

INFILTRATION OF MOLTEN Al-7wt.%Si INTO TiC BEDS WITH THE AID OF A K-Al-F BASED FLUX

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Abstract

Trials to infiltrate TiC beds with and without flux were conducted with an Al-7wt.%Si alloy. The metal infiltrant is simply placed on top of the ceramic bed and the two are heated to 680, 820 and 1100°C in an Ar atmosphere or in atmospheric air and held at temperature for 1 hour. TiC powder was mixed with the K-Al-F flux in different ratios. Infiltrated specimens were microstructurally characterised using scanning electron microscopy (SEM), energy dispersive X-ray analysis (EDX) and X-ray diffraction (XRD). It was found that TiC beds could not be infiltrated, with and without flux, across the interval of temperatures studied in air, only partial infiltration was seen with a high flux ratio. Conversely, when the flux was present in Ar, successful infiltration occurred at temperatures as low as 680°C and the single TiC bed was only infiltrated at elevated temperature. The K-Al-F flux, which is similar to cryolite and has high solubility for Al₂O₃, is thought to dissolve the oxide skin and prevent further oxidation of the melt enabling thus infiltration to occur as low as 680°C. The microstructural characterization revealed different levels of reaction depending on infiltrating temperature, the reaction products being Al₄C₃ and complex Ti-Al-Si intermetallics.

Keywords: Infiltration, TiC, Fluxes, MMC's, Interfacial reactions

Resumen

Se realizaron intentos para infiltrar camas de TiC con una aleación Al-7wt.%Si con y sin fundente. La aleación a infiltrar es colocada sobre la cama cerámica y el ensamble es calentado a 680, 820 y 1100°C en atmósfera de Ar o en aire atmosférico y es mantenido a la temperatura por una hora. El polvo de TiC fue mezclado con el fundente base K-Al-F en diferentes proporciones. Las muestras infiltradas fueron caracterizadas microestructuralmente por microscopia de barrido de electrones, análisis de energía dispersiva de rayos X (EDRX) y difracción de rayos X (DRX). Se encontró que las camas de TiC no infiltraron con y sin fundente en el intervalo de temperaturas evaluado en aire, únicamente se observó infiltración parcial con un alto contenido de fundente. Por el contrario, cuando el fundente estuvo presente en Ar, la infiltración fue exitosa a temperaturas de 680°C y la cama de TiC sin fundente únicamente infiltró a 1100°C. Se piensa que el fundente base K-Al-F, el cual es similar a los baños criolíticos y tiene una alta solubilidad por el Al₂O₃, disuelve la capa de óxido del aluminio líquido y previene su reoxidación, permitiendo que ocurra infiltración a temperaturas de 680°C. La caracterización microestructural reveló diferentes grados de reacción dependiendo de la temperatura de infiltración, siendo los productos de reacción Al₄C₃ e intermetálicos complejos Ti-Al-Si.

Palabras Claves: Infiltración, TiC, Fundentes, Materiales compuestos, Reacciones interfaciales

1. INTRODUCTION

TiC, a hard and stiff ceramic with low density, is known to be wetted by Al and Al-alloys at temperatures around 900°C [1]. Thus Al and Al-alloys infiltrate TiC preforms above 900°C, in inert conditions, without the need to apply pressure [2]. To decrease the cost of processing, however, lower

infiltration temperatures, similar to those used in Al casting (650-750°C), are required. In order to overcome difficulties imposed by the oxide layer and the poor wettability exhibited in Al/ceramic systems, procedures such as alloying of the melt, surface treating of the ceramic and the use of fluxes have been attempted. The use of fluxes, in

particular, has proved very effective [3,4]. The present study seeks to explore the possibility of infiltrating TiC beds by an Al-7wt.%Si alloy. In terms of the simplicity, versatility and cost, the use of a pressureless infiltration process is sought after at casting temperatures and preferably in air.

2. EXPERIMENTAL PART

2.1 Materials

Angular TiC powder, with an average particle size of 18 μm , and, according to the specifications of the supplier (KENNAMETAL, Latrobe, USA), a chemical composition, $\text{TiC}_{0.96}$, a K-Al-F based flux (a mixture of KAlF_4 and KAlF_6 close to the eutectic composition in the KF-AlF_3 system) and an Al-7wt.%Si alloy were used to conduct infiltration trials. The alloy was made by melting pure Al (99.9%) and adding 99.99% pure Si. The flux employed in the present project is a by-product of the reaction of fluoride salts to produce Al-Ti-B master alloys. Chemical analysis of the flux revealed low impurity levels of 0.062wt.%Ti and 0.019wt.%B. The morphologies of the TiC and flux powders are shown in Figure 1 and the chemical analyses for the aluminium and the Al-7wt.%Si alloy are listed in Table 1.

2.2 Infiltration Trials

Infiltration trials were carried out without flux and with TiC/flux mixtures in different mass ratios. The initial TiC/flux ratio was 2:1 and, depending on the result of the trial, the flux content was either increased or decreased in the range 1:1 to 10:1. TiC powder and the mixtures were poured into graphite crucibles and tapped to increase the packing density to between 60-65% of theoretical. Metal pieces (between 4 and 5 g) were placed on top of the bed as shown in Figure 2. Adhesive tape on the bottom of the crucibles was used to prevent escape of the powders from the graphite crucibles when handling. The samples were placed in a stainless steel boat and positioned at the centre of a horizontal tube furnace either under flowing argon or in atmospheric air. The length of the hot zone in the furnace allowed the testing of four different samples at the same time. Processing was performed by heating from room temperature, at a rate of 20°C/min, to either 680°C, 820°C or 1100°C, holding for 65 minutes, and then furnace cooling. The temperatures reported correspond to actual temperatures in the hot zone of the tube.

