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Oxy-Acetylene Flame Thermal Spray of Al/SiC_p Composites with High Fraction of Reinforcements

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Aluminum matrix composites reinforced with more that 50 vol.% of SiC particles were fabricated using oxyacetylene thermal spraying. The sprayed material consisted of mixtures of aluminum powder with 60-85 vol.% of SiC particles. To favor the processing of the composite, in some cases, the SiC particles were coated with silica following a sol-gel route. This allowed obtaining as-sprayed samples with thickness above 2 mm and with porosity values below 2%. Post-processing of the samples by hot pressing allowed to reduce further the porosity of the composites and to enhance their microstructural homogeneity. The whole process of spraying and hot pressing has been optimized and the role played by the different spraying parameters and by time length and temperature of hot pressing has been also studied.

Keywords aluminum metal matrix composites, bulk materials, SiC reinforcement, thermal spray

1. Introduction

The electronics industry requires increasing the packaging density and the power of electronic and microwave devices, resulting in the need of implementing carrier and wave confining materials that allow handling higher powers while fitting well into current technology (Ref 1, 2). These materials must have coefficients of thermal expansion (CTE) compatible with those of ceramic substrates used nowadays (alumina, beryllium oxide, or aluminum nitride), or with Si or GaAs semiconductors. In addition, high thermal conductivity is required to prevent the component heating.

Kovar is the most used material because of its low CTE in spite of its reduced thermal conductivity and high density. Molybdenum and tungsten, or metal-metal composites such as W-Cu and Mo-Cu, have compatible CTEs and higher thermal conductivities, although they are heavier. Currently, the application of metal matrix composites (MMCs) with high ceramic particle content is getting interest. In particular, AlSiC, i.e. aluminum matrix composites reinforced with more than 50 vol.% of silicon carbide particles (SiC_p), combine adequate CTE values (6.5-9 ppm/K at 25-150 °C, tailored by the type and content of particle reinforcement), with high thermal conductivity (from 170 to 200 W/m K), reduced density (below 3 g/cm^3) and outstanding values of specific strength and stiffness (Ref 3-5).

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AlSiC raw materials are affordable, but processing of highly reinforced composites is expensive because high infiltration pressures are usually required, and the machining or welding of these materials is also extremely costly. The development of nearly net shape technologies for the fabrication of this type of composites would be clue for the industrialization of the AlSiC materials.

However, the fabrication of AlSiC composites shows some problems such us heterogeneity, tendency to the agglomeration of particles and porosity formation in the matrix. The main problems related to the processing of these materials through a liquid route are the low wettability of SiC particles by molten aluminum at low temperatures and, at higher ones, the high reactivity between molten aluminum and SiC that produces Al_4C_3, a brittle compound that degrades the composite. Both problems can be controlled by modifying the surface of SiC using a sol-gel silica coating that reacts with Al increasing the wetting but avoiding SiC_p getting into contact with molten Al (Ref 6-8).

Spray techniques allow fabricating coatings and bulk materials with compositions and structures that are not reachable with other processing techniques (Ref 9-16). These methods consist of melting material feedstock to accelerate and propel heated particles toward a substrate where rapid solidification and thickness build-up occur. Plasma spray process has been used to produce bulk and near-net-shape form of aluminum metal matrix composites with 55-75 vol.% SiC_p, but to obtain these high volume fraction of SiC it requires a powder preparation like mechanical alloying (Ref 14, 15). Plasma spray and high velocity oxy-fuel (HVOF) processing are also feasible ways for producing coatings of aluminum matrix composites (Ref 17-19), but these coatings were porous and required post-processing methods. Although most processes allow obtaining differently reinforced composites, the reinforcement rates obtained are usually below 20 vol.% (Ref 20). The cold gas dynamic spray (CGDS) and the pulsed gas dynamic spray (PGDS) processes are an emerging thermal spray coating technology considered to as solid-state processes. Al-SiC composite coatings are successfully produced by CGDS and PGDS techniques (Ref 21-24). However, the percentage of the hard particles confined within the deformed ductile matrix particles in the coating is low compared to that of the original feedstock powder.

The present authors have obtained high-quality SiC_p reinforced aluminum composite coatings with 30 vol.% SiC_p reinforcement using a low-cost and low-temperature thermal spraying procedure (Ref 25-27).

The present study is proposed with the objective of investigating the possibility of producing bulk AlSiC composites with high volume percentage of reinforcement using the thermal spraying technique. In this work, bulk AlSiC composites with reinforcement rates above 50 vol.% and with porosity values lower than 5% using mixtures of aluminum powder and SiC_p are produced. The application of a hot-pressing procedure after thermal spraying increased further the reinforcement rates and reduced the porosity of the manufactured composites to values close to 1%.

2. Experimental Procedure

2.1 Materials Used to Spray

The sprayed material was obtained by mixing aluminum spray powder with different percentages of SiC particles. The SiC particles were supplied by Navarro SiC S.A with a 99% SiC composition and α-SiC 6H crystalline structure. Two different SiC_p granulometries were used: F-240, which had an average size of 52.0 μm, and F-180, which had an average size of 110 μm. The aluminum spray powder was supplied by Castolin (99.5% Al rich) with a particle average size of 125 μm. The morphology of the powder was characterized by XRD and SEM in previous investigations (Ref 25).

2.2 Coating of SiC Particles by Sol-Gel Route

The surface of the SiC_p used as reinforcement in the bulk materials was modified in order to improve their integration with the aluminum matrix. For this purpose, a porous silica coating was deposited on the SiC_p by following a sol-gel silica route.

