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The characteristics of intermetallic compounds and hardness of Ni-Cr/AC8A composites under different infiltration temperatures†

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Abstract

With the rapid development of aerospace and automobile industries, there is an increasing need for structural materials with excellent mechanical properties such as can be used at high temperatures. Aluminum matrix composite have attracted much attention because of its excellent performance, particularly the existence of the high temperature resistance inter-metallic compounds. Aluminum-based composites with inter-metallic compounds have been studied recently. In this study, Ni-Cr porous preform is reinforcement when Al-alloy (AC8A) is base metal and Ni-Cr/AC8A composites were manufactured under low pressure infiltration limited to the maximum of 0.5 Mpa at 700°C, 750°C, 800°C and 850°C, respectively. The microstructure and phase composition of the composites were evaluated by optical microscope, X-ray diffraction (XRD) and electro-probe micro analyzer (EPMA), intermetallic compounds Al_3Ni and CrSi were found as newly formed phases in the composites. In addition, Vickers hardness of Ni-Cr composites was also tested.

Keywords: Metal matrix composites; Inter-metallic compounds; Low pressure infiltration; Microstructure; Hardness

1. Introduction

In recent years, with the rapid development of aerospace and automobile industries, considerable theoretical and experimental investigations have been focused on the mechanical materials with the merits of high strength, large ductility, low density and low cost. Among all the developed materials, Al-based metal matrix composites (MMCs) are one of the most potential candidates, because of their improved strength, hardness and wear resistance over traditional Al alloys [1-3]. Recently intermetallic compounds have attracted much attention as high-temperature materials, they often offer a compromise between ceramic and metallic properties when hardness and resistance to high temperatures is important enough to sacrifice some toughness and ease of processing [4]. Al-Ni system intermetallic compounds stand out as one of the most important and promising candidates for high-temperature materials for the use in harsh environments [5, 6].

In addition, particle or fiber reinforced Al-based composites have been studied a lot. However, during the wear process, particles or fibers fell from matrix metal easily, the metal matrix composites became abrasive grain causing the reduction of the abrasion performance. In addition, in high temperature environment, reinforcement will be washed away with matrix softening, thus lose the reinforcement effect [7]. So in this research, we manufactured Ni-Cr/AC8A composites using Ni-Cr network preform as reinforcement at different infiltration temperatures, the porous Ni-Cr preform can bear the load and improves wear resistance of the composites during wear process.

In this paper, microstructure and hardness of intermetallic compounds in Ni-Cr/AC8A composites were tested and then the temperature influence on microstructure and hardness was evaluated.

2. Experimental method

2.1 Materials

In this study, Ni-Cr porous preform was applied as reinforcement, which has network multi-hole structure with 5% volume fraction (V_f). As Fig. 1(a) shows, the Ni-Cr porous was cylinder, 10 mm in radius and 30 mm in height, with aluminum alloy (AC8A) as the matrix metal shown in Fig. 1(b). Table 1 shows the chemical composition of the AC8A.

2.2 Manufacture conditions

We chose low pressure infiltration process to manufacture Ni-Cr/AC8A composites, the infiltration temperatures are 700°C, 750°C, 800°C and 850°C, respectively. The sketch map

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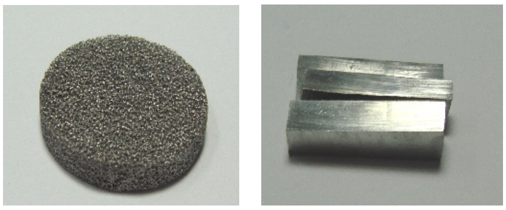
Table 1. Chemical composition of aluminum alloy AC8A (wt %).

Cu	Si	Mg	Fe	Mn	Ni	Ti	Cr
0.99	12.2	1.05	0.38	0.12	1.02	0.06	0.04



(a) (b)

Fig. 1. (a) Ni-Cr porous preform; (b) aluminum alloy (AC8A).

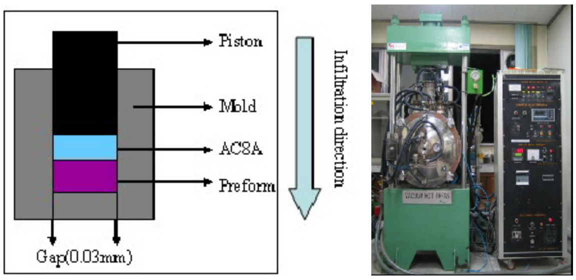


Fig. 2. Sketch map of infiltration principle and vacuum hot press for manufacturing composites.

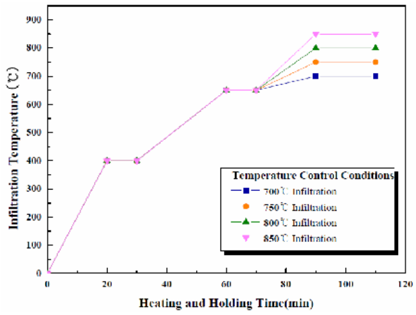
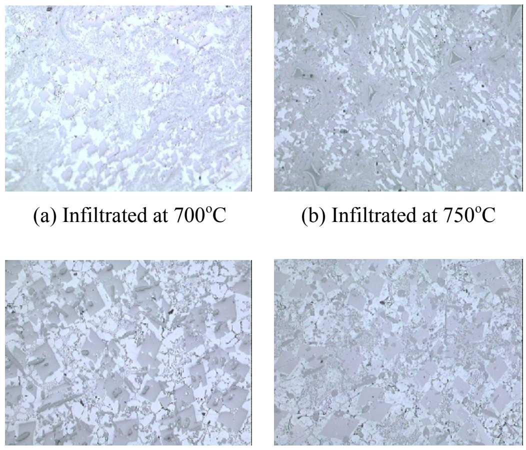