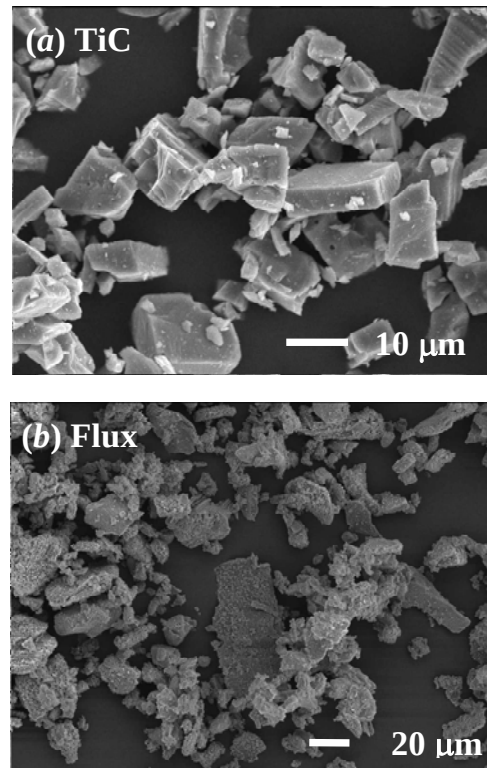


Figure 1. Morphologies of the (a) TiC and (b) flux powders.

Table 1. Chemical composition of the Al and Al-7wt.%Si alloy used (wt.%).

Ti	Fe	Si	Cu	Mn	Mg	Al
<0.01	0.05	<0.01	<0.01	<0.01	<0.01	Bal.
<0.01	0.02	7.16	<0.01	<0.01	<0.01	Bal.

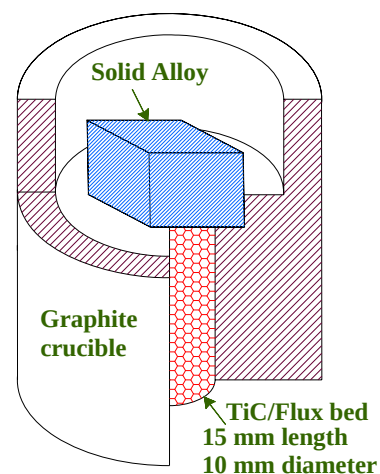


Figure 2. Experimental set up used in the infiltration trials.

2.3 Microstructural Characterization

Microstructural characterization of the infiltrated specimens was performed using a scanning electron microscope (SEM) with attached energy dispersive X-ray analysis (EDX) system. Metallographic preparation of the infiltrated samples was carried out by mounting the specimens in conductive bakelite. Rough grinding was performed using SiC paper grades 240, 400, 800 and 1200. Fine grinding was performed using hard polishing cloths with diamond compounds (9, 6, 3 and 1 μm), for less than four minutes for each step. Final polishing was carried out with a soft polishing cloth using 1 μm diamond paste for about 1 minute. Throughout the metallographic preparation the use of water was avoided to preserve the presence of any Al_4C_3 that might be present. Instead methylated spirit was used. Observations and analysis in the SEM were performed without coating the surface of the samples.

X-ray diffraction (XRD) analysis was carried out to identify the phases present in the final product. Scanning was made at steps of $0.05^\circ/\text{s}$ for 2θ angles from 10 to 90° with a dwell time of 2 s using $\text{CuK}\alpha$ radiation. Scans were made on planar solid samples ground using SiC papers up to 1200 (15 μm grit size), using methylated spirit as a cooling medium. The XRD patterns were compared with standard spectra from powder diffraction files

2.4 Thermal Analysis

Differential scanning calorimetric (DSC) experiments were carried out in order to follow the sequence of events during the infiltration process in both Ar and air, using a NETSZCH 404 DSC. Samples were placed in high purity graphite and BN crucibles for experiments under Ar and in air, respectively, and heated to 800°C , at a heating rate of $20^\circ\text{C}/\text{min}$. Al_2O_3 crucibles could not be used due to their interaction with the flux. Graphite was used in Ar and BN was used in experiments in air, both did not show any “noise” in the traces as a result of interaction with the flux or oxidation in air. Runs with the individual materials were conducted in order to detect the thermal events that take place in each material during heating. The combinations involved in the infiltration process were then evaluated, namely TiC/flux, flux/Al-7wt.%Si and TiC/flux/Al-7wt.%Si.

3. RESULTS

3.1 Infiltration Trials

Table 2 shows the results of the infiltration trials. It was found that TiC beds with no flux present could only be infiltrated at 1100°C under a protective atmosphere of Ar. When the flux was present, successful infiltration occurred at temperatures as low as 680°C . Infiltration occurred at all temperatures under Ar even with a 3:1 mass ratio, but only partial infiltration was seen in air even at 1100°C with a 1:1 ratio. The non-infiltrated part of the beds crumbled readily indicating that flux was not longer present and a discoloration of the TiC powder was also evident.

Table 2. Results of the infiltration trials (TiC:Flux).

