Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 54 ISSUE 1 September 2012

Processing and properties of AA7075/porous SiO_2-MgO-Al_2O_3 composite

M.H. Robert*, A.F. Jorge
Faculty of Mechanical Engineering, University of Campinas, SP, Brazil
* Corresponding e-mail address: helena@fem.unicamp.br

Received 11.07.2012; published in revised form 01.09.2012

Materials

ABSTRACT

Purpose: the work presents a new composite based in Al matrix reinforced with porous, lightweight and low cost SiO_2/MgO/Al_2O_3 ceramic particles. The new material can present a unique combination of properties: those related to metal/ceramic composites and still associating some characteristics of cellular materials, as the low density and high plastic deformation under compression stresses.
Design/methodology/approach: processing technique involves the infiltration of AA7075 alloy in the semisolid thixotropic state into a layer of porous ceramic particles. Products were analyzed by X-ray tomography, optical and electronic microscopy to observe microstructure and metal/ceramic interfaces. Density was measured by He picnometry; semi-static compression tests were performed to evaluate the deformation ability of the material. Thermal properties were theoretically evaluated.
Findings: concerning the production method, thixoinfiltration is a feasible processing route, with no difficult control of parameters and does not rely on specific and onerous equipment. Moreover, it is flexible to different alloys. Concerning the product, low density composites can be produced with good dispersion of reinforcement and reliable internal quality; this material presents a plateau of plastic deformation at low stresses under compression, signalizing a potential application as energy absorbers. Theoretical simulations show also good thermal insulation ability.
Research limitations/implications: as a new product, the full characterization of properties of the new composite is still to be achieved. Therefore, the full potential of commercial application is to be determined. The product can present limitations for application involving tensile stresses due to poor metal/ceramic interfaces.
Practical implications: the thixoinfiltration can represent an alternative, low cost processing route for low density composites. The new composites presented are low weight and low cost material, presenting a unique combination of properties which can bring a whole new application field, as low cost, low density components for energy absorption and thermal insulation.
Originality/value: both the processing route and the material produced – a low density metal/ceramic composite, using porous ceramic particulates as reinforcement, are new concepts under development by the proposing group at FEM/UNICAMP
Keywords: Composites; Cellular material; Low density composites; Thixoforming

Reference to this paper should be given in the following way:
M.H. Robert, A.F. Jorge, Processing and properties of AA7075/porous SiO_2-MgO-Al_2O_3 composite, Journal of Achievements in Materials and Manufacturing Engineering 54/1 (2012) 7-15.

1. Introduction

New demands in modern engineering very often have to face difficult challenges in the area of materials to fulfill specific requirements like physical, mechanical, etc., properties for particular purposes. Composite materials, in particular metal matrix reinforced with ceramic fibers, whiskers or particulates, came out in the past 50 years, and find today a well established market. With a range of properties combining those of the metal matrix like plastic deformation ability with those typical of ceramic materials like low thermal and electrical conductivities and high hardness, MMCs have been utilized in different industrial areas as wear resistant material, components for high temperature applications, etc.

In some applications as structures for high temperature exposure, in spite of being successful used, the high weight of MMCs can be a limitation. High costs of fibers, whiskers, etc. are other usual barrier for wider industrial applications of MMCs.

In the last two decades, another kind of material have been under increasing development and commercial utilization in different sectors of the economy such as building and architecture, mechanical, chemical industries: cellular metallic materials. These materials are highly porous, with relative density lower than 0.3, and present an interesting combination of properties, as low weight, high impact absorption, damping properties, sound and thermal insulation, etc [1-3]. In addition, cellular metals can be classified, according to the Rio summit in 1992, as an eco-material category 4 – Materials for society and human health, sub-category III.b - Materials for reducing human health impact [4].

Cellular structures may present different arrangement of empty space and metallic walls delimitating them; such arrangement is called the architecture of the material. Most of the cellular metals lye in two categories: sponges (open and interconnected cells) and foams (closed gaseous cells). A particular class of foam is the syntactic foam, presenting hollow, rigid structures as cells [5]. A typical example of syntactic foam is Al containing an array of hollow glass microspheres which result in low relative density; for example, in the order of 0.3-0.4 [6].

A new syntactic foam can be considered if the material to produce the internal cells are low density, porous particulates, instead of totally hollow constituents. This material, a syntactic filled-cell foam, is in fact a low density composite, and therefore could present some properties of conventional foams associated with typical properties of MMCs [7].

Several processing routes are already available for the production of cellular metals and also for metal matrix composites, some based on simple concepts and involving simple operational methods and others dealing with complex techniques which may present difficulties related to processing control.

As shown by the authors in previous works, SSM technology has proved suitable to produce cellular Al alloys by infiltration of the metal in the thixotropic semi-solid condition into a porous pre-forms of removable space holder particles, resulting in open-cell material [6,7,8]. SSM also has already been used to produce MMCs based on Al alloys reinforced with SiC particles [9].

The present work aims to contribute to the development of a new material, a lightweight metallic composite with low cost reinforcement (porous ceramic particulates), produced by an innovative technique which deals with SSM technology. The use of SS metals implies in lower temperatures when compared to liquid processing, resulting in higher operational control and costs savings. The main characteristics and physical / mechanical properties of the composite based on AA7075 alloy reinforced with low density, porous SiO_2-MgO-Al_2O_3 are investigated.

