers the particles of the powder. The presence of this layer makes the diffusion process more difficult in a solid state sintering, and also in a liquid phase sintering It is known that secondary processing of discontinuously reinforced composites can lead to break up of whisker agglomerates, to the reduction and elimination of porosity, as well as improving bonding and mechanical properties. In this way, this secondary process allows the efficient breakage of the oxide layer in small particles which are dispersed easily in the aluminum matrix [7]. Extrusion has been used as the most common secondary processing operation because of its excellent preferential axial alignment of discontinuous fibers [8]. MMCs usually have poor workability compared with non-reinforced metals because of the presence of some amount of non-deformable particles or fibers in the microstructure. Unless an appropriate deformation process design is employed, fractures can occur during the consolidation process, like extrusion or forging.

In this work, mineral silica fibers were used as the reinforcement elements of a commercial aluminum powder matrix and the Al-5SiO_2 fiber composite was obtained. The process adopted to obtain the composites was hot extrusion after the fiber/metal mixture had been conditioned in a protective aluminum shell. Compressive hot tests were performed to evaluate the composite's workability by simulating a forging process.

2. EXPERIMENTAL PROCEDURE

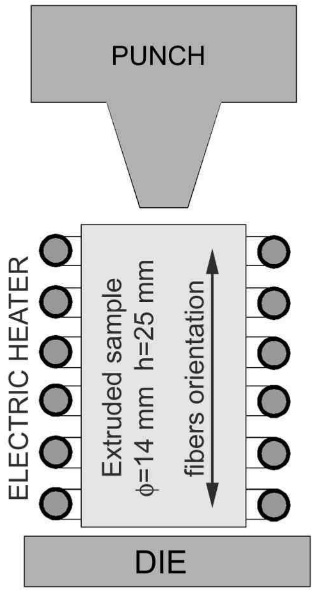

Fig. 1. Schematic diagram of the hot workability test in the longitudinal direction.

The Al-5SiO_2 fiber composite used in this study was prepared by a method previously reported [9]. In this method, mineral silica fibers *Silexil* (99.0% SiO_2 min) with average diameter 15.8 μm (Standard Deviation 3.2 μm) and average length 220 μm (SD 125 μm) were incorporated into commercially pure Al powder *Alcoa PO 101P* with average diameter 9.4 μm (SD 2.4 μm). The silica fibers were obtained from great natural geological deposits in Brazil and known as *spongilites*. Its use has been restricted in the last few years as a reinforcement material in the ceramics industry. The powder and silica fibers were mixed together in a conical blender until the mixture was homogeneous. This aluminum/fibers mixture was conditioned in a commercial aluminum cylinder by pressing at approximately 100 MPa to accommodate the largest amount of material in this recipient and both sides were covered with the same aluminum. After 4.5 hours at 450 ^{o}C in an electric furnace, the cylinder was extruded at 200^{o}C and its diameter was reduced from 100 to 18 mm.

From the extruded bar, samples of 14 mm diameter and 25 mm length were used hot indented to evaluate the composite's workability. The hot indentation was performed in a MTS test machine at 25^{o}C (room temperature), 300 and 400^{o}C using 0.1 mm/s strain speed with a maximum 19.6 KN force. The test was stopped when this force was achieved. The tests were performed in the longitudinal and transversal direction of the composite, according to the alignment of the fibers induced by extrusion. Figure 1 shows a schematic diagram of this test. The deformed samples were cut and polished to show the deformation lines caused by the test. To evaluate the mechanical properties of the composite, samples were taken from the extruded bars according to ASTM D 3552-77 and submitted to tensile tests at 0.2 mm/s rate. Cyclical tests of load and unload were done for accurate evaluation of the end of the elastic zone and the beginning of plastic deformation. The fracture surface obtained in the tensile test was analyzed by SEM and polished longitudinal sections were analyzed by optical microscopy.