T ($^\circ\text{C}$)	TiC		(3:1)		(2:1)		(1:1)	
	Ar	Air	Ar	Air	Ar	Air	Ar	Air
680	×	×	✓	×	✓	×	–	✓×
820	×	×	✓	×	✓	×	–	✓×
1100	✓	×	✓	×	✓	×	–	✓×
✓ Infiltrated				✓× Partially infiltrated				
× Non-infiltrated				– Not performed				

Figure 3 shows the typical appearance of the infiltrated samples without and with a flux ratio of 3:1, both in Ar. A very different appearance between these samples can be noticed. Whilst the sample infiltrated without flux looks dark and rounded, the flux-assisted infiltrated sample exhibits a white-metallic surface with some irregularities. The dark color of the fluxless TiC bed is because the sample strongly adhered to the walls of the graphite crucible. This sample exhibited very little macroporosity as can be seen in its longitudinal cross section.

The samples with flux were readily removed from the crucibles due to a shrinkage effect caused by the displacement of the flux during infiltration. The flux-assisted infiltrated samples presented random presence of round macropores, irrespective of processing temperature and flux content. In many cases the presence of flux was evident within these pores.

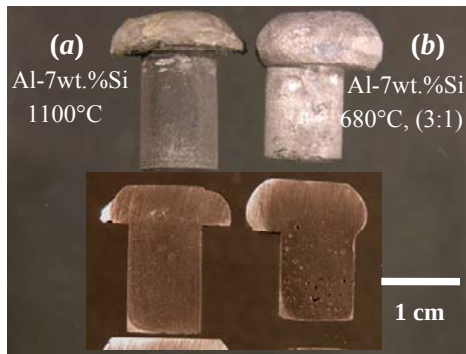


Figure 3. Appearance of the infiltrated samples.

3.2 Microstructure

Figure 4a shows a mixture of TiC and flux powders on the surface of a loosely compacted pellet. This image illustrates the type of microstructure expected in the bulk of the beds. Due to the large difference in particle size, 18 μm for TiC and from submicron to approximately 600 μm for the flux, mixing is not homogeneous and clusters of each phase can be observed. Figure 4b shows a cross section of the same pellet after heating it up to 680°C, holding for 15 minutes and cooling under flowing Ar. It can be seen that when the flux becomes liquid, it spreads throughout the TiC bed.

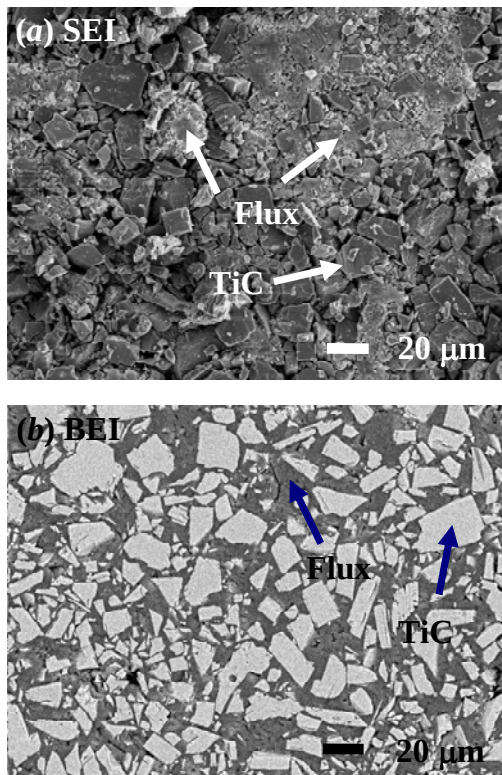


Figure 4. (a) TiC/flux mixture in the mass ratio 2:1 and (b) appearance of the same mixture after heating to 680°C, holding for 15 minutes and cooling.

Typical microstructures of the infiltrated samples are shown, in backscattered mode, in Figure 5 and a magnified view of these microstructures is shown in Figure 6. The white phase corresponds to the TiC particles embedded in the dark gray matrix (Al-7wt.%Si). SEM also showed the presence of discontinuities such as porosity and round defects, both small and large (such as those indicated by the arrow in Figure 5a), within the matrix. These round defects were found to be, according to EDX analysis, rich in K and F and are therefore most likely composed of flux.