The sol-gel coatings were obtained from TEOS (tetraethylorthosilicate) diluted in absolute ethanol 1:11 and distilled water 1:5. This mixture hydrolyzed for 2 h at room temperature under acid conditions. Particles were then placed in the sol and stirred for 2 h. After filtering and cleaning with distilled water and alcohol, particles were dried for 1 h at 120 °C. Finally, particles were heated at 500 °C for 1 h to evaporate organic compounds and reduce silica porosity. The temperature used in this last stage determines the specific surface of the coatings which is directly related with the kinetics of their chemical reactivity with molten aluminum. The treatment chosen in this research was the one that provides the highest reactivity, and therefore the optimum wetting behavior between SiC_p and Al (Ref 7).

2.3 Thermal Spray Process

Feedstock powders with 60, 70, 75 and 85% in volume of sol-gel coated or uncoated SiC_p were prepared by a conventional rotating ball-milling machine using a plastic jar with alumina balls. Ball milling was carried out in air for 15 min with a ball-to-powder weight ratio of 1:1, filling 25% of jar volume. Reinforcement particles were homogeneously mixed with the aluminum ones, and they were not joined to the aluminum powder. None of the sol-gel coatings showed breakages on their surfaces after the milling process (Ref 25).

Afterwards, the mixtures were directly used to feed the thermal spray equipment. The mixing process used was identical for coated and for uncoated particles.

A low-velocity oxy-acetylene thermal spray gun from Castolin (DS8000 with a SSM40 modulus) was used. The spraying parameters used to produce the bulk materials were neutral flame, gun speed of 150 cm/min, feeding rate of 1 g/min and spraying distances of 20, 15 and 10 cm.

The procedure used to fabricate bulk composites was similar to that proposed by the present authors to obtain AlSiC coatings on steel substrates (Ref 25-27). For bulk composites, the powdered mixture was sprayed on polished and cold F112 carbon steel plate, avoiding any adhesion of the sprayed material to the substrate by means of using a graphite spray for demoulding and by keeping its surface flat. The AlSiC material was sprayed until an ingot of $120 \times 20 \times 2$ mm^3 was obtained. After cooling, this composite ingot was easily removed from the steel plate. Afterwards, sprayed ingots were cut into smaller pieces for characterization.

2.4 Hot-Pressing Processing

To densify the sprayed composite reducing its porosity, the as-sprayed specimens were hot pressed (ADES PL 200-B Hot Plate Press) applying a pressure of 500 MPa for different temperatures (ranged from 350 to 500 °C in 50 °C stages) and times (30 and 60 min). Under those conditions, specimens with average roughness, R_a, between 11.0 to 6.3 μm were obtained.

2.5 Characterization and Analysis

Samples for microscopy characterization were prepared from the transversal section of material and observed by scanning electronic microscopy (SEM) with an energy dispersive x-ray spectrometry (EDX) from Philips (ESEM XL30). Porosity and reinforcement percentages were measured using an image analysis software (Image Pro Plus) on the SEM images. Dilatometric measurements of the coating were carried out from room temperature to 200 °C heating at 5 K/min (TMA Q400, TA Instruments).

3. Results

3.1 As-Sprayed Materials

Table 1 resumes the different samples fabricated along with their main microstructural features, i.e. true reinforcement and porosity, obtained in SEM from the transversal sections of the samples. Figure 1 shows the transversal section of the as-sprayed composites in which three types of defects can be observed in the composites produced using uncoated (Fig. 1a) and sol-gel coated SiC_p (Fig. 1b): pores, particle clustering and banding. Pores and particle clustering appear to be less frequent in the composite with sol-gel coated SiC_p.

The zones of reinforcement accumulation coincide with those where pores appeared, showing that sprayed aluminum was not capable of filling the interparticle spaces as a consequence of the low wettability of SiC by molten aluminum (Fig. 1c). The sol-gel coated particles were better integrated within the aluminum matrix and the penetration of molten aluminum through the interparticle spaces was favored (Fig. 1d). However, in this case, particles tended to accumulate forming bands because aluminum droplets can stick either onto aluminum splats or onto sprayed SiC_p, while SiC_p can only adhere to aluminum. So, if the amount of aluminum sprayed is not enough, the incorporation of ceramic particles will find difficulties.

In all cases, the presence of smaller pores inside the matrix was also detected because the aluminum splats were not completely deformed when they impacted with the previously sprayed material. This defect was favored in the composite fabricated with uncoated SiC, where the high contact angle of aluminum with the particles favored the recovery of the spherical shape of the splats.

The values of reinforcement rate and porosity for the different as-sprayed composites are shown in Fig. 2, where the number of each column refers to the samples indicated in Table 1. The true reinforcement rates achieved in the composites (Fig. 2a) were less sensitive to the spraying parameters than porosity (Fig. 2b). The maximum reinforcement rates obtained were approximately 50 vol.% for mixtures containing 70 vol.% SiC_p in the gun powder feeder. In all cases, there was an important loss of SiC_p.

Porosity values measured at the composites ranged from 1.6 to 14.6% for the different spraying conditions tested. The role played by the incorporation of sol-gel coatings, feeding mixture and size of SiC_p will be discussed later in detail.

3.2 Sprayed and Hot-Pressed Samples

To minimize the porosity of the specimens, some samples were hot pressed after spraying. For these tests a reduced set of spraying conditions were chosen. Table 2 resumes the processing conditions of the samples manufactured following this procedure, as well as the porosity and the true reinforcement rates obtained. Figure 3 shows the microstructure of samples sprayed at the same conditions of Fig. 1 after a hot-pressing stage at 400 °C for 60 min. The main noticeable change observed in both materials with uncoated particles (Fig. 3a) and sol-gel coated ones (Fig. 3b) was the porosity reduction to values of 1.5 and 1.4%, respectively.

Observing both samples at higher magnifications (Fig. 3c and d), it could be determined that there was a good integration of the SiC_p within the aluminum matrix, which filled the zones between particles, where pores tended to be formed in the as-sprayed specimens. In contrast, in the particle clustering zones, SiC_p have been damaged by the compressive stresses applied (arrowed zones of Fig. 3c and d) which seems to be excessive for the edges of the particles where stress concentrated.