2. Experimental procedures

The alloy AA 7075 was used as matrix; expanded lamellar ceramic particulates, commercially known as vermiculite, were utilized as reinforcing material.

AA 7075 alloy presents high mechanical properties among Al alloys, finding important application in the aeronautical field. The alloy used in the experiments presents the following composition (in weight): 5.1% Zn, 2.2% Mg, 1.5% Cu, 0.2% Cr.

Vermiculite, used as discrete, irregular particles is a natural magnesium-aluminum-iron silicate with lamellar structure. This mineral occurs in nature highly hydrated; heating promotes gas formation from entrapped water present within its layers causing expansion and resulting in a porous, low density material.

In the expanded condition the vermiculite presents density ranging from 0.08 to 0.14g/cm^3. The characteristic layered configuration of this material is shown in Figure 1.

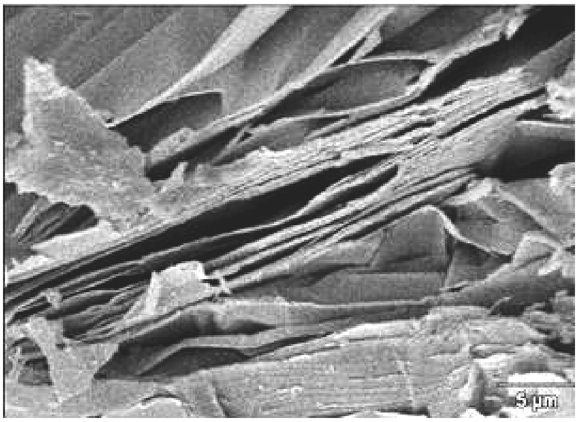


Fig. 1. General aspect of the expanded vermiculite particulates used as reinforcing material

Table 1.
Composition of the vermiculite particles used in the experiments (%wt)

SiO_2	MgO	Al_2O_3	Fe_2O_3	Na_2O
38 ~ 46	16 ~ 35	10 ~ 16	6 ~ 13	5.6 ~ 4.6

CaO	TiO_2	H_2O	K_2O	Others
1 ~ 5	1 ~3	8-16	1 ~6	0.2 ~12

Chemical composition of vermiculite used in the work is presented in Table 1.

It can be observed the lamellar layered structure of the vermiculite, with free empty volume within the lamellae, which makes the structure highly compressible.

In the experiments two groups of particles were employed, classified according to their average dimensions as: fine (F) - with sizes ranging from 1.6 to 3.15mm, and coarse (C) - with sizes from 3.15mm to 5mm.

As the manufacturing technique to produce the composite involves the metallic alloy in the semi-solid state, it was necessary to analyze previously the thixoforming windows of the AA7075 alloy, it meaning the temperature range within the processing in the semi-solid state is controllable. *Solidus* and *liquidus* temperatures (T_s and T_l), and the variation of liquid fraction with temperature (f_l x T) in the solidification range were determined by differential scanning calorimetry (DSC). Thermodynamic simulations using a commercial package also helped to identify transformations temperatures.

The manufacturing technique employed to produce the composites was as follows: a certain amount of loose ceramic particles, selected according to their classified dimensions, was placed in a mould with cylindrical geometry and covered with a plate of the alloy. A mass ratio of 17:1 of the alloy to the vermiculite particles was used in all the experiments. The alloy was used from hard deformed condition, thus presenting fine, elongated grains with average dimensions around 13μm width x 170μm long.

The assembly was heated to a pre-determined temperature within the solidification range of the alloy to promote the formation of the thixotropic metallic slurry; as the required temperature was reached, compressive uniaxial stress was applied to promote the infiltration of the semi-solid into the layer of ceramic particles. A conventional servo-hydraulic press was used for this operation. Heating temperature was defined to promote liquid fraction in the order of 50% in the thixotropic semi-solid. Vermiculite is stable and does not interact with the semi-solid metal in the processing conditions. Temperature and applied forces were monitored throughout the operation.

General quality of obtained products was verified by X-ray tomography, which also helped to analyze the reinforcing particles distribution in the volume of the obtained samples. Images of parallel sections were taken each 1.5mm.

Density of the products was determined by He picnometry.

Electronic microscopy (MEV) was used to analyze the final structure of the metallic matrix in the composites produced as well as the ceramic/metallic interfaces.

Mechanical properties under compression were determined by uniaxial semi-static tests using a conventional servo-hydraulic equipment, at room temperature.

Thermal conductivity of the obtained products was estimated by theoretical calculations, considering different models from the literature.

3. Results and discussions

3.1. Processing aspects

Results of DSC analysis to identity phase transformations in the alloy related to temperature are presented in Figure 2. It is also presented in the same figure, the liquid fraction variation with temperature (f_l x T).

The main peak observed is related to the melting of α- phase. In the cooling cycle, not presented here, a small endothermic peak was observed around 470-475ºC, related to the formation of the intermetallic phases M ($MgZn_2$), T (AlCuMgZn) and S (Al_2CuMg).

