EFFECT OF OPERATIONAL PARAMETERS IN THE SEMI-SOLID PROCESSING OF Al/SiC COMPOSITES FROM MACHINING CHIPS

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Abstract

This work analyses the influence of processing parameters in the quality of Al/SiC composites,produced from AA7075 machining chips, employing semi-solid technology. Processing route involves the following basic steps: mixing of chips and reinforcing particles, compacting of mixtures, heating and thixoforming the compact. It was analyzed the influence of some operational parameters of the different processing steps, in the general distribution of SiC particles in the matrix and in the porosity and density of products. Results show better reinforcement dispersion in the matrix when reducing initial chips dimension; increasing mixing time and intermediate thixoforming temperature; extra addition of Si and Al_2O_3 powders leads to lower porosity in the product when coarse chips are used and has the opposite effect when fine chips are used.

1. Introduction

When dealing with metal matrix composites, a reasonable range of metal/reinforcement combinations is already available for different applications. However, the area is under constant development, as the demand for new materials with properties tailored for specific applications grows constantly. The required combination of properties of a composite depends not only on the appropriate choice of its constituents, but also strongly on the processing conditions, which determine the reinforcement distribution in the metallic matrix, the type of constituents interaction, etc. [1-6].

Furthermore, society has been focusing on the development of low cost, sustainable processing technologies; in this scenario, the technology of semi-solid has become attractive. SS technology aims to reduce processing costs associated with high quality composites, mainly related to the improvement of the dispersion of the reinforcing particles in particulate MMCs. Particles added to the SS metallic matrix are more easily entrapped in the liquid among globular solid phase and particles segregation in the solidification front is much less significant in a thixocast process. Additional application of pressure to the SS composite can further improve the quality by reducing porosity [7].

In this work, a new approach is presented: composites are produced by thixoforming a pre-compacted mixture of particles of the metal matrix and the reinforcing material. As matrix, chips of the high strength Aluminum alloy AA7075, employed in the aeronautical industry are used, with the additional purpose to contribute to the recycling of wastes into a new, noble material.

2. Experimental Procedures

Metal matrix composites were produced from AA7075 chips and SiC particles. Chips were generated by machining of aeronautical parts and presented basic chemical composition as 6.3wt%Zn, 2.4wt%Mg, 2.1wt%Cu. A general scheme of the production process is shown in Figure 1, and processing variables studied are specified in Table 1.