The reinforcement rates obtained after pressing (Fig. 4a) were up to 20% higher than the as-sprayed ones for the same spraying conditions, and reinforcement rates above 65 vol.% were obtained. In addition, a relevant reduction of the mean porosity of the samples was

Table 1 Thermal spraying parameters, true reinforcement and porosity of the AlSiC composites

				True reinforcement, vol.%		Porosity, %	
Sample	SiC_p in feeder, vol.%	SiC size, μm	Spraying distance, cm	Medium	Standard deviation	Medium	Standard deviation
1	85	52	20	46.0	2.1	2.2	0.4
2	85 s-g	52	20	49.2	6.2	2.7	0.8
3	75	52	20	49.6	3.1	12.2	3.1
4		52	15	37.7	2.3	8.0	2.5
5		110	20	50.6	6.1	11.0	6.3
6	70	52	20	43.7	5.0	1.9	0.9
7	70 s-g	52	20	49.0	5.6	1.6	0.3
8	60	52	15	42.8	1.9	8.6	1.8
9		52	10	42.6	1.34	5.3	1.8
10		110	15	32.5	1.3	3.8	1.5
11		110	10	36.6	1.6	12.6	4.3
12	60 s-g	52	15	33.3	1.5	5.4	2.2

s-g denotes that the SiC_p were coated with sol-gel silica

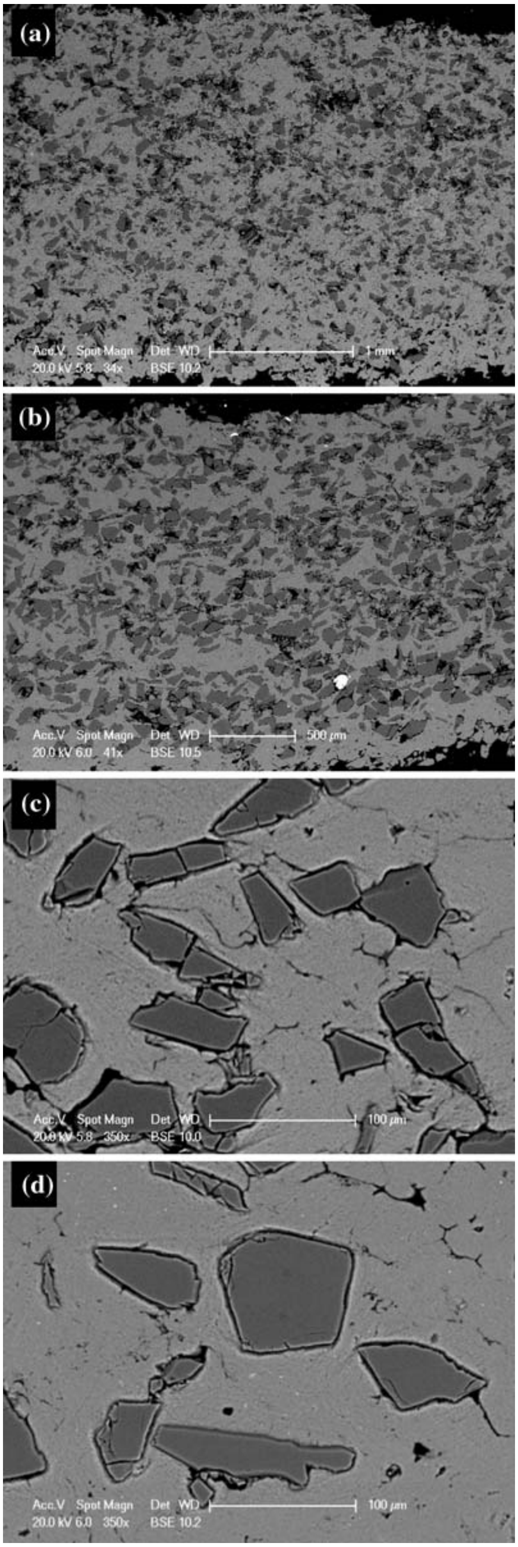

Fig. 1 SEM transversal sections of composite materials fabricated with 70 vol.% SiC_p in feeder: (a) with uncoated SiC_p, (b) with sol-gel coated SiC_p, (c) detail of (a), and (d) detail of (c)

obtained; it was reduced to 5.5% in the as-sprayed samples to 1.8% after hot pressing. Even samples with porosity below 0.5% were obtained. Considering simultaneously