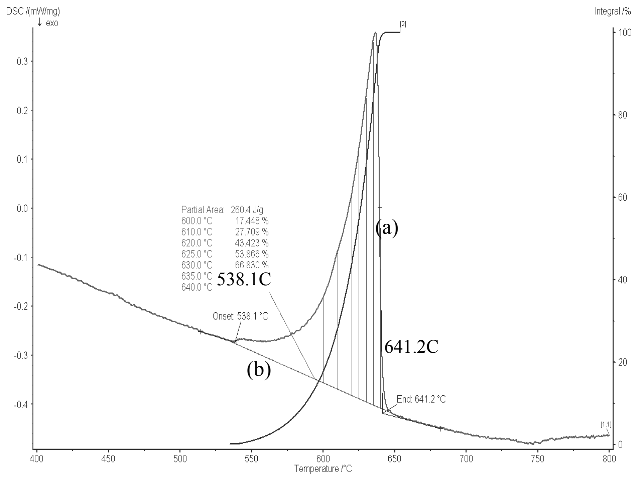


Fig. 2. Results of DSC tests for AA 7075 alloy. (a) energy variation x T; (b) f_l x T. Heating cycle at 5ºC/min

Liquid fraction variation with T presents higher slope from around 600ºC to the end of the melting at around 640ºC, when f_l=100%. As DSC experiments are highly sensitive to the conditions considered, simulations were carried out to help the identification of phase transformations and the variation of f_l x T, in order to properly define the conditions for the infiltration of the semi-solid AA7075 alloy used in the work to produce the composites. Results of thermodynamic simulations, using a commercial package, for the considered alloy are presented in Figure 3.

It can be observed more clearly the initial stages of liquid formation occurring at around 470ºC due to the melting of intermetallic phases, generating around 8 to 10% liquid. The liquid fraction increases slowly as temperature rises to circa 575ºC, as different intermetallic phases in the system melt; at this temperature, the slope of the curve f_l x T increases more significantly due the melting of the main primary phase (α-phase). The onset of the melting is observed at 637ºC.

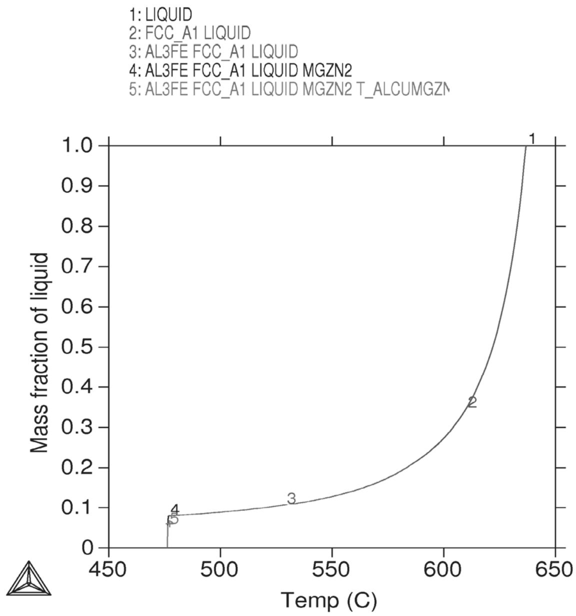
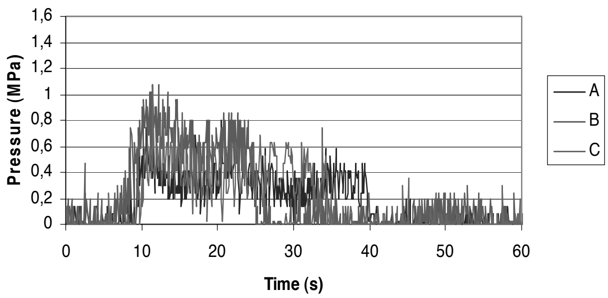


Fig. 3. Variation of f_l x T for the AA 7075 alloy, according to thermodynamic calculations using a commercial package (Thermocalc[R]). Scheil condition

a)



b)

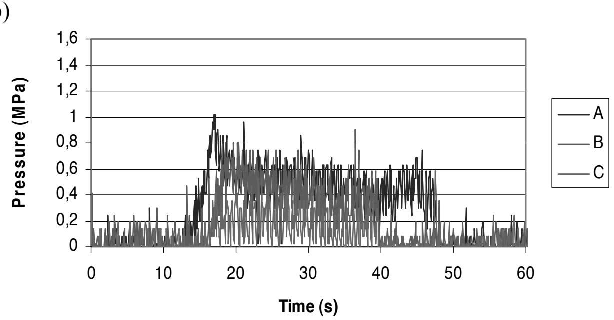


Fig. 4. Variation of P x t during filling of pre-forms of: (a) fine; (b) coarse vermiculite particles. Three repetitions (A, B, C)

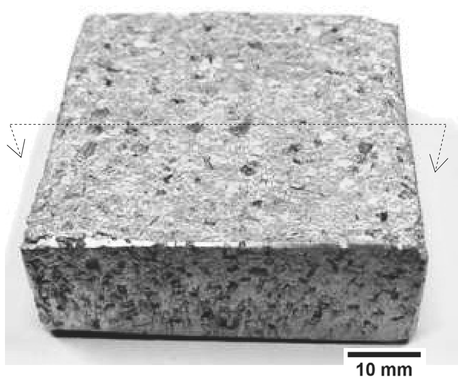
According to these results it was decided to produce semi-solid by heating up the alloy to 625ºC. At this temperature, liquid fraction must be 0.55. By holding the alloy at this temperature for 5min spheroidization of the solid α phase is promoted, through recrystallization/detachment mechanisms, and a thixotropic slurry with appropriate viscosity to promote thixoinfiltration is achieved.