3. RESULTS AND DISCUSSION

Figure 2 obtained from uniaxial tensile strain test shows the stress-strain curve for the fiber extruded composite Al-5SiO_2. The samples analyzed had a high UTS (134 MPa) relatively to an aluminum non-reinforced in spite of the small volumetric fraction of reinforcement (5%). The composite presented a high deformation before the failure (16.7%), bigger than others produced with the same volumetric fraction, but with different reinforcements, as SiC or alumina particles. The linear tensile strain and load-unload tests

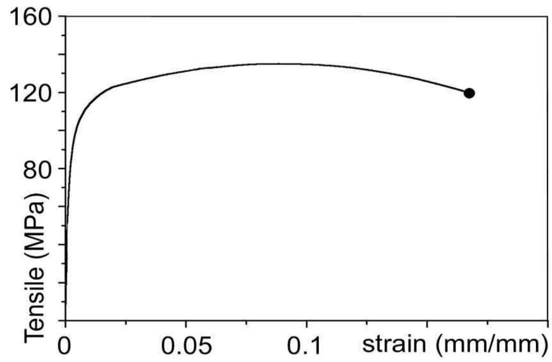

Fig. 2. Stress-strain curve obtained from Al-5SiO_2 silica fiber extruded composite

show that the E module remained the same of a commercial non-reinforced aluminum and that the small volumetric fiber reinforcement did not contribute to increase it.

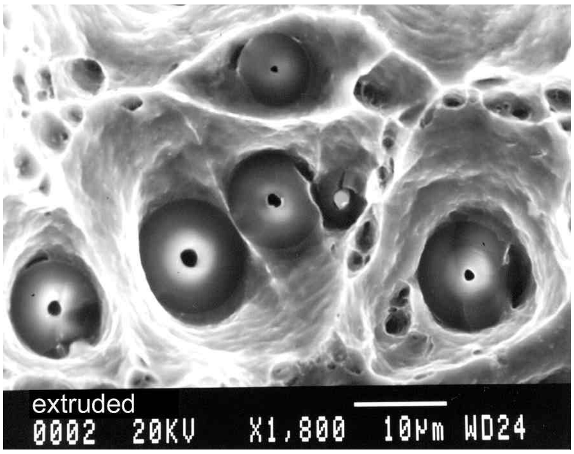

Fig. 3. SEM fractograph of tensile specimen showing no pull-out of fibers.

Figure 3 obtained from SEM at the fracture surface shows that the reinforcement fiber does not pull out and that a uniform plastic flow of the matrix is observed at the fracture surface. The ductile fracture behavior in the matrix is due to the improvement of microstructural densification and interface bonding, which is supported by dimples with fibers in the center, indicating the ductile behavior and necking of the matrix after the fiber failure.

Figure 4 obtained in an optical microscopy at the cross-sectional fracture surface, confirms the SEM observations as it can be seen clearly that necking and dimple formation are associated with fiber failure and the fracture moving inside the matrix until finding the fiber that absorbs the energy. The dimple morphology is according with elevated strain obtained in tensile strain tests performed.

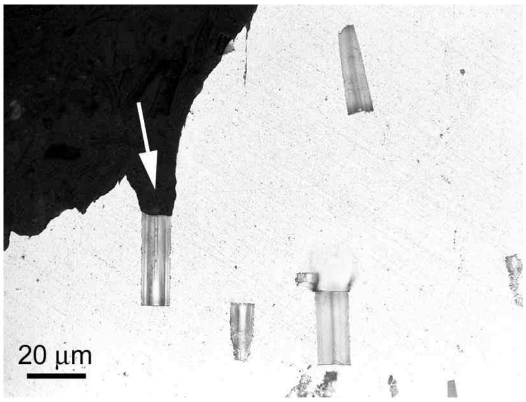

Fig. 4. Optical microscopy of the polished fracture surface showing a fractured fiber strongly inserted into the dimple

Figure 5 shows the appearance of samples submitted to workability test in the longitudinal and transversal sections. The transversal tests show that only the samples deformed at room temperature remained without failures. The others samples tested at 300 and 400^{o}C show fractures as indicated by the arrows at the external surface. The analysis of these samples indicates that the fracture did not initiate from cracks on the samples surface, and were caused by tensile stresses inside the aluminum matrix. The cracks on the surface did not propagate inside it because they were stopped by the fibers. Longitudinal sections of the samples did not show cracks in the region below the upper die. Samples with modified flow lines patterns did not show micro-cracks.