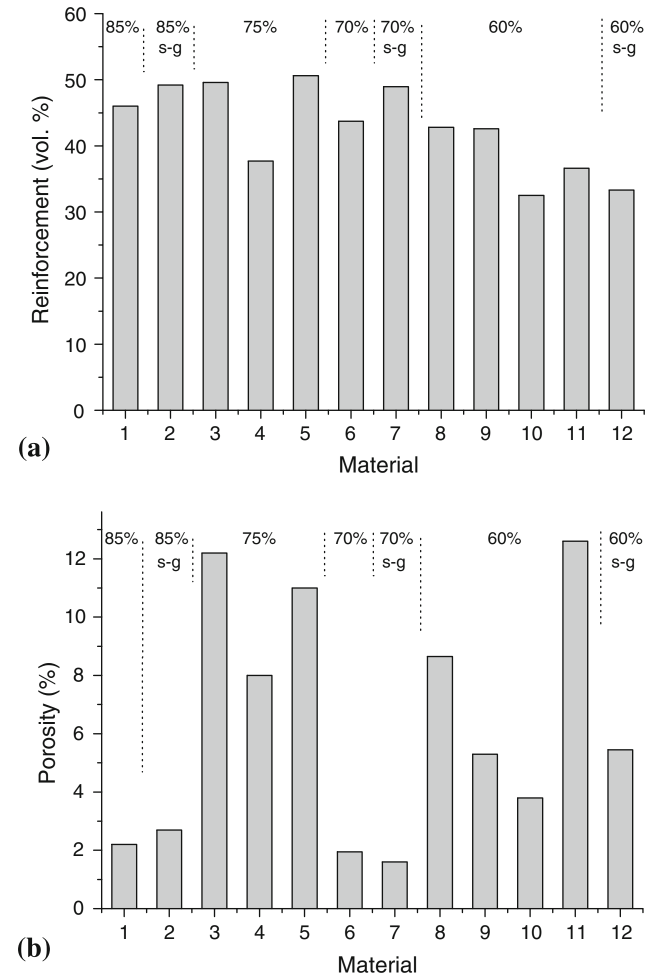

Fig. 2 Microstructural features of as-sprayed composites: (a) reinforcement and (b) porosity proportions

the evolution of porosity and reinforcement, it can be concluded that the reduction of porosity was the main responsible effect of the reinforcement increase for the samples pressed at low temperature. Most samples treated at 500 °C show an increase in reinforcement that must also come from the flow of aluminum outward the central part of the specimens.

Finally, the structure of the hot-pressed AlSiC composites seemed to be less affected by the processing parameters than the as-sprayed ones. The influence of each of them in both types of manufactured composites is discussed in the following sections.

3.3 Coefficient of Thermal Expansion

The CTE of the samples was measured in the range 50-200 °C for the hot-pressed specimens (Table 3). The data obtained have been fitted to the most common models used in the literature: the rule of mixtures, the Kerner model and the Turner one.

The rule of mixtures considers that both species follow their dilatation trend and that the load transference does

Table 2 Pressing conditions, true reinforcement and porosity of the AlSiC composites

Sample	SiC_p in feeder, vol.%	Pressing conditions		True reinforcement, vol.%		Porosity, %	
		Temperature, °C	Time, min	Medium	Standard deviation	Medium	Standard deviation
1	85	350	30	48.9	5.2	0.4	0.2
2		400	30	52.5	3.8	1.6	0.6
3	85 s-g	350	60	46.4	4.1	1.3	0.6
4		400	60	41.0	5.8	2.0	0.5
5		450	60	39.9	2.1	1.6	0.3
6		500	60	44.3	2.6	1.9	0.4
7	70	400	30	41.4	3.0	3.1	0.9
8		400	60	47.0	2.6	1.5	0.4
9		500	30	56.8	2.7	1.3	0.3
10	70 s-g	400	30	57.0	2.1	2.1	0.7
11		400	60	65.6	3.7	1.4	0.4
12		450	60	60.7	2.1	2.1	0.7
13		500	60	52.8	4.5	3.0	0.9

s-g denotes that the SiC_p were coated with sol-gel silica

not imply a change in the volume of the sample; its expression is:

$$\alpha_C = \alpha_p V_p + \alpha_m V_m \quad \text{(Eq 1)}$$

where α is the CTE, V is the volume fraction, m refers to the matrix, and p refers to the particles.

The Kerner model (Ref 28) assumes that the reinforcement is discontinuous, spherical and that it is perfectly wetted by the a uniform layer of matrix. This model gives the composite's CTE as:

$$\alpha_C = \alpha_p V_p + \alpha_m V_m + (\alpha_p - \alpha_m) \times V_p V_m \frac{K_p - K_m}{V_p K_p + V_m K_m + \frac{3}{4} K_p K_m G_m} \quad \text{(Eq 2)}$$

where K is the bulk modulus of the components of the composite, which is related to the Young's modulus E and the Poisson's ratio ν of isotropic materials by

$$K = \frac{E}{3(1-2\nu)} \quad \text{(Eq 3)}$$

G is the shear modulus, which is

$$G = \frac{E}{3(1+\nu)} \quad \text{(Eq 4)}$$

The Turner model (Ref 29) assumes homogeneous strain throughout the composite and that only uniform hydrostatic stresses exist in the phases.

$$\alpha_C = \frac{\alpha_p V_p K_p + \alpha_m V_m K_m}{V_p K_p + V_m K_m} \quad \text{(Eq 5)}$$

This model is expected to be more valid for continuous reinforcement because it is based on considering the same dimension change, in average, of each component of the composite in comparison with the composite itself.

Table 3 shows that the rule of mixtures and the Kerner model indicate that the CTE data corresponded to composites whose reinforcement rate was lower than that measured by image analysis, with reduction of reinforcement by 13 or 30% for the material sprayed with 70 and 85% of SiC_p, respectively. This difference can arise from various causes. In AlSiC, the reinforcement is far from being spherical, as supposed for the Kerner model, so the shear modulus at the matrix-reinforcement interfaces may play a more relevant role than that assumed by the model. On the other hand, this result can be explained by the fact that some particles of the composite were not well incorporated into the matrix and were acting during dilatation as pores; or that residual stress in the SiC-Al interface caused during fabrication and cooling was conditioning the expansion of the samples. From this point of view, the effective reinforcement rate measured for the sample sprayed with 70 vol.% of SiC_p and hot pressed was above 45 vol.%, so that there was less than 5 vol.% of particles that did not properly act as reinforcement.

Finally, the Turner model did not fit well to the measurements obtained. This indicates that the different species, i.e. matrix and reinforcement, follow different dimensions change, as it was expected for a particle reinforced material in which the main phases show very different CTEs.

Other thermal property that is worth considering is thermal conductivity. Silica is an isolator and reduces the conductivity of the system by reducing the heat transfer from the aluminum matrix to the SiC particles. The conductivity of silica (1.4 W/m K) is much lower than that of SiC (120 W/m K) and aluminum (210 W/m K). However, the thickness of the silica coating reduces its isolation properties and it does not affect the conductivity of the matrix. Nevertheless, a reduction of about 15% in the conductivity of the composites by the presence of sol-gel may take place.