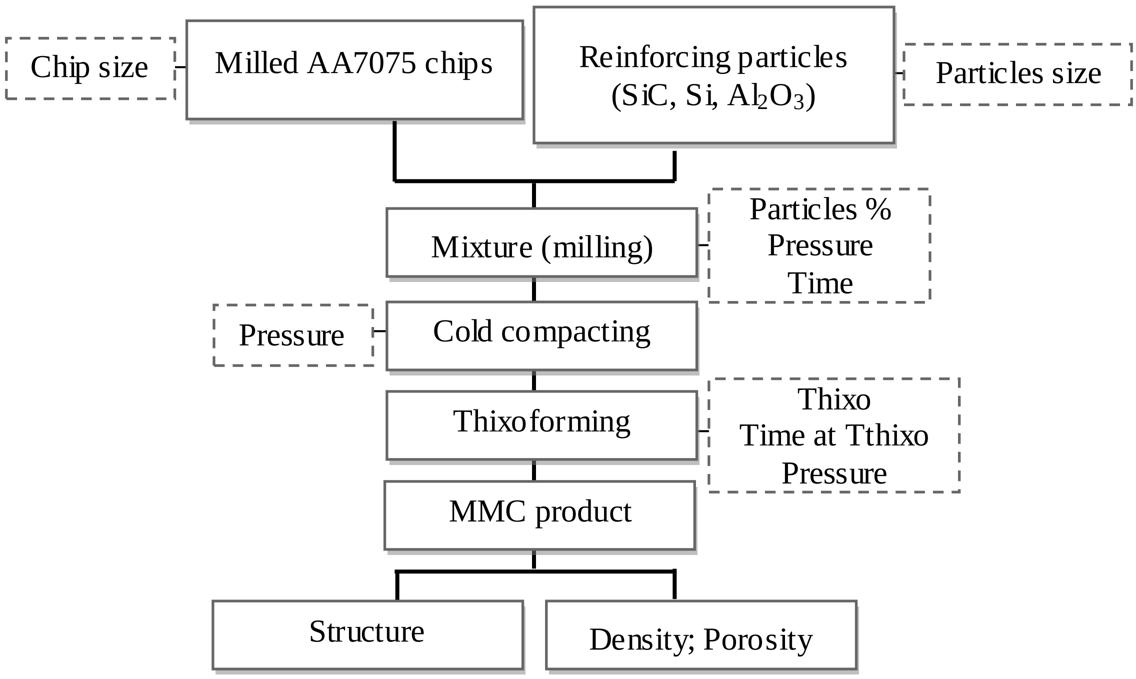


Figure 1. Schematic representation of the general steps for the production of MMCs by thixoforming. Frames with dotted lines indicate parameters investigated in each operation.

Parameters	**Values of the parameters**		
Chip size (cs)	cs< 1.7mm	1.7mm <cs< 3.6mm	
SiC particles size	40µm	1 µm	
SiC content	10wt%	20wt%	30wt%
Milling time for mixing	1:00h	4:00h	4:30h
Milling pressure	10dN	12dN	
Additives	0%Si/ 0%Al_2O_3	1%Si/ 1%Al_2O_3	0%Si/ 0%Al_2O_3
Compacting pressure	63 MPa	160 MPa	
Thixoforming temperature	620°C	625°C	630°C
Holding time at Tthixo	30 min	60 min	90 min
Thixoforming pressure	63 MPa	160 MPa	

Table 1. Parameters investigated in the processing of MMCs samples.

Chips received from the machining shop were initially milled to reduce size, and classified according to dimensions. Mixtures of SiC/Si and Al_2O_3 powders were prepared in a Fritsch Mill. Zinc stearate was added to improve the adhesion of reinforcing particles and Aluminum chips. Prepared mixtures were compacted in a die lubricated with zinc stearate. Compacted samples were heated at a rate of 20°c/min to the thixoforming temperature, hold for different times at this temperature and then thixoformed into a pre-heated die.

Thixoforming temperatures were chosen according to athixoforming window determined for the AA7075 alloy. Differential Scanning Calorimetry (DSC) was used to determine the variation of liquid fraction with temperature (fl x T) and the sensibility of this variation (dfl/dT x T) within the solidification range of the alloy. Results are presented in Figure 2.

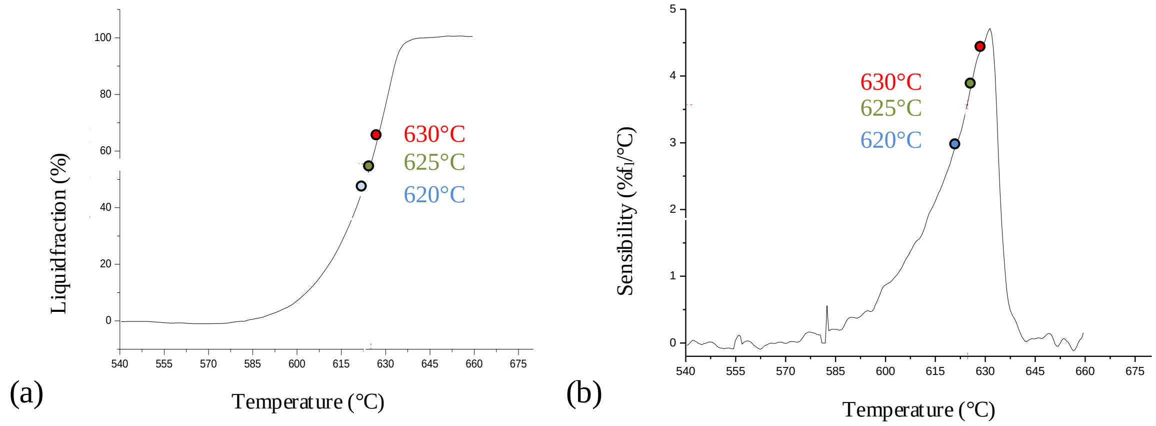


Figure 2. DSC analysis of AA7075 alloy: (a) fl x T; (b) dfl/dT x T within solidification range.