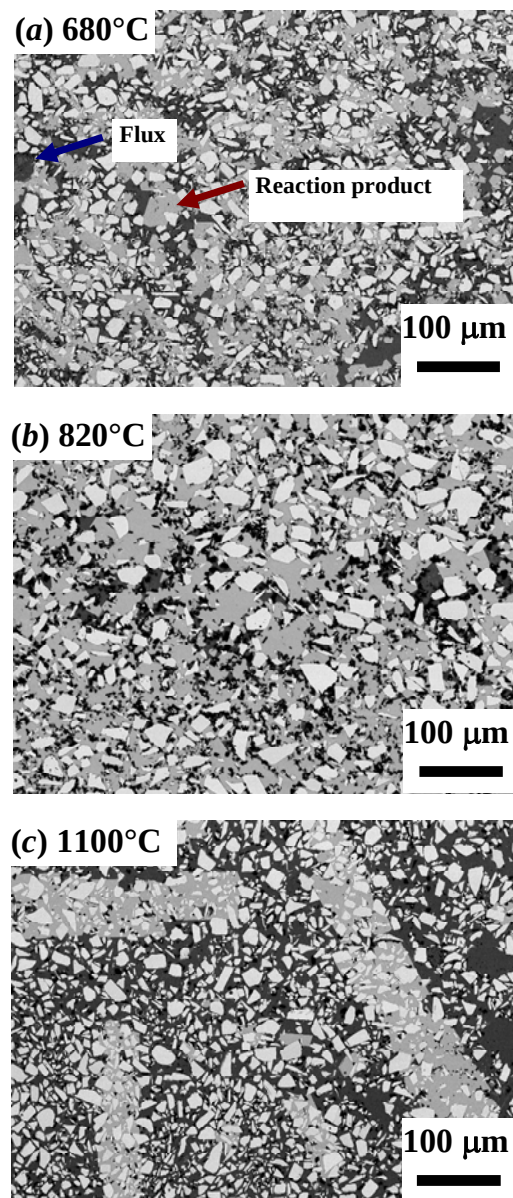


Figure 5. Typical microstructures of the infiltrated samples.

Microstructures of the Al-7wt.%Si-TiC composites show that the level of reaction taking place depended on the infiltrating temperature. At 680°C, besides the irregular white TiC particles, particles of a light gray blocky phase (several tens of micrometers in size), such as the one indicated by the arrow in Figure 5a, are present. At higher magnifications small (a few micrometers) black precipitates were observed, mostly located at the surface of the TiC particles.

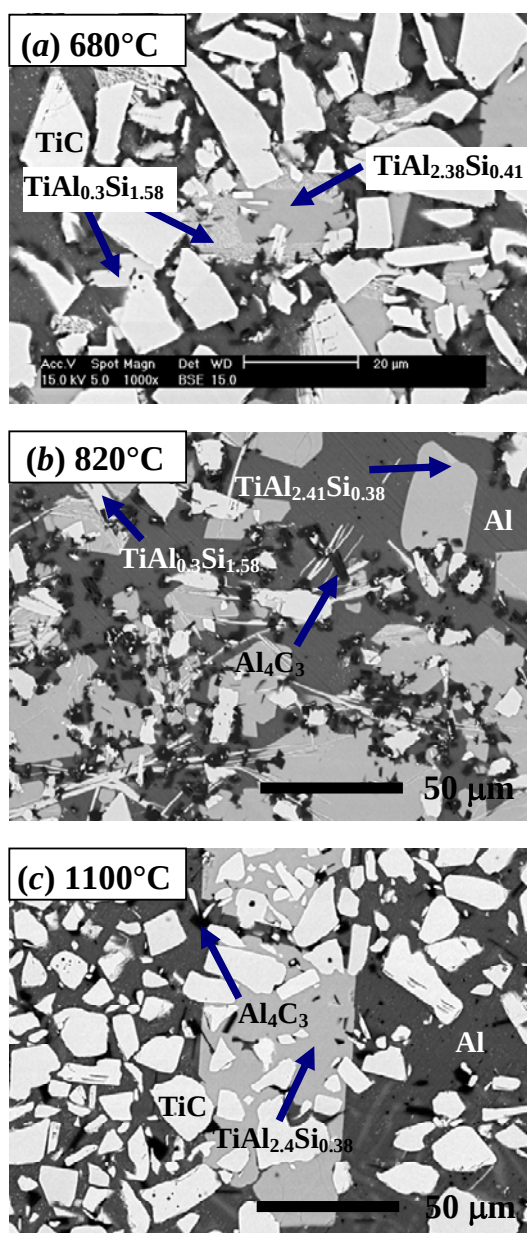


Figure 6. Microstructural details of the infiltrated samples.

At 820°C the microstructure was dominated by the presence of large light gray blocks which had coalesced to such an extent that in large areas of the sample the aluminium matrix was mostly replaced by this phase, as clearly observed in Figure 5b. The presence of the small black precipitates also considerably increased at this temperature and many TiC particles were found to be partly or fully surrounded by this phase.

At 1100°C no blocky particles of the light gray phase were seen. Instead, this phase appeared in the form of elongated large needle-shaped areas, several hundreds of micrometers in length. The number of small black precipitates was significantly reduced. A thorough examination of the reaction products was carried out using EDX analysis. These results revealed the small black phase to be an Al-C compound, most closely corresponding to Al_4C_3 and the light gray blocks and elongated needles to be ternary compounds with the average composition $\text{TiAl}_{2.39}\text{Si}_{0.39}$. Table 3 shows the average compositions of the complex intermetallic found in the different samples. At 680°C, besides the above ternary intermetallic, another ternary compound with the approximate composition $\text{TiAl}_{0.3}\text{Si}_{1.58}$ was also detected, the size of this intermetallic was far smaller than the $\text{TiAl}_{2.39}\text{Si}_{0.39}$ compound and most of the times the former was associated with the latter, as observed in Figure 6a. At 820°C, in isolated regions, thin needles with the approximate composition $\text{TiAl}_{0.3}\text{Si}_{1.58}$ were also detected (Figure 6b) but not observed at 1100°C (Figure 6c).

Table 3. Compositions for the intermetallic phases as measured by EDX analysis (at.%).