Indeed, the semi-solid material produced in such condition presented globular solid phase (α) with globules diameter around 160μm. Due to the high flowing behavior of the thixotropic material, a complete infiltration into porosities of the pre-forms was achieved at low values of applied pressures. Infiltration pressures required were in the order of 0.4 - 0.6 MPa; these values are low enough to prevent compression of the ceramic particle in the pre-forms. As the vermiculite particles were loose in the forming die, they could move and accommodate during filling, keeping the pressure almost constant during the processing, as shown in Figure 4 for several tests. Pre-forms of fine particles tended to require higher pressures, due to the higher facility of accommodation, leading to smaller empty spaces to be filled.

3.2. AA7075/SiO_2-MgO-Al_2O_3 products: general and macroscopic aspects

Figure 5 presents general aspect of a typical product obtained by infiltration of semi-solid AA7075 into a pre-form of vermiculite particles. In the transversal section it is possible to observe the internal reinforcement distribution into the matrix: even though the particles are located and orientated randomly in the metallic matrix, the material can be considered reasonably homogeneous in a macroscopic scale.

a)



b)

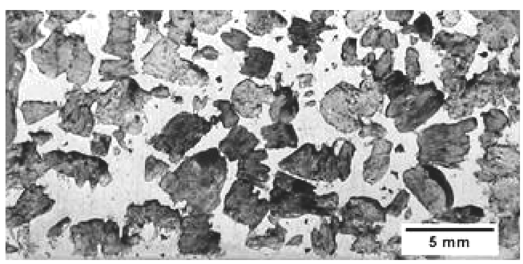


Fig. 5. Typical sample produced by thixoinfiltration of AA7075 into a layer of fine vermiculite particles; (a) general aspect; (b) transversal section

There is no evidence of deformation of the ceramic particles by the applied pressure required for the infiltration of the semi-solid metal: the vermiculite particles in the composite are similar to those in the raw material.

All the samples produced were analyzed by X-ray tomography to observe the internal quality, particularly the presence of defects related to imperfect metal infiltration.

Figure 6 shows X-ray tomography images of typical samples of composites produced with fine or coarse vermiculite particles. The metallic matrix shows in the images as a white structure, while the reinforcement particles are dark (almost transparent to the X-ray). Results indicate good internal quality of the product, given by the ability of the semi-solid to infiltrate evenly in the voids among the reinforcing particles. No significant lack of metal infiltration was detected in any of the produced samples. The material can be considered reasonably homogeneous in a macroscopic scale.

a)

b)

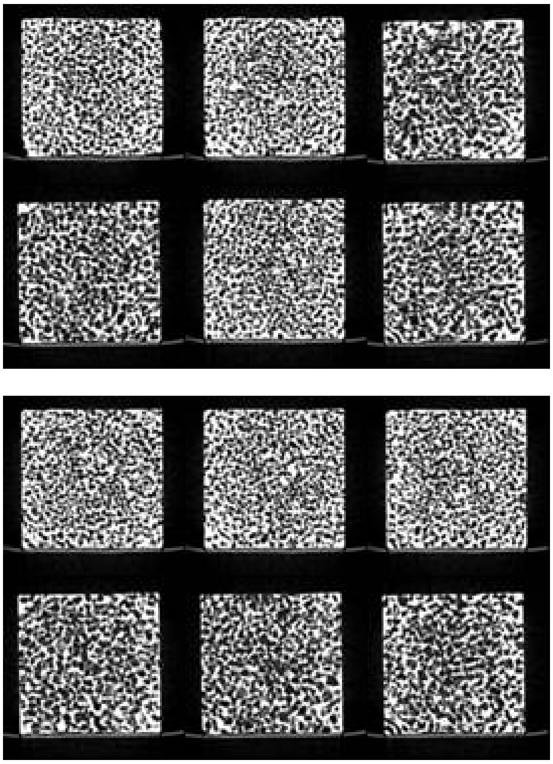


Fig. 6. X-ray tomography images of parallel planes of typical samples of AA7075 matrix MMC, produced by thixoinfiltration into (a) fine, (b) coarse reinforcing vermiculite particles

The volume fraction of the reinforcing constituent in the composite material produced was determined by image analysis of several transverse planes in the samples. Average values of 0.60 (60%) were obtained for composites produced from coarse or fine SiO_2-MgO-Al_2O_3 particles. No significant dispersion of the average value condition was observed, indicating a good distribution of the particles throughout the volume of the composite samples. It was not observed agglomeration of particles.

The infiltration of semi-solid material into a layer of loose particles allowed their movement and accommodation as the metal filled the mould. The presence of the solid phase in the metallic slurry prevented the agglomeration and fluctuation of the light vermiculite particles and was a positive factor to promote their good dispersion in the final product.

3.3. AA7075/SiO_2-MgO-Al_2O_3 products: microscopic aspects

Figure 7 shows SEM images of the produced AA7075/SiO_2-MgO-Al_2O composites, showing both the metallic matrix structure and the vermiculite particles.

It can be observed in general good infiltration of the metal into the pre-form of reinforcement particles. The low viscosity of the thixotropic semi-solid metal promoted a tight coupling between matrix and reinforcement, with the alloy penetrating into free regions among particles and even filling irregularities in their external surfaces. As some particles presented large open porosities (with the magnitude of tenths of millimetres) in the direction perpendicular to their expansion axis, the alloy was able to infiltrate into those open porosities at some extent, resulting in a mechanical interlocking between the metallic matrix and the reinforcement material, as observed in the figures.