According to the DSC method, liquid formation starts around 580°C. However, according to results of thermodynamic simulation by Fonseca, the alloy AA7075 can present circa 8% liquid already at temperatures around 475°C [8], due to the melting of non-equilibrium phases. In this work, as higher liquid fraction is required, the thixoforming window suggested, between 610 and 630°C, takes in account only the melting of the primary α phase. Liquid fraction ranges from 20% to 70% and the variation of liquid fraction with temperature from 3 to 5 % fl/°C in the thixoforming window suggested.

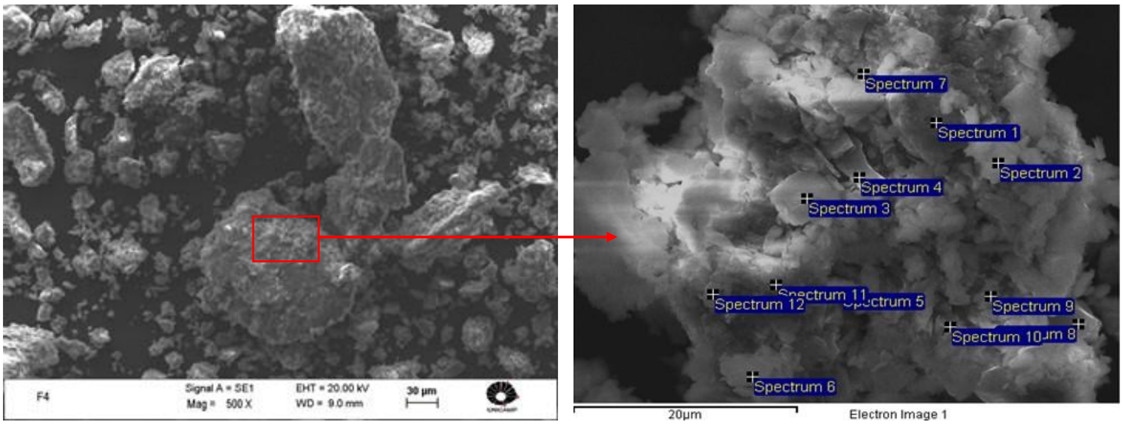
Microstructures of composites were observed using Scanning Electron Microscope (SEM); porosity was measured by Archimedes method and by image analysis, using Image J® software. DOE tool from Minitab® software was used for a statistical approach in the analyses of the effect of studied parameters in the density and porosity of the products.

3. Results and discussions

3.1. Effect of milling conditions

In the original chips: it was observed reduction of size and smoothing the sharp edges of the chips with increasing milling time and energy; total reduction after 4:30h was around 40%.

In the mixing ability: no homogeneous dispersion of constituents was obtained in any of the tested conditions; however, increasing milling time and energy does increase adhesion of SiC, Si and Al_2O_3 particles to the chips surface, as observed in Figure 3. EDS analysis shows similar tendency of adhesion of the different particles indicates rich Al/O, Si, Si/O regions. High Zn contentin some regions are due to the Zn stearate used as lubricant. Milling in the tested conditions did not affected the reinforcing particles, apart eventual fracture in the hard SiC particles.