Temperature (°C)	Ti	Al	Si	Compound
680	26.34	62.83	10.83	$\text{TiAl}_{2.38}\text{Si}_{0.41}$
680	34.68	10.44	54.88	$\text{TiAl}_{0.3}\text{Si}_{1.58}$
820	26.28	63.58	10.14	$\text{TiAl}_{2.41}\text{Si}_{0.38}$
820	34.68	10.44	54.88	$\text{TiAl}_{0.3}\text{Si}_{1.58}$
1100	26.43	63.50	10.07	$\text{TiAl}_{2.4}\text{Si}_{0.38}$

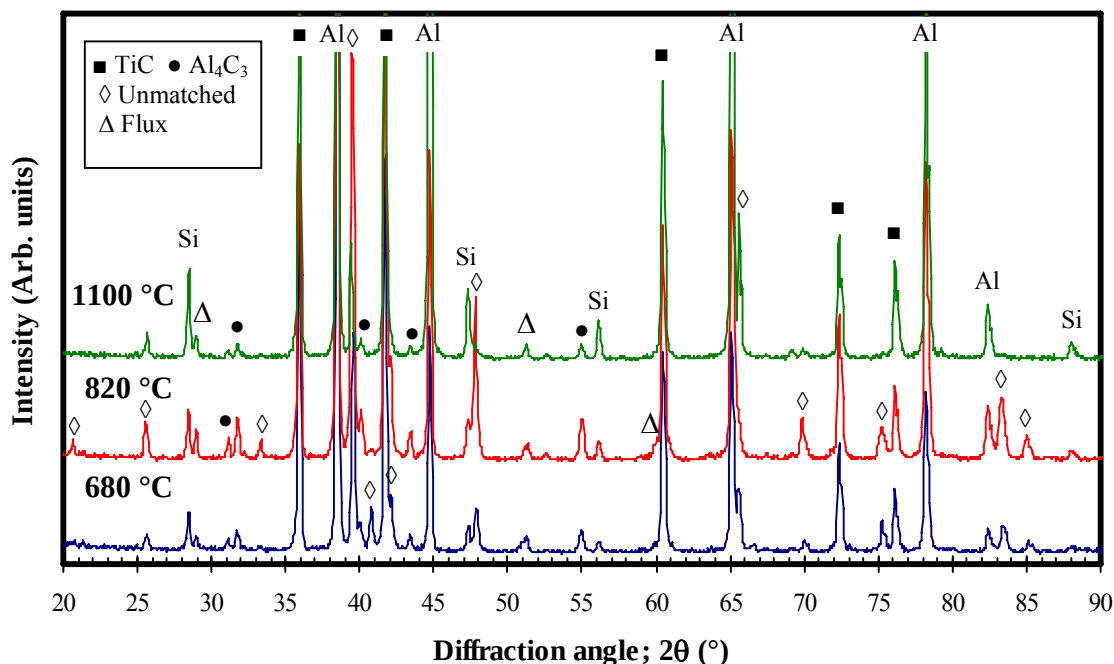


Figure 7. XRD patterns for the infiltrated samples in Ar using a TiC/flux ratio 2:1.

Complementary XRD analysis of the infiltrated samples confirmed the presence of some of the phases observed in the SEM, as shown in the XRD patterns in Figure 7. In addition to TiC and Al, reflections corresponding to the flux were present in all the patterns. The XRD patterns reveal the presence of Si, Al_4C_3 and a number of diffraction peaks that did not match with any of the JCPDS standards available. SEM-EDX characterization suggests that the unmatched reflections correspond to the ternary intermetallics. A semi-quantitative appreciation of the intensity of the peaks agrees well with SEM observations. At 820°C, the intensity of the diffraction peaks of Al_4C_3 and the unmatched reflections increase in comparison to 680°C, whilst conversely, at 1100°C, their intensity decreases, consequently, the intensities of Al and Si increase.

3.3 Thermal Analysis

Figures 8 and 9 show the DSC traces for the single components (TiC, flux, and the Al-7%wt.Si alloy) and for binary and ternary combinations of these phases when heating under flowing Ar and in air, respectively. Exothermic oxidation of TiC occurs in air but this was not observed when heating in argon and the trace is a straight line. Although an endotherm can be observed in the trace for the flux

at low temperature, followed by two minor events, these events correspond to the release of moisture from the flux and a number of solid state phase transformations. Melting of the flux occurs at approximately 545°C. Melting of the Al-7%wt.Si alloy exhibits two overlapping endothermic events, melting of the eutectic at 577°C and melting of primary aluminium at approximately 603°C. The Al-Si alloy is fully molten at 613°C.

Figure 8b shows the thermal events for the different binary combinations of TiC, flux and the Al-7%wt.Si alloy. Flux was present in all the samples and it was observed to melt at the same temperature in all cases, at 545°C. This melting event is overlapping with the Al-Si melting. In Ar, no interaction was observed between TiC and the flux and no obvious interactions were observed between the flux and the Al-7%wt.Si alloy. There were no obvious interactions in the ternary mixture, as shown in Figure 8c.