4. Discussion

4.1 Effect of Sol-Gel Coated SiC Particles

Among the processing parameters analyzed, the use of silica coatings applied by sol-gel on the SiC_p surface was

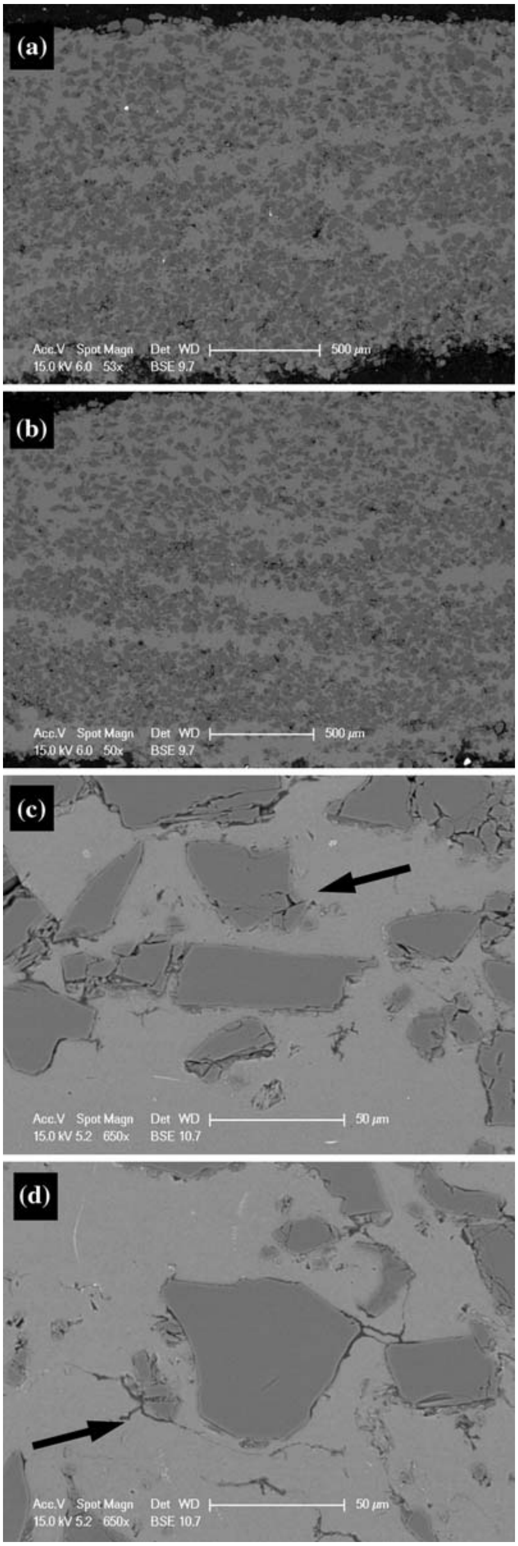

Fig. 3 SEM transversal sections of the composite materials fabricated with 70 vol.% SiC_p in feeder after hot pressing: (a) with uncoated SiC_p, (b) with sol-gel coated SiC_p, (c) and (d) details of (a) and (b), respectively

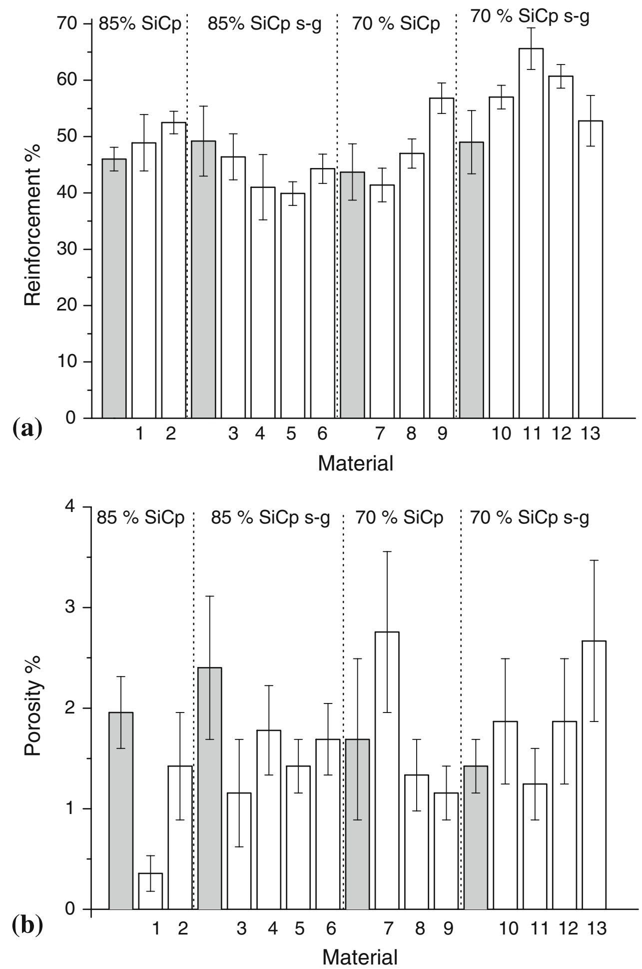

Fig. 4 Microstructural features of composite material fabricated at 20 cm spraying distance and 52 µm SiC size, as-sprayed material (grey columns), hot-pressed materials (white columns): (a) reinforcement and (b) porosity proportion

the main difference that can be found with other previously reported methods, and it has been a key factor for the fabrication of highly reinforced coatings on aluminum or steel substrates (Ref 25-27). For the fabrication of bulk composites, the use of sol-gel coated SiC_p in the as-sprayed samples provides also higher reinforcement values (Fig. 5a), reaching up to 50 vol.% reinforcement rates (about 5 vol.% more than without sol-gel) when feeding the spraying system with mixtures containing either 70 or 85 vol.% of SiC_p.