Samples deformed with axial load also did not show internal cracks even in the region below the upper die. However, it can be observed a non-uniform deformation that caused the samples barreling. Longitudinal sections of these samples showed flow lines aligned with the cracks formed inside the samples. These flow lines represent shear stresses caused by severe strains due to the motion of the samples during the tests. Future experiments need to hold the samples properly on the lower die to prevent this motion and promote a homogeneous deformation. The samples showed no superficial failures that could be responsible for the barreling. At this test direction, as the fibers were aligned with the flow lines, the fibers could not stop the cracks. The real reasons for this barreling and the fibers orientation with the flow lines remained unsolved with this test.

Figure 6 shows longitudinal sections taken from deformed samples submitted to workability tests at 25, 300 and 400^{o}C. These sections, when analyzed by optical microscopy, confirm that the cracks can only be found at the most external samples surface. The internal microstructures remained intact for all temperatures tested.

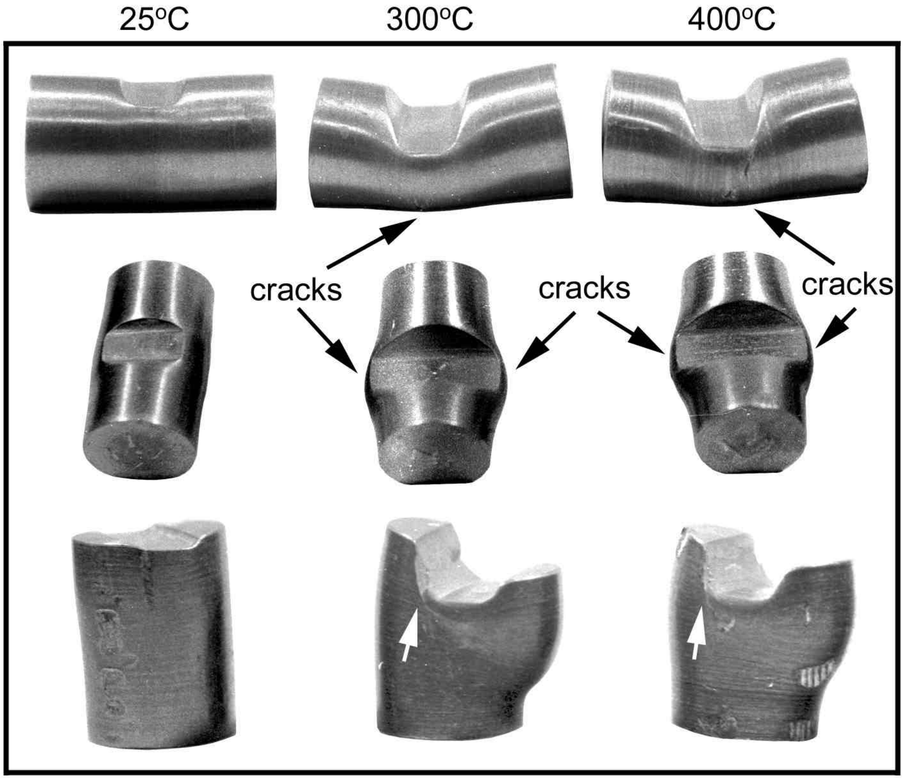

Fig. 5. Samples submitted to workability test in the transversal and longitudinal directions showing some cracks induced by the workability test