Figure 9 show the traces for the experiments conducted in air. Under this condition, the behavior described by the traces of the single components is as observed in Ar, except for TiC. Exothermic oxidation of TiC occurs in a number of stages, starting at approximately 430°C. In Figure 9b, the TiC/flux couples exhibit two consecutive

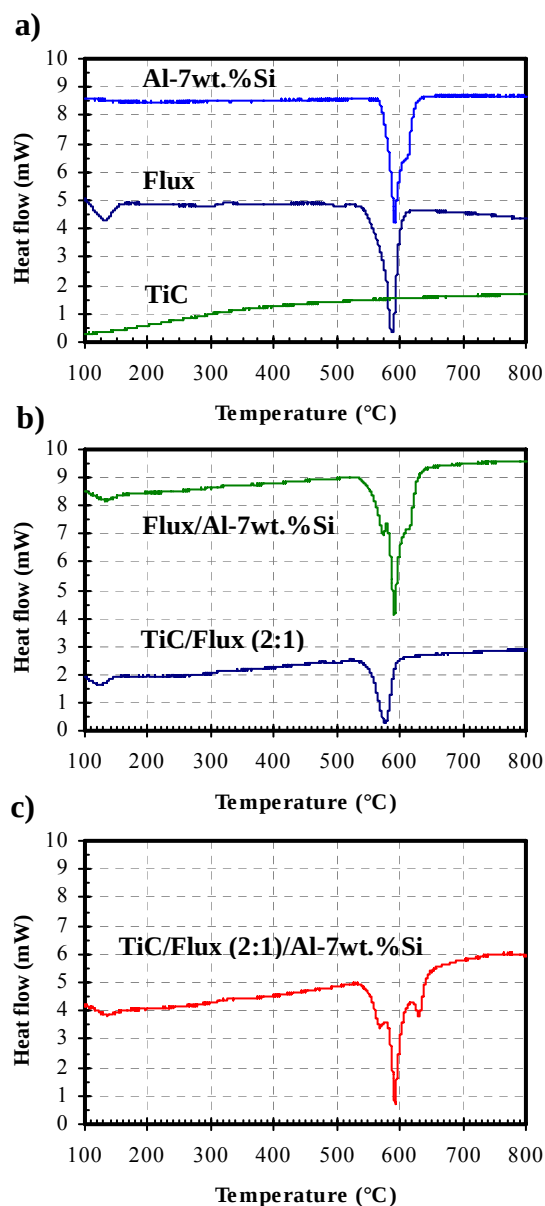


Figure 8. DSC traces for the single components and combinations of the phases involved in the flux-assisted infiltration process in Ar.

exothermic events, starting at approximately 430°C, followed by endothermic melting of the flux. For the 1:1 mass ratio, after flux melting, the trace returns to the baseline, whereas for the 2:1 mass ratio, an exothermic event is observed. In the flux/Al-7wt.%Si couple, melting endotherms of these phases overlap and after melting of the alloy is completed, there is an exothermic event and then the trace returns to the baseline.

Figure 9c shows the thermograms for the ternary mixtures heated in air. In all the samples TiC and flux are present, accordingly there are two

consecutive exothermic events followed by endothermic melting of the flux and the alloy. In the TiC/flux/Al-7wt.%Si system for a ratio 2:1, after melting of the alloy, the trace describes a large exothermic event which is interrupted by another small thermal event, after this, the trace seems to head back to the baseline. For the same combination, but for a ratio 1:1, the large exotherm observed for the 2:1 ratio after melting of the flux does not take place.

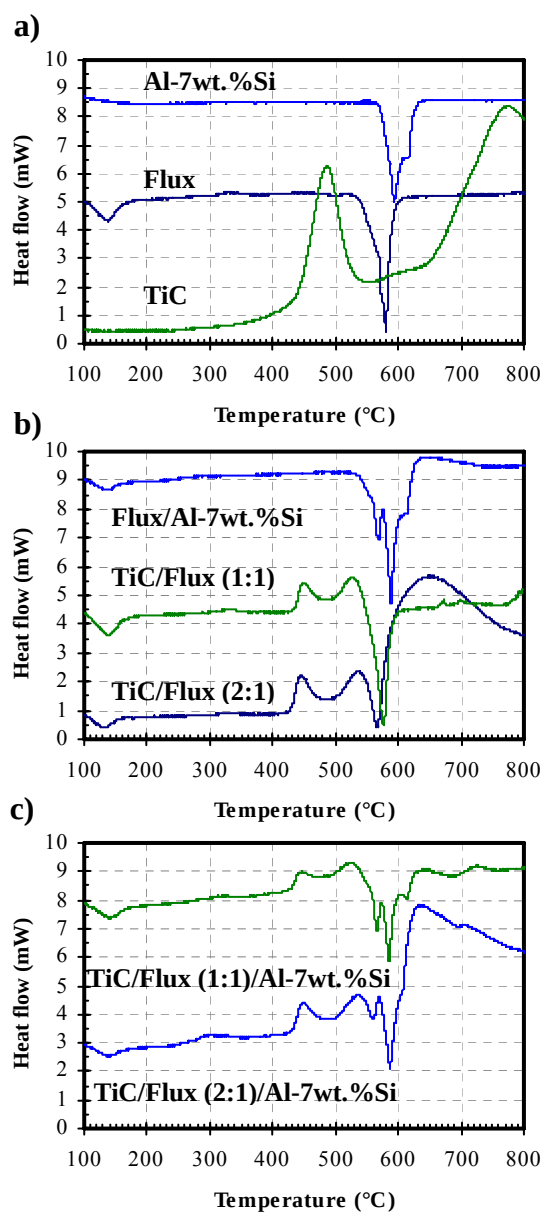


Figure 9. DSC traces for the single components and combinations of the phases involved in the flux-assisted infiltration process in air.