The effect of applying the sol-gel coatings on the porosity rate of the composite was not as decisive as it was for the composites coatings manufacture (Ref 27). In this case, it did not always led to lower porosity values, but in some cases, such as in the mixture containing 70 vol.% of SiC_p, it allowed reducing the porosity from 2.0 to 1.6%, i.e. 20% reduction. Apart from this, the main effect of sol-gel coatings was reducing the presence of discontinuities between particles and matrix, increasing the integration of

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Table 3 Coefficient of thermal expansion and true reinforcement of SiC, Al and AlSiC composites in the range 50-200 °C

			Vol.% SiC		
Spraying mixture	Reinforcement rate, vol.%	Measured CTE, 10^{-6} °C^{-1}	Rule of mixtures	Kerner model	Turner model
Al/70% SiC	47	18.7	41	41	16
Al/85% SiC	41	16.1	28	28	12

$CTE_{Al} = 24.8 \times 10^{-6}$ K^{-1}; $CTE_{SiC} = 3.36 \times 10^{-6}$ K^{-1}

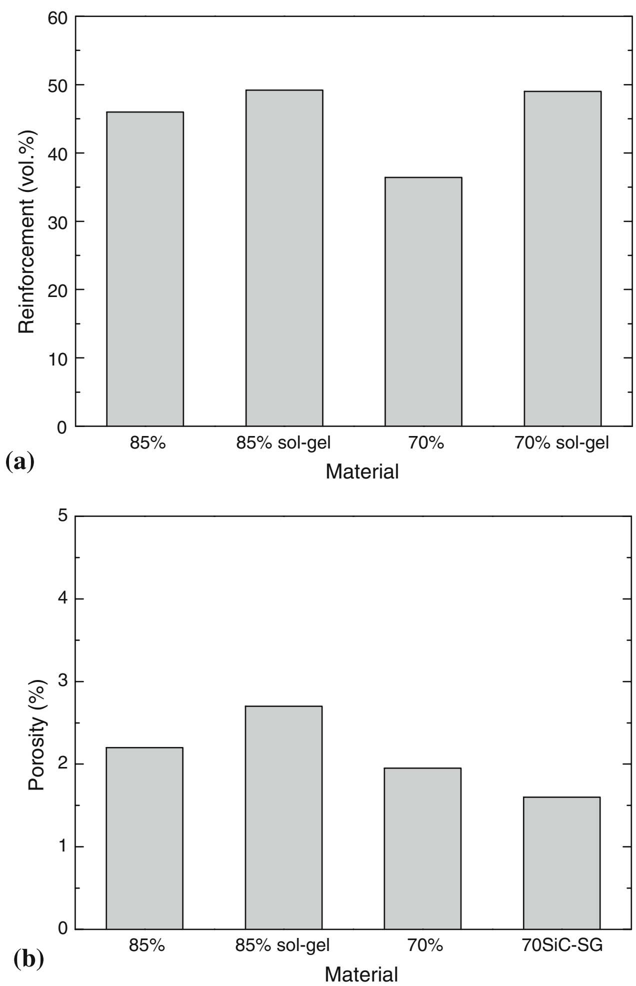

Fig. 5 (a) Reinforcement and (b) porosity proportions of the as-sprayed composites with 85 and 70% SiC_p, with and without sol-gel silica coatings

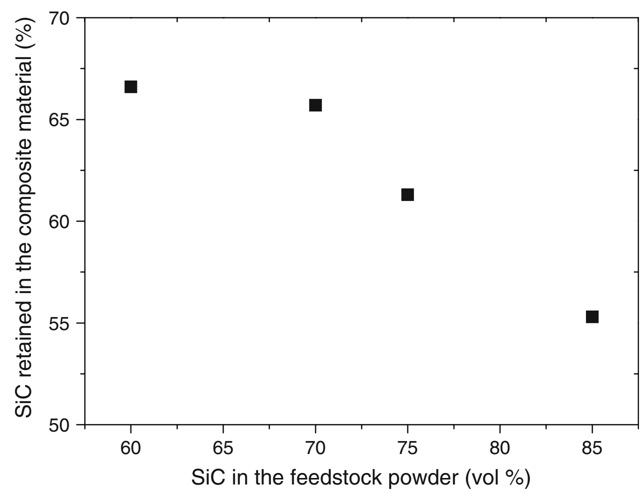

Fig. 6 Fraction of SiC_p retained in the composite material as a function of the SiC content in the feedstock powder

the particles in the composite (Fig. 1c and 1d), because it enhanced the wettability of the reinforcement by molten aluminum.

After the application of the hot-pressing stage, sol-gel coatings did not have relevant effects on the reduction of porosity and on the increase of the reinforcement rates; there were no noticeable differences between specimens with coated or uncoated particles (Fig. 2a and b).

4.2 Proportion of SiC_p in Powder Feeder

The proportion of SiC_p in the powder feeder had a strong effect in the final amount of SiC_p incorporated in the composite. The fraction of SiC retained in the composite material was found to decrease as the SiC volume fraction in the feedstock powders increased, as illustrated in Fig. 6. However, proportions of particles above 70 vol.% in the feeder gave rise to materials with the same reinforcement rate (Fig. 2a) because the efficiency of the deposition of the SiC_p depends on the percentage of SiC_p in the sprayed mixture. Aluminum droplets can stick either onto aluminum splats or onto sprayed SiC_p, while SiC_p can only adhere to aluminum. So, if the amount of SiC_p at the surface of the sprayed layer is high, the incorporation of more ceramic particles will find difficulties. This implies that part of the sprayed particles will always be lost and that there will be a maximum reinforcement rate achievable with this technique that is slightly above 50 vol.%, being responsible of the banding effects observed in the particle distribution of the sprayed composites; when the outer layer deposited is rich in SiC_p, only aluminum particles would be adhered. In general, the dependence of efficiency and porosity in the fabrication of bulk materials was equivalent to that of similar or more expensive techniques (Ref 20, 25-27).