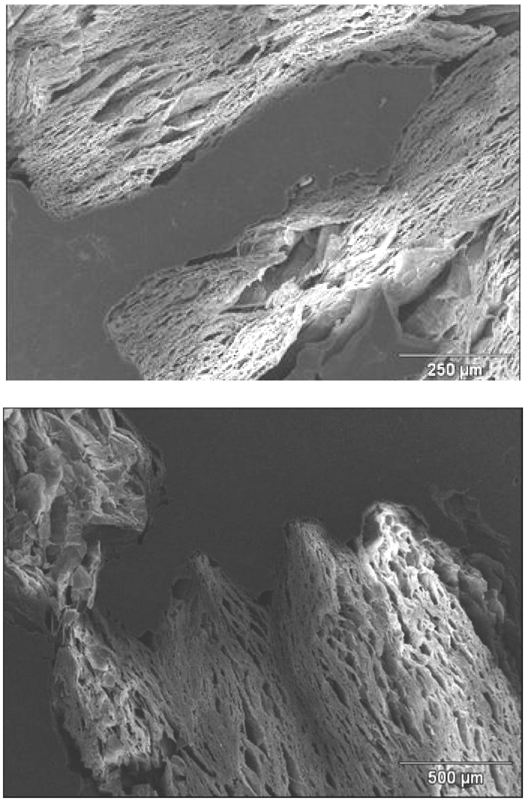


Fig. 7. SEM images of a section of a typical AA7075/SiO_2-MgO-Al_2O_3 composite produced by thixoinfiltration. SS metal can penetrate into the particle of porous vermiculite

It can also be observed that apparently the vermiculite particles did not suffer damage by the infiltration processing, as they look similar to the original condition.

Figure 8 shows the microstructure of the metallic matrix; it is possible to observe that the primary phase presents fine, equiaxial dendrites, with average dimensions around 230μm. Boundaries are occupied with also fine eutectic phase. This structure is not a typical thixotropic structure, where the primary phase presents globular morphology. Considering that the slurry used for infiltration presented globular α phase with dimensions around 160μm, as mentioned previously, what is observed now in the final product must be a result of the growth of the original globules after infiltration. As the reinforcing particles are ceramic material, the solidification rate of the metal among them could be low enough to promote growth of the original globules and to develop a tendency to the dendritic morphology. Another possibility is the occurrence of separation of liquid from the slurry during infiltration; this liquid would solidify with the typical dendritic morphology for this alloy.

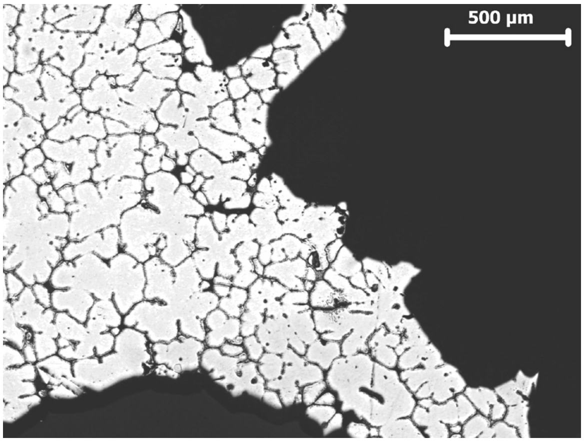


Fig. 8. Microstructure of the metallic matrix in the AA7075/SiO_2-MgO-Al_2O_3 composite produced. Optical microscopy

However, no significant liquid segregation during infiltration was observed as the structure throughout the material was similar to the one shown in the Figure and no region of α phase concentration associated with lack of eutectic phase could be observed within the material. Such would be the case of significant segregation of liquid from the flowing front of the SSM during infiltration.

3.4. AA7075/SiO_2-MgO-Al_2O_3 products: density

Figure 9 shows values of the average relative density of the AA7075/SiO_2-MgO-Al_2O_3 composites, for both groups of particles employed, coarse and fine.

Low relative densities were obtained, around 0.4 (~ 40% of the density of the alloy without reinforcing particles), which means a significant decrease in the density in the material. Those values are coherent with the reinforcement content in the composite, according to the law of mixtures.

Results show a slight tendency of higher relative densities in the composites produced with coarser vermiculite particles, which can be attributed to better metal infiltration within the free spaces of the coarser particles.

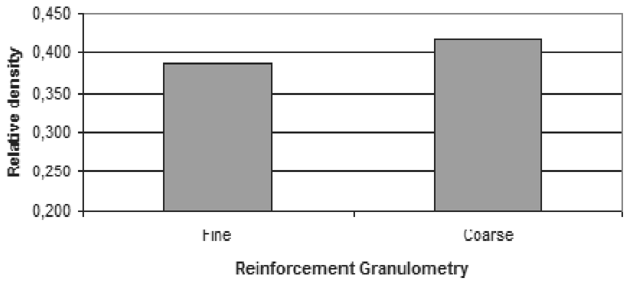


Fig. 9. Relative density of the AA7075/SiO_2-MgO-Al_2O_3 composite produced

These values of relative density of the Al-vermiculite composites are not far from those of typical densities of Al syntactic foams, like those produced by infiltration of the metal into pre-forms of hollow glass spheres obtained by Robert [6].As the Al-vermiculite composite produced presents a second constituent with low density and high compressibility, the material could be classified as syntactic foam containing partially filled cells. Therefore, some of the properties of cellular metals, particularly metallic foams, can be present in the low density AA7075/SiO_2-MgO-Al_2O_3 composite produced: such as high plastic deformation at relatively low and constant stresses and high energy absorption in compressive mechanical solicitation.