4. DISCUSSION

4.1 Infiltration

The presence of an oxide skin on Al melts represents a mechanical obstacle that has to be overcome before the actual wetting characteristics are exhibited in Al-alloy/TiC systems so that infiltration can occur. Since it was possible to infiltrate TiC beds with the aid of flux at temperatures as low as 680°C in both Ar and air (partially) and because it was impossible to infiltrate TiC beds without flux even at 1100°C in air, it is evident that the presence of flux in the TiC beds plays a decisive role in assisting the infiltration process. The K-Al-F flux, which is similar to cryolite and has high solubility for Al_2O_3 [5], is thought to dissolve the oxide skin and prevent further oxidation of the melt.

Thermal analysis indicated that on heating up to 800 °C in Ar, melting of the flux occurs first and, as revealed by the SEM, it spreads through the TiC network, forming a liquid coating on the surface of the particles. Melting of Al-7wt.%Si occurs when the temperature increases and the liquid flows by displacing the flux and filling the interstices left behind. It is thought that as soon as the flux melts and comes into contact with the aluminium, dissolution of the oxide skin can start [6]. After the Al-7wt.%Si melts, the presence of the flux and the Ar atmosphere prevents the Al from re-oxidising and intimate contact between TiC and a clean surface of Al-7wt.%Si is achieved. The fact that after heating the ternary mixtures in the DSC, TiC/flux/metal, a single metallic sphere coated by a thin and weak white film was obtained, suggests that wetting and spreading take place instantaneously and spontaneously and the bed is infiltrated without the need to apply pressure. Moreover, this fact also indicates that molten Al-7wt.%Si wets TiC at low temperatures if the oxide film is removed.

The sequence of events occurring during the infiltration process in air was found by DSC to firstly be exothermic oxidation of TiC, until the flux melts at 545°C, followed by endothermic melting of Al-7wt.%Si at 577°C. An exothermic event was observed in the Al-7wt.%Si/flux trace, which is thought to be combustion reaction between the melted flux, the surrounding air and solid or liquid alloy. This exothermic event may be related to the crust formation observed in the infiltration trials conducted in air. After the flux

melts and before it dissolves the Al_2O_3 layer, it spreads over the entire surface of TiC particles forming a liquid shield which protects the particles from further oxidation and cleans the particles of the light oxidation that had occurred up to that point. The different behavior described by the DSC traces for the TiC/flux mixtures suggests that a minimum quantity of flux is required to provide effective protection to the TiC particles from excessive oxidation which in fact agrees well with the results obtained in the infiltration trials.

It is known [7] that increasing the content of alloying additions to Al decreases the efficiency of the flux in dissolving the oxide skin. Molten Al-7wt.%Si infiltrated the TiC beds in Ar, but only partial infiltration was achieved when the trials were performed in air. A high content of Si and the enhanced oxidising conditions may have changed the composition of oxide film to such an extent that the flux could not efficiently remove it. It is known, however, that fluxes are capable of dissolving silicon oxides [8]. A possible explanation for partial infiltration of the Al-7wt.%Si alloy, could be due to interaction between the flux and the metal which consumes flux leaving the bed unprotected from oxidation. In the worst scenario such an interaction leads to the formation of a crust which impedes any infiltration.

4.2 Microstructure

The majority of the flux was displaced to the outer surfaces of the samples but there was a random macro and microscopic distribution of flux trapped within the Al matrix. The flux entrapment mechanism is not fully understood, liquid flux and Al are immiscible one in another, although, effects such as minimal difference in density between them (2.385 g/cm³ for liquid Al [9] and 2.2 g/cm³ for liquid flux [10]) and an increase in the viscosity of the flux due to dissolution of the oxide [11] are likely to contribute to flux entrapment. The presence of macropores may be ascribed to the wide particle size distribution of the flux and its entrapment during infiltration, so that these large pockets of trapped flux can readily come out during cutting and grinding of the samples.

SEM observations and XRD analysis showed different levels of TiC reaction with the matrix according to the infiltrating temperature, the reaction products being Al_4C_3 and $\text{TiAl}_{2.39}\text{Si}_{0.39}$, with the largest quantity of reaction products at 820°C. The reaction kinetics are slow in the pure

Al-TiC system with long holding periods being required to produce appreciable dissolution of TiC [12]. There is, however, a large interval above which TiC is thought to be thermally stable in molten Al and information about the kinetics of the reaction is limited. It is known, however, that the presence of Si accelerates the dissolution of TiC in liquid Al to produce Al_4C_3 and $\text{Ti}_x\text{Si}_y\text{Al}_{1-(x+y)}$ compounds [13,14]. Besides, the findings of this work agree well with the thermal stability of TiC particles in Al-7wt.%Si melts [15] in which the largest degree in reactivity was detected at 800°C, in a diluted system, with Al_4C_3 and $\text{TiAl}_{2.14}\text{Si}_{0.38}$ as the reaction products. It was determined that the ternary intermetallic has the crystalline structure of Al_3Ti with Si atoms partially replacing Al, which results in a sub-stoichiometric compound, a decrease in the lattice parameter and a shift in the X-ray reflections to higher 2θ angles. At higher temperatures the microstructure was characterized by intermetallics with an elongated needle shape and scarce Al_4C_3 , very similar to the microstructure of the sample infiltrated at 1100°C.

The formation of reaction products is of concern to the mechanical properties of the resulting composites. It is possible that reaction could be avoided with changes in processing parameters. Figure 10 shows the microstructure of Al-7wt.%Si-TiC samples infiltrated at 680°C when holding at temperature for 30 and 120 min. The crowded presence of reaction products when holding for 30 min confirms that the reaction occurs rapidly in this system and indicates that shorter times are required to minimize reaction. Alternatively, temperatures around 900°C with short holdings at temperature may also lead to composites with reduced levels of reaction products.