In addition, in specimens subjected to hot pressing after spraying, the material sprayed with 85 vol.% SiC_p showed lower reinforcement rate that the 70 vol.% mixture (47 vol.% versus 54 vol.%). If we look at every spraying condition (Fig. 4), we can observe that, in general, the spraying mixtures with lower SiC_p content gave rise to higher reinforced materials and the material sprayed with higher contents of SiC_p showed lower porosity values. The presence of hard SiC_p in the spraying powder may have helped to deform and break the aluminum splats, limiting the formation of pores.

The presence of banding is more accused in the highest reinforced composites. To reduce it, preheating at higher temperatures or using a system that allows more energetic particles or spraying with faster passes would help to homogenize the coating.

4.3 Size of SiC Particles and Spraying Distance

To evaluate the effect of the size difference between the aluminum powder and the SiC_p on the spraying efficiency of the different kind of particles, two SiC_p sizes were mixed with the aluminum particles and sprayed at different distances to distinguish the relevancy of size and of the kinetic energy of the sprayed material.

Figure 7 shows that spraying larger particles, i.e. F-180 with 110 µm mean size versus F-240 with 52 µm mean size, led to lower reinforcement degrees for the all distances and spraying mixtures tested, with the only exception of the longest distance.

Porosity was reduced by the presence of larger particles, partially because it was easier for the aluminum to cover them due to their larger size and flatter surfaces. The reinforcement rate reduction also helped to obtain lower porosity values.

The results show that the reinforcement rate did not increase while increasing the kinetic energy of the particles by using shorter spraying distances. There seems to be an optimum kinetic energy for the spraying system used for which the sprayed SiC_p deform the aluminum splats at the sample and get adhered to it. Higher kinetic energies allow producing higher deformation of the previously deposited aluminum and SiC_p may get into contact with other SiC_p to which they cannot adhere. The lower kinetic energy favors the sticking to material previously sprayed if it has high percentages of SiC_p. However, this lower energy also implied higher porosities because aluminum particles were not able to deform and fill all the voids formed in the interparticle spaces.

Finally, the high porosity value obtained at the shortest distance (100 mm) was due to the massive melting of the deposited material. The lack of wetting of particles by the aluminum limited their incorporation to the composite and gave rise to the formation of nearly spherical aluminum splats with big spaces between them.

4.4 Effect of Hot-Pressing Conditions

The effect that temperature and time of hot pressing had on the microstructural features of the composites is shown in Fig. 8 and 9. Surprisingly, the higher the temperature, the lower the reinforcement rate (Fig. 8a) and the higher the porosity (Fig. 8b) measured.

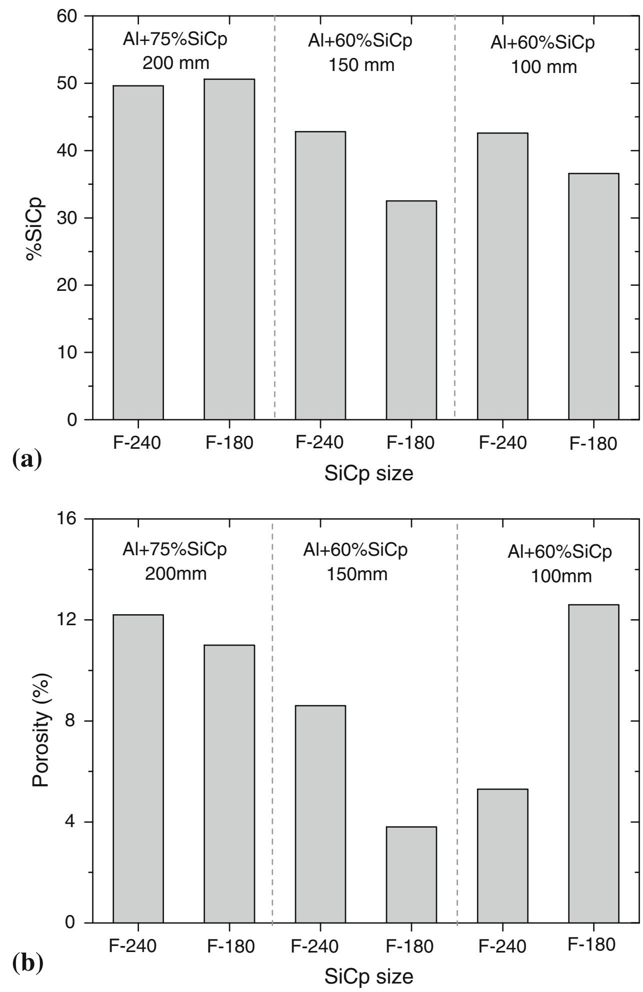

Fig. 7 (a) Reinforcement and (b) porosity of sprayed mixtures of F-240 (52 µm) or F-180 (110 µm) SiC particles at different proportions and spraying distances

Uniaxial pressure was applied to the samples for two different times: 30 and 60 min. The results obtained (Fig. 9) show that the system evolved during the last 30 min, improving the continuity of the aluminum matrix and the integration of the particles in it. As a result, in average the porosity was reduced from 3.1% to approximately 1.5% for all materials, following the reinforcement rate of a similar trend.

The porosity diminution aroused as a result of the combined effect of three factors that have importance at the temperatures applied: the yield stress of aluminum reduces strongly with temperature increasing its plastic strain and providing the extension of the contact area between adjacent splats; creep is also favored by the temperatures and times considered; and finally, the diffusion mechanisms of aluminum may have also helped to increase the contact area between aluminum splats.