Spectrum	O	Mg	Al	Si	Cu	Zn
1	6.10	1.85	77.26	1.55	3.05	9.59
2	25.08	1.32	53.32	9.17	1.05	4.68
3	14.97	0.34	13.96	67.46	0.50	1.17
4	5.00	0.86	42.12	10.48	2.34	9.07
5	9.34	1.18	50.94	5.26	2.41	9.95
6	24.28	1.35	54.04	8.50	1.12	4.65
7	2.16	0.91	32.93	2.25	7.96	34.44
8	12.18	1.03	45.99	19.48	2.39	10.36
9	19.04	1.23	51.66	10.72	1.15	5.31
10	23.63	1.43	55.67	6.67	1.19	5.19
11	20.57	0.66	28.80	40.01	0.58	3.43

Figure 3. SEM image of a mixture of AA7075 chips /10%SiC / 1% Si / 1% Al_2O_3after 4:30h of milling; EDS results of selected regions shown in the accompaining table.

As far as products is concerned, the observed effect of milling conditions in the general quality of the produced MMCs was as follows: higher milling energy and time results in higher reduction of the chips size, better adhesion of reinforcing particles, better compacting ability; as consequence, products present better reinforcement dispersion and lower porosity.

Figure 4 presents examples showing better reinforcing phase dispersion in the composite produced from mixtures submitted to longer milling time. In case (a), the mixture was submitted to higher compacting pressure, which however did not result in a good dispersion of the SiC particles.

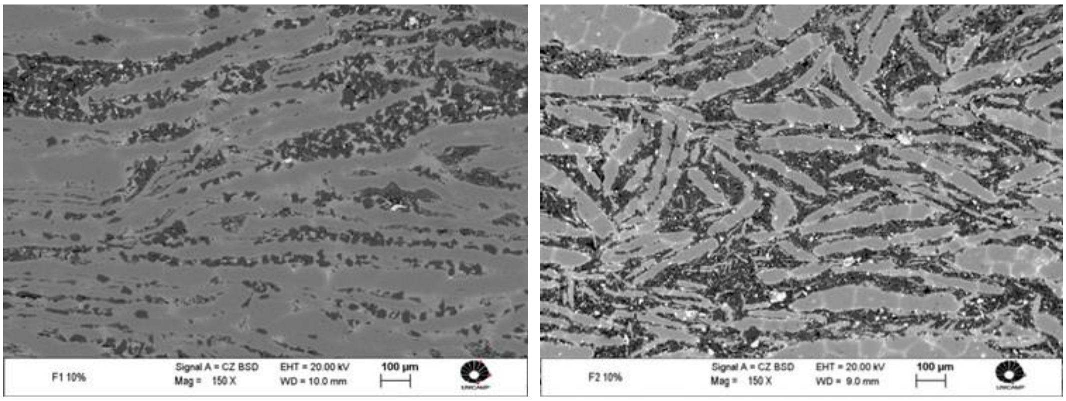


Figure 4. AA7075 /10%SiC composites produced from mixtures submitted to (a)1:00h; (b) 4:00h of milling.

3.2. Effect of size of particles and compacting conditions

Particles size: smaller sizes of the constituents (chips and reinforcing particles) can result in more homogeneous mixtures and better compacting ability, which could lead to better composite quality (better reinforcement dispersion and lower porosity). Finer particles can be also more effective to penetrate in the liquid present in the interglobular region in the semi-solid chips, promoting their disaggregation and resulting in better reinforcing dispersion in the product. On the other hand, fine particles may present tendency to agglomerate, with a detrimental effect in the final dispersion of reinforcement in the composite. Therefore, the effect of particles size in the quality of composites depend on the compromise between their ability to penetrate into the semi-solid chips and the agglomeration tendency.

Concerning the effect of extra addition of fine Si and Al_2O_3 particles results showed improvement in the quality only of composites reinforced with coarse SiC.

As far as SiC content effect, it was observed that as it increases, more efficient is the disaggregation of SS chips, resulting in better distribution of reinforcing particles in the Aluminium matrix, as observed in Figure 5, for the composite produced.