3.5. AA7075/SiO_2-MgO-Al_2O_3 products: behavior under compressive stresses

As the composites produced present low density and a component (the porous reinforcement) which is compressible, it can be pertinent to compare their properties under compression with those of metallic cellular material. Figure 10 shows the typical stress-strain behaviour of cellular metals as already established [10-11]. Deformation curves show three distinct regions: a short period of elastic deformation followed by a long plateau of plastic deformation with negligible stress increase due to the collapse of the porous inside the structure, and a final stage, after densification of the material, when further deformation requires significant stresses.

The mechanical behaviour of the AA7075/SiO_2-MgO-Al_2O_3 composites produced with fine and coarser vermiculite particles were evaluated by semi-static compression tests. Typical results are shown in Figures 11 (a) and (b) which presents stress-strain curves obtained respectively for composites with fine and coarse vermiculite particles. Results for two different samples of each condition are shown, with one of them (dotted line) related to a test which was interrupted before the end of densification. Numerical values of some parameters are presented in Table 2.

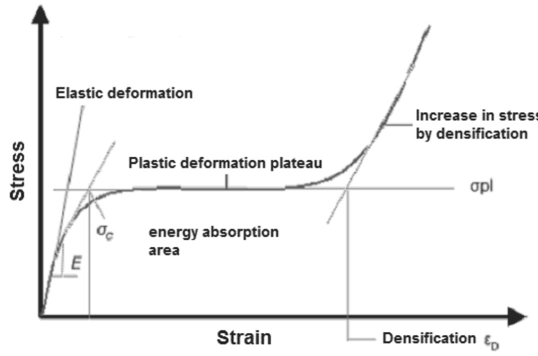


Fig. 10. Typical stress x strain curves of cellular metallic structures under compression

It can be observed that the resulting stress-strain curves show a deformation plateau at low values of stress, as a cellular material, for all samples tested. The overall behaviour of the stress-strain curves is similar for both types of composites.

a)

b)

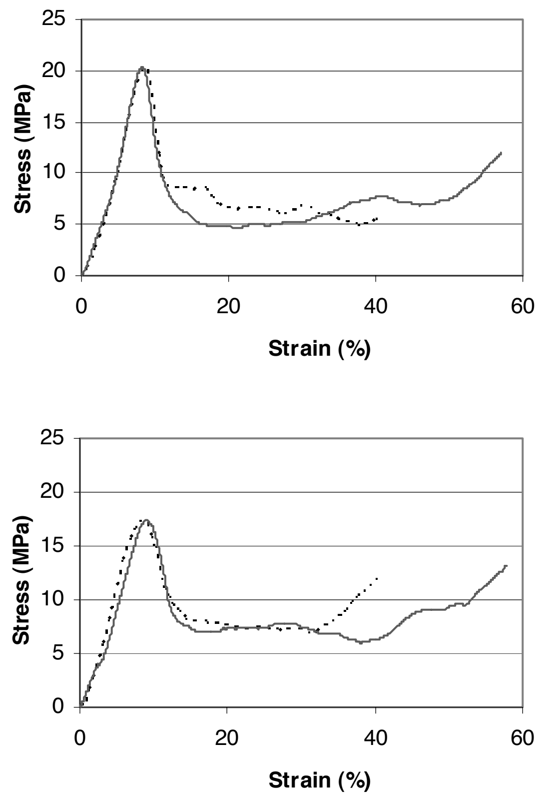


Fig. 11. Stress x strain curves in semi-static compression tests of AA7075/SiO_2-MgO-Al_2O_3 composites containing reinforcing particles with different sizes: (a) composite with fine vermiculite particles; (b) composite with coarse vermiculite particles. (Results for two different samples tested for each condition are shown. The tests represented by dotted lines were interrupted before onset of densification stage)

Table 2.
Mechanical behavior under semi-static compression tests of the AA7075/SiO_2-MgO-Al_2O_3 composites produced

Rel. density (ρ_{comp}/ρ_{bulk})	σ_c (MPa)	σ_{pl} (MPa)	EN (J/g)	ε_D (%)
0.39 (fine)	20.1	7.0	4.14	56
0.44 (coarse)	19.3	8.0	3.86	48

σ_c = compression stress; σ_{pl} = average stress in the plateau region; EN = total absorbed energy to the end of densification; ε_D = total deformation at the end of densification.

Curves present an initial region of nearly linear variation of stress x strain, with high slope, defining the elastic region. The stress rises up to a peak value, which is considered the compression stress (σ_c) for these materials. After that, an important drop in the stress level occurs, followed by a high plastic deformation without significant increase in the required stress. At this point the less resistant material starts to deform - particles of vermiculite starts to present plastic deformation by densification of the lamellar structure.

The value of the plateau stress (average stress during plastic deformation) is far higher than the value of the compression stress. That significant difference between the peak and plateau suggests the occurrence of rupture of eventual thin metallic walls around ceramic particles; in this stage, the presence of the reinforcement acting as a damping element can inhibit the failure of the structure.

The plateau stress is well defined, with a considerable amount of plastic deformation sustained at low stresses.