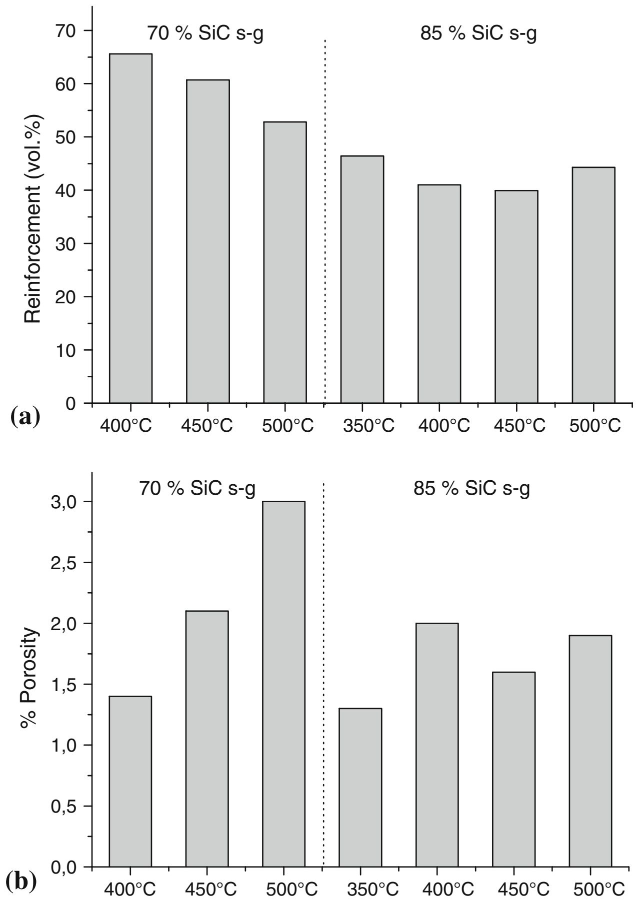

Fig. 8 (a) Porosity and (b) reinforcement of the hot-pressed composites at different temperatures

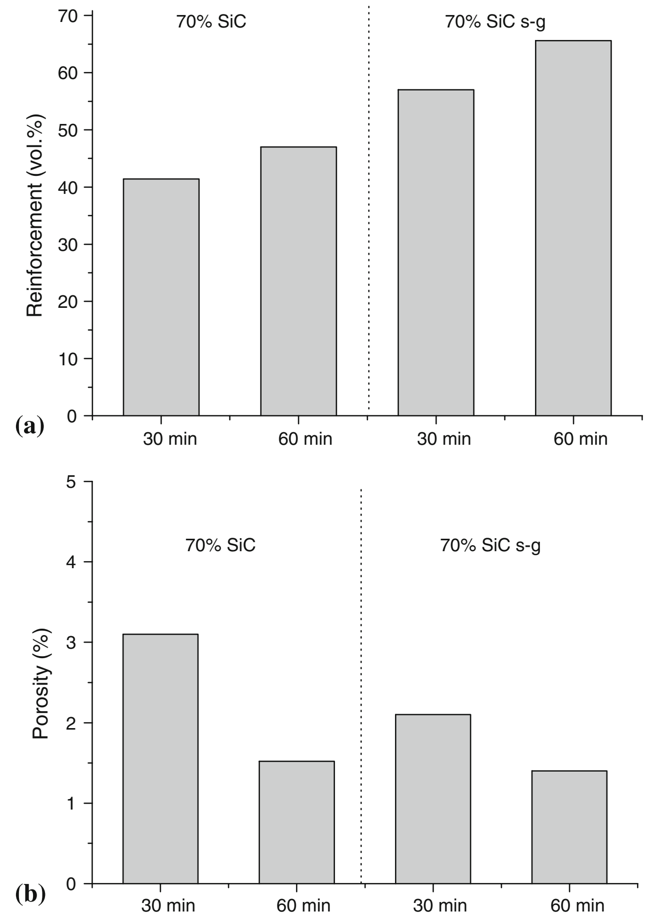

Fig. 9 (a) Porosity and (b) reinforcement of the sprayed and hot-pressed composites for the different times used

In particular, for the highest temperature used, i.e. 500 °C, aluminum could flow to the lateral parts of the samples, increasing the reinforcement rate achieved.

Finally, the limit found for the porosity reduction was related with the maximum load that the SiC_p can support before breaking. Aluminum matrix transferred the load to the particles through the contact interface and they broke presumably because stress concentrated at its edges (Fig. 3). As a result of the breakage, new voids among the particle fragments appeared. Therefore, incorporating higher percentages of SiC_p gave rise to higher porosity values after hot pressing, because the stress concentration at the adjacent matrix was increased.

5. Conclusions

Oxy-acetylene thermal spraying has allowed obtaining bulk AlSiC composites with reinforcement rates above 50 vol.% and with porosity values below 5%. The application of a post-processing stage of hot pressing increased the reinforcement degree up to 65% and reduced the porosity rate to mean values of 1.5%.

The use of sol-gel coatings on the particles enhanced, in some conditions, the reinforcement rate and reduced the porosity, improving the integration of the particles in the composite.

The proportion of SiC_p in the composite increased with the amount of particles added into the spraying feeder, up to rates below 70 vol.%. Higher values only implied that more SiC_p were lost during spraying because they found difficulties to stick to the composite. Moreover, using lower energy conditions favored the increase of the reinforcement rate achieved, although it caused porosity in the composites.

Hot pressing allowed reducing the AlSiC porosity and enhanced the continuity between matrix and particles only up to temperatures of 400 °C. Using higher temperatures caused the massive fracture of SiC particles.

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