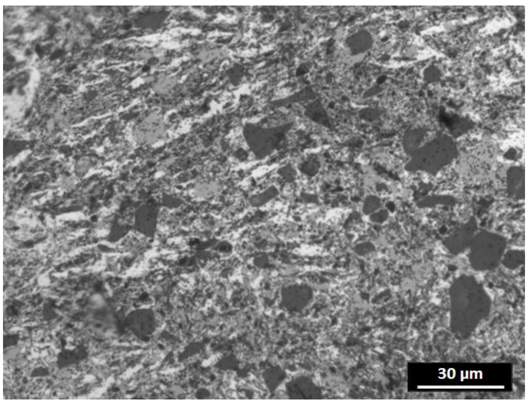


Figure 5. AA7075/20%SiC composites produced from mixtures containing extra addition of 1%Si and 1%Al_2O_3.

Compacting pressure: it was not observed significant improvement in compacting ability and in the final composite structure or porosity, for the compacting pressures studied (63MPa and 160MPa).

3.3. Effect of thixoforming conditions

Thixoforming temperature: practical results do not show the presence of 40% of liquid in the SS material at 620°C, as predicted by DSC analysis. Two facts must be taken in account: first one, the different conditions used to heat up the alloy in the DSC test compared to the heating conditions in the thixoforming experiments; second one, the oxidized surface of the Aluminium chips. Both conditions would be responsible for the apparently lower liquid fraction in the SS. However, significant liquid formation in the chip structure was observed at temperatures higher than 625°C. Thixoforming was successful both at 625°C and 630°C. No sensible effect of these temperatures in the structure of the composites was detected.

Holding time at the thixoforming temperature: certain holding time at the thixoforming temperature can guarantee the thermodynamic equilibrium condition in the material, and the required liquid fraction in the SS. Besides, kinetics of spheroidization of the structure must be also accomplished. Results showed that increasing holding time allows the promotion of globular microstructures; however, globules sizes can increase by coalescence, which must be avoided to prevent deterioration of the dispersion of reinforcing particles in the matrix.

Thixoforming pressure: low pressure is required in thixoforming process because the SS metal presents thixotropic flow behavior. However, in the process investigated, low thixoforming pressures did not result in composites with good dispersion of the reinforcing element. The presence of oxide layers in the surface of the Aluminum chips demanded higher pressures in the thixoforming processing to push SiC particles through these layers. Therefore, increasing thixoforming pressure, disaggregation of chips is facilitated by disruption of oxide layers and better dispersion of reinforcement can be obtained.

Figure 6 shows typical globular microstructure within the original Aluminum chip, and the occurrence of the globules detachment, leading to the chip disaggregation, by action of applied pressure and SiC and other particles penetration in the liquid present in the interglobular region.

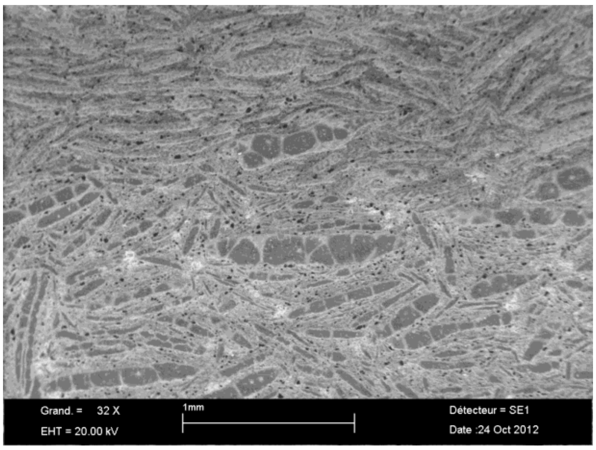


Figure 6. Microstructure of composite AA7075 chips / SiC produced by thixoforming: typical globular structure within the chips and its disaggregation.

3.4. Effect of operational parameters in the porosity– statistical approach

The presence of pores was observed in all the produced composites, due to the poor interfacial cohesion between the metallic matrix and the ceramic reinforcement, and to poor compressibility of the constituents. Results on porosity and density measurements showed a negative influence of the use of coarse chips as raw material in the composite production. Lower density was obtained in this case as a result of poor compaction ability. Fine chips, with rounded edges are more compressible, leading to composites with higher density.

Main effects plot for porosity was built to analyze the most influential factors on the porosity. The following variables were considered: chip size, SiC particles size, extra addition of Si, extra addition of Si and Al_2O_3 together.