Tests for different samples in the same condition (presenting fine or coarse particles of the ceramic material) presented good coincidence of results. Typical results shown in Figure 11 for two samples produced in the same condition indicate coincidence of the curves, mainly in the elastic region. In the plastic region perturbations arise due to the complex deformation mechanism, involving both densification of the porous ceramic constituent and plastic deformation and also to eventual fracture of the metallic phase. Fracture in the microstructure of thin metallic layers among the reinforcing particles would promote reduction in the stress level, resulting in the fluctuation observed in the plateau region. This instability of the stress in the plateau region is also very often observed in cellular metals.

During the plateau, the porous constituent is squeezed and suffers densification. Most of the energy is absorbed by this deformation. At around 45-55% of plastic deformation, stresses required increases significantly, due to the deformation of the metallic walls.

The dimension of reinforcing particles in a composite, for a specific volume fraction, is an important architectural parameter once influences the metallic mass distribution. Therefore, it can influence the mechanical behaviour of the material as a whole, and consequently its suitability for a specific application. Finer vermiculite particles tend to promote better mass distribution than coarse particles, which can be reflected in the mechanical behaviour of the composite. It is possible to observe that the influence of the dimension of the reinforcing particles, in the investigated range, although not too significant in the material behaviour, shows a tendency to higher values of the plateau stress and lower values of deformation when coarser particles are employed. As mentioned before, in this case also the density tends to be higher, which would be responsible for the higher requirement for deformation of the composite.

Results on calculations of absorbed energy during plastic deformation show significant values: the densification of the ceramic particles used as reinforcement gives to the composite a feature which is characteristic of a cellular material. As a result of the higher deformation observed for the composite with fine particles of vermiculite, the absorbed energy in this case tends to be higher than the energy absorbed by the composite with coarse reinforcing particles.

3.6. AA7075/SiO_2-MgO-Al_2O_3 products: theoretical evaluation of thermal properties

The produced low density composites had their thermal behavior estimated by using theoretical modeling; three different models were used to calculate the thermal conductivity of the materials.

At first, two models commonly employed to estimate the thermal conductivity of particle-filled composites, from classical models of Maxwell [12] and Russell [13]. Maxwell's model based on potential theory calculates the thermal conductivity of randomly distributed and non-interacting spheres in a homogeneous medium and is given by:

$$k_c = k_m \left[\frac{k_f + 2k_m + 2\phi(k_f - k_m)}{k_f + 2k_m - \phi(k_f - k_m)} \right] \tag{1}$$

where:
k_c = conductivity of the composite;
k_m = conductivity of the metallic matrix;
k_f = conductivity of the reinforcement;
ϕ = volume fraction of reinforcement.

Russel's model calculates the thermal conductivity using a series-parallel network, assuming that the particles are isolated cubes of the same size in a homogeneous medium, and is given by:

$$k_c = k_m \left[\frac{\phi^{2/3} + \frac{k_m}{k_f}\left(1 - \phi^{2/3}\right)}{\phi^{2/3} - \phi + \frac{k_m}{k_f}\left(1 + \phi - \phi^{2/3}\right)} \right] \tag{2}$$

where the parameters are as indicated in (1).

Another model used was the mixture rule associated with the correction coefficients proposed by the partially empirical model from Ashby e Gibson [14] for cellular materials. This gives:

$$k_c = k_m(1-\phi)^q + k_f(\phi)^q \tag{3}$$

where:
q = empirical coefficient between 1.65 and 1.8 (those two extremes of the interval were used for calculations). Other parameters as indicated in (1).

The input data for all calculations were:
k_m= 155W/m*K
k_f= 0.10 W/m*K
ϕ = volume fraction of reinforcement:
for (fine particles) = 0.64 and for (coarse particles) = 0.52

Table 3 and Figure 12 show the results obtained by the applied models. In all cases thermal conductivity of the composites is considerably inferior to that of the bulk AA7075 alloy (128W/mK). However, there are differences in the results, according to the different models employed. Maxwell's model is considered more suitable for composites with low particles content, but even so results were similar to Russel's model. The lowest values were obtained with the mixture rule model.

Table 3.
Thermal conductivity values (W/mK) of the produced composites, estimated by Maxwell's, Russell's and mixture rule with Ashby coefficients

Particles dimension	Maxwell	Russell	Mix. rule (q=1.8)	Mix. rule (q=1.65)
Fine	42.32	44.50	24.67	28.75
Coarse	46.37	48.90	28.49	32.81

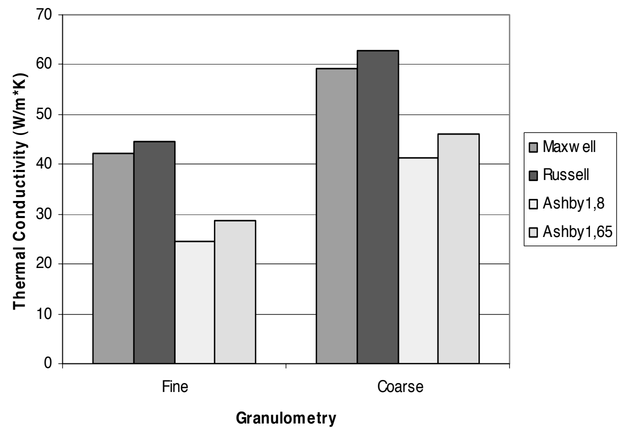


Fig. 12. Thermal conductivity of AA7075/SiO_2-MgO-Al_2O_3 composites, estimated by different theoretical models

To establish which model is more precise for such new material as MCC with porous reinforcement, experimental data must be obtained. Different techniques [15, 16] to determine thermal properties of cellular metals can be employed and this is a subject still under development.