5. CONCLUSIONS

An Al-7wt.%Si alloy was successfully infiltrated into TiC beds at temperatures as low as 680°C in Ar with the aid of a K-Al-F based flux. With flux, partial infiltration was seen in air whilst the single TiC bed was only infiltrated in Ar at 1100°C.

When processing in Ar, the main function of the flux is to dissolve the oxide layer on the still solid Al-alloy and prevent any re-oxidation by isolating the surface from the surrounding atmosphere. When the Al melts and the oxide layer has been dissolved by the flux, intimate contact occurs between the liquid and the particles followed by

infiltration of the bed and the displacement of the flux to the outer surfaces of the sample. When processing in air, however, the molten flux also protects the TiC particles from heavy oxidation by spreading over the surface of the TiC particles.

Porosity and flux trapped in the aluminium matrix were observed in the microstructure. A significant degradation of the TiC particles to produce Al_4C_3 and $\text{TiAl}_{2.4}\text{Si}_{0.38}$ was seen at all processing temperatures with the largest quantity of reaction products observed at 820°C. The degree of reactivity and the reaction products are according to the findings in the thermal stability of TiC particles in Al-7wt.%Si melts.

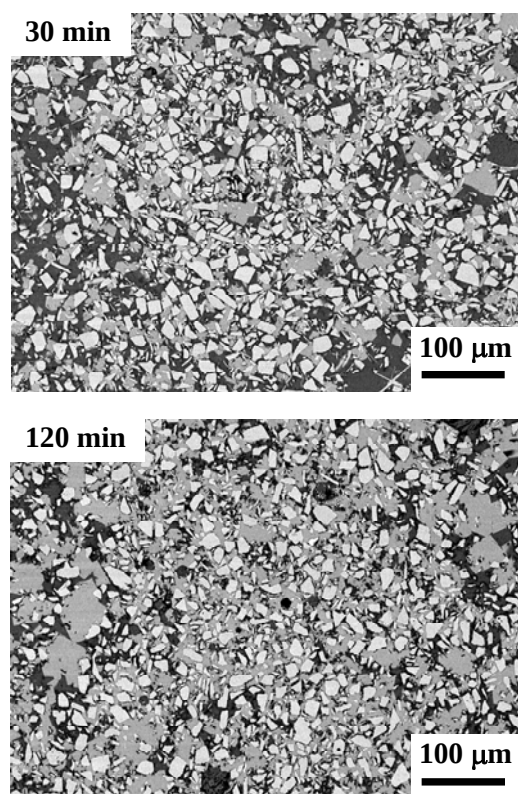


Figure 10. Microstructure of Al-7wt.%Si-TiC composites infiltrated at 680°C with different holding times.

6. REFERENCES

- [1] León CA, López VH, Bedolla E, Drew RAL, *J. Mat. Sci.* 2002; **37** (16): 3509-3514.
- [2] Contreras A, López, VH, León CA, Drew RAL, Bedolla E, *Adv. Technol. Mater. Mater. Proc. J.* 2001; **3** (1-2): 27-34.
- [3] Rocher JP, Quenisset JM, Naslain R, *J. Mater. Sci.* 1989; **24** (8): 2697-2703.
- [4] Jha A, Dometakis C, *Mater. Design.* 1997; **18**

- (4-6): 297-301.
- [5] Schamm S, Rabardel L, Grannec J, Naslain R, Bernard C, Relave O, *Calphad* 1990; **14** (4): 385-402.
 - [6] Roy RR, Sahai Y, *Mat. Trans. JIM*. 1997; **38** (6): 546-552.
 - [7] Field DJ, Steward NI, "Mechanistic Aspects of the Nocolok Flux Brazing Process". In: *SAE Technical Paper Series*, No. 870186. Detroit (USA): SAE International, 1987.
 - [8] Keller R, Welch BJ, Tabereaux AT, "Reduction of Silicon in an Aluminum Electrolysis Cell". In: Bickert CM (ed.), *Light Metals 1990* (Proceedings of the Technical Sessions of the Tms Light Metals Committee, 119th Annual Meeting). Warrendale (USA): The Metallurgical Society, Inc., 1990, p. 333-340.
 - [9] Brandes EA, Brook GB, *Smithells Metals Reference Book*, 7th Ed. Oxford (United Kingdom): Butterworth-Heinemann, 1992.
 - [10] Karantzalis AE, *Characterization of Al-TiC Composites Produced by a Flux-Assisted Casting Technique*, Ph D Thesis. Nottingham (United Kingdom): University of Nottingham, 1997.
 - [11] Torklep K, Oye HA, *Electrochim. Acta* 1980; **25** (2): 229-235.
 - [12] Kennedy AR, Weston DP, Jones MI, *Mat. Sci. Eng. A-Struct* 2001; **316** (1-2): 32-38.
 - [13] Mohanty PS, Gruzleski JE, *Scripta Metall. Mater.* 1994; **31** (2): 179-184.
 - [14] Mohanty PS, Gruzleski JE, *Acta Metall. Mater.* 1995; **43** (5): 2001-2012.
 - [15] López VH, Scoles A, Kennedy AR, *Mat. Sci. Eng. A-Struct* 2003; **356** (1-2): 316-325.