Figure 7 presents the results of main effects for porosity using chips size and dimensions of SiC as processing parameters. The plots clearly demonstrate that the most important variable is the chips size; therefore, using fine chips as raw material, resulted composites present lower porosity.The size of SiC particles has a certain degree of influence; particles with larger dimensions tend to produce composites with lower porosity than composites fabricated with small particles of reinforcement. Probably, small particles of SiC can form clusters with internal porosity among agglomerated particles; besides, these clusters prevent the filling of voids by individual SiC particles during compacting and thixoforming.

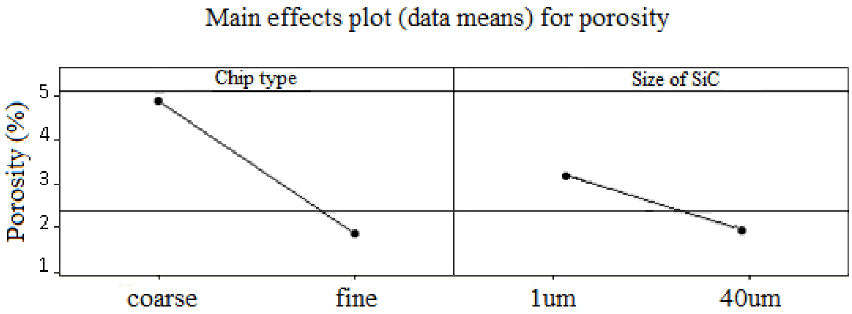


Figure 7. Main effects plot for porosity: chip type and size of SiC particles.

Figure 8 presents the results of main effects for porosity using addition of Si and addition of Al_2O_3+ Si as processing parameters. In this case, the stronger influence of Al_2O_3+ Si on the porosity is a consequence of the higher compacting ability of the mixture due to the filling of voids by the higher content of fine particles. However, it is important to consider that in some circumstances, the addition of fine particles can cause clusters, worsening the distribution of the reinforcement in the matrix.

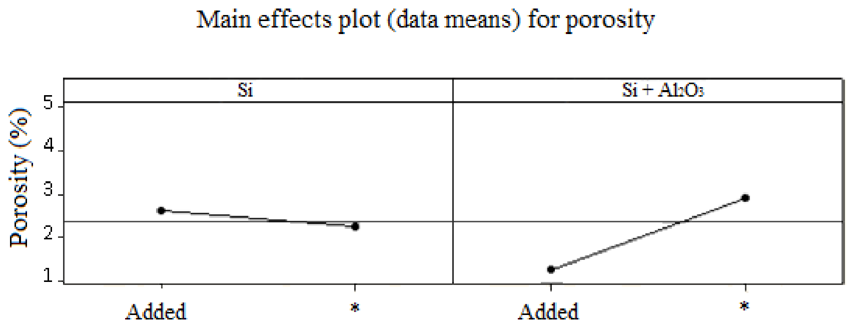


Figure 8. Main effects plot for porosity: addition of Si and addition of Si + Al_2O_3.

Summary

The work showed that an appropriate combination of parameters can result in Al/SiC composites with acceptable reinforcement distribution and low porosity, by thixoforming of compacted mixtures of recycled Al chips and SiC particles. Specific comments can be made:

1) Chips size and SiC particles play a determinant role in the final quality of the product. Fine particles of Aluminum chips and SiC coarse particles seems to be the better combination, resulting in composites with low porosity and better reinforcement dispersion in the matrix;

2) Milling time for mixing and extra addition of fine particles also showed great influence in the MMC's quality. Longer mixing time is favorable to reduce chips size and to improve interaction between constituents, resulting in better distribution of SiC particles in the metallic matrix; extra addition of fine particles reduces porosity in the product;

3)Holding time at thixoforming temperature and thixoforming pressure exerted strong influence in the final quality of the composites. Holding time must be such to allow the promotion of globular structure in the chips; thixoforming pressure must be such to promote disaggregation of SS chips.

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