Although not conclusive, results presented show with no doubt that significant reduction on thermal conductivity of the alloy can be achieved in composites containing porous vermiculite as reinforcement.

Concerning the dimensions of the particles, it is possible to observe that composites with coarser reinforcing particles present higher thermal conductivity. Since the thermal conductivity of vermiculite particles was considered the same for both particles dimensions, that result is a direct consequence of the higher matrix mass fraction and higher density of the composite containing coarse vermiculite particles, as mentioned previously.

4. Conclusions

Results show that the use of porous ceramic particles as reinforcing material in the production of MMC results in a composite with interesting combination of properties: low density, high plastic deformation in compression, meaning the ability to absorb energy during deformation (which can be interesting for impact and damping purposes). Simulations also show that the new material can present low thermal conductivity, in the order of 30% of the conductivity of the alloy without reinforcement (depending on the volume fraction of reinforcement).

Moreover, results also show the feasibility of the application of semi-solid technology to produce MMC composites in a process involving the thixoinfiltration of the alloy into pre-forms of the ceramic porous particulates. The process is easily handled and controlled.

Results concerning the composite based in AA7075 alloy as matrix and SiO_2-MgO-Al_2O_3 expanded particles (vermiculite) as reinforcement show no significant influence of dimensions of the ceramic particles in the structural features and properties of the composite, in the range of dimensions used in this study, from 1.6 to 5mm.

Acknowledgements

The authors want to thank financial support from Brazilian Government agencies CAPES and CNPq.

References

[1] V. Paserin, J. Shu, A.M. Liu, B.Q. Yu, L. Renny, M. Groo, Commercial production and applications of Ni-based specialty foams, Proceedings of the 5th International Conference on Porous Metals and Metallic Alloys, MetFoam' 2007, Montreal, Canada, 2007, 121-124.

[2] J.A. Reglero, E. Solorzano, M.A. Rodriguez-Perez, J.A. de Saja, Design and testing of an energy absorber prototype based on aluminum foams, Materials & Design 17 (2010) 1-6.

[3] A. Ejlali, A. Ejlali, K. Hooman, H. Gurgenci, Application of high porosity metal foams as air-cooled heat exchangers to high heat load removal systems, International. Communications in Heat and Mass Transfer 36 (2009) 674-679.

[4] R. Nowosielski, A. Kania, M. Spilka, Development of eco-materials and materials technology, Journal of Achievements in Materials and Manufacturing Engineering 21 (2007) 27-30.

[5] J. Weise, J. Baumeister, O. Yezerska, N. Salk, G.B.D. Silva, Syntactic iron foams with integrated microglass bubbles produced by means of metal powder injection moulding, Advanced Engineering Materials 12/17 (2010) 604-608.

[6] M.H. Robert, F. Gatamorta, J. Weise, Manufacture of metallic syntactic foams by thixoinfiltration. Proceedings of the International Conference on Cellular Materials CELLMATT'2012, Dresden, Germany, 2012, (to be published).

[7] M.H. Robert, A.F. Jorge, F. Gatamorta, R.R. Silva, Thixoinfiltration: a new approach to produce cellular and other low density metallic materials, Journal of Achievements in Materials and Manufacturing Engineering 40/2 (2010) 180-187.

[8] M.H. Robert, D. Delbin, Manufacturing of cellular A2011 alloy from semi-solid state, Journal of Achievements in Materials and Manufacturing Engineering 24/1 (2007) 115-122.

[9] M.H. Robert, L. M. P. Ferreira, A. F. Jorge, E. Bayraktar, Production of metal matrix composites using thixoinfiltration techniques, Proceedings of the 12th International Congress and Exposition on Experimental and Applied Mechanics SEM'2012, Costa Mesa, CA, USA, (2012) 25-32.

[10] S. Das, D.P. Mondal, A.K. Gupta, Compressive deformation and damping behaviour of Aluminium composite foam, Proceedings of the 7th International Conference on Porous Metals and Metallic Alloys, MetFoam' 2011, Busan, Korea, 2011, 12-18.

[11] H.P. Degischer, B. Kriszt, Handbook of Cellular Metals: Production, Processing, Applications. Wiley-VCH, Weinheim, 2002.

[12] J.C. Maxwell, A treatise on electricity and magnetism, Third Edition, New York, Dover, 1954.

[13] H.W. Russel, Principles of heat flow in porous insulation. Journal of the American Ceramics Society 18 (1935) 1-5.

[14] M.F. Ashby, A.G. Evans, N.A. Fleck, L.J. Gibson, J.W. Hutchinson, H.N.G. Wadley. Metal Foams: A Design Guide, Butterworth-Heinemann, Boston, 2000.

[15] A. Pusz, A. Januszka, S. Lesz, R. Nowosielski, Thermal conductivity measuring station for metallic glasse, Archives of Materials Science and Engineering 47/2 (2011) 95-102.

[16] G. Wróbel, S. Pawlak, G. Muzia, Thermal diffusivity measurements of selected fiber reinforced polymer composites using heat impulse method, Archives of Materials Science and Engineering 47/2 (2011) 25-32.