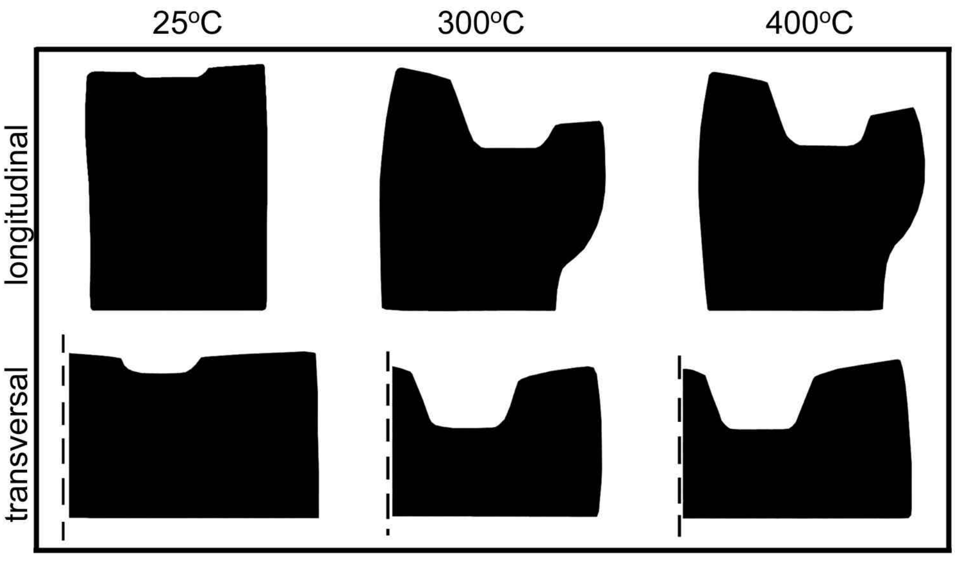

Fig. 6. Longitudinal sections taken from the center of deformed samples in the workability test showing the increase in deformation with temperature and the barreling formation induced by motion of the samples.

4. CONCLUSIONS

4.1 The Al-5SiO_2 short fiber composite were manufactured by hot extrusion under 50:1 ratio of previously mixture of mineral silica fibers and commercial powder aluminium. Microstructural observations revealed that the fibers align with the extrusion direction but the fibers fracture was severe.

4.2 The UTS of the extruded composite was improved to a greater degree, better than those of the non-reinforced matrix alloy but the E module remained the same.

4.3 Fractographs of tensile tested specimens shows a series of dimples, indicating the ductile fracture behaviour of the matrix, although the composites exhibited limited ductility on a macroscopic scale. The necking and dimple formation are associated with fiber failure and the reinforcement fibers does not pull out.

4.4 Samples submitted to hot workability test in the longitudinal and transversal directions show some fractures at the external surfaces. In the transversal test the fractures were stopped by the fibers but in the longitudinal tests they were not. The internal microstructure of all samples did not show cracks even in the region below the upper die.

REFERENCES

1. A.E.Standage and M.S.Gani, Journal of the American Ceramic Society, 50, 2 (1967) 101.
2. A.A.Baker and P.W.Jackson, Glass Technology, 9, 2(1968) 36.
3. D.Cratchley and A.A.Baker, Metallurgia (1964) 153.
4. M.C.Breslin, J.Ringnalda, J.Seeger, A.L.Marasco, G.S.Daehn and H.L.Fraser, Ceramic Eng. Sci. Proceedings, 15, 4(1994) 104.
5. W.Liu and U.Koster, Journal of Materials Science Letters, 15(1996) 2188.
6. V.M.Kevorkijan, Composites Science and Technology, 59(1999) 683.
7. E.A.Feest and J.H.Tweed, Powder Metallurgy – An Overview, The Institute of metals Series on Powder Metallurgy, (1991) 267.
8. C.A.Standford-Beale and T.W.Clyne, Composites Science and Technology, 35(1989) 121.
9. E.N.Gregolin, R.G.Santos and H.Goldenstein, Key Eng. Materials 189-191 (2001) 529