Fig. 3. Graph of relation between infiltration temperature and heating time.

of infiltration principle and vacuum hot press for manufacturing composites are shown in Fig. 2. Low pressure infiltration process can fabricate MMCs with a low infiltration pressure of less than 1.0 Mpa [8]. In this study we employed hydraulic cylinders and load cells for detecting the load, and the pressure used to induce penetration of the reinforcement by the matrix metal was limited to the maximum of 0.5 Mpa. The relation between infiltration temperature and heating time was shown in Fig. 3.

2.3 Microstructure and hardness analysis

Microstructure was observed by optical microscope first, then component analysis was conducted by XRD (X-ray diffraction), and lastly EPMA (electron probe X-ray microanalyses) were used for qualitative analysis.



(a) Infiltrated at 700°C (b) Infiltrated at 750°C

(c) Infiltrated at 800°C (d) Infiltrated at 850°C

Fig. 4. Optical microscope micrograph (X100) of Ni-Cr/AC8A composites manufactured at different infiltration temperature.

Micro-Vickers hardness measurements were undertaken on micro-hardness tester (model: MVK-G1), using a load of 50g and for 10 seconds, at least ten measurements were made on phase of each sample. Then the hardness of phases under different temperatures were analyzed and compared.

3. Results and discussion

3.1 Microstructure and phase analysis

The phases were mainly identified by the microstructure, XRD and EPMA analyses. Microstructure images of Ni-Cr/AC8A composites under different infiltration temperatures were shown in Fig. 4. We can see that when infiltration temperature is at 700°C and 750°C, the microstructures are similar, there're some elongated and gray colour phases and a little Ni-Cr preform structure remained, but when infiltration temperature increased to 800°C and 850°C, gray colour phases became nearly quadrate shape and appeared some dark colour phases, and Ni-Cr preform framework nearly disappeared, because with the increasing of the infiltration temperatures, the reaction can be completed, and lead to the forming of new phases.

From the XRD results Fig. 5, four main components were detected. At four different infiltration temperatures, Al, Al_3Ni and Si component were detected, but CrSi were only detected from the composites manufactured at 800°C and 850°C.

The primary importance of EPMA is the ability to acquire precise, quantitative elemental analyses at very small "spot" sizes. So we use it to analyze the components of different appearances.

Fig. 6 shows the electron images, according to the atomic ratio data, we know the gray colour phase is Al_3Ni. The dark colour phase near the gray phase (Al_3Ni) is CrSi, and CrSi intermetallic compound just exist in the composites of infiltration temperature at 800°C and 850°C. We know Si and Al phase also were found, but from microstructure, we can't

Table 2. Hardness average values of intermetallic compounds under different infiltration temperatures.

Infiltration temperature	700°C	750°C	800°C	850°C
Al_3Ni	660HV	654HV	660HV	723HV
CrSi	-	-	672HV	887HV

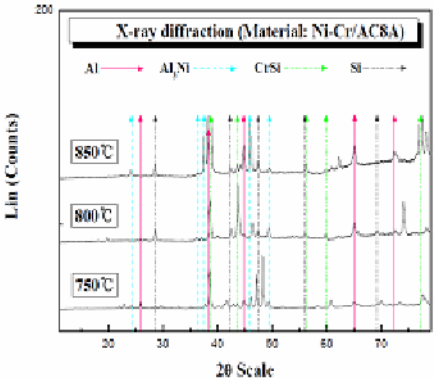
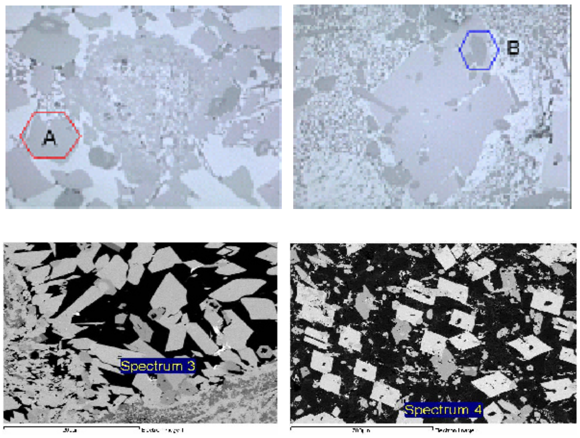


Fig. 5. XRD analysis of Ni-Cr/AC8A composites with infiltration temperatures at 750°C, 800°C and 850°C.



Elem.	A		B	
	Al	Ni	Si	Cr
Atomic%	75.05	24.95	45.77	32.23
Totals	100.00		100.00	

Fig. 6. Microstructure image (X500) and EPMA data analysis of phase.

clearly distinguished Si and Al, the two elements colour are similar, Si and Al phases are almost together.

3.2 Vickers-hardness measurements

We obtained Vickers-hardness of intermetallic compounds Al_3Ni and CrSi phase in Ni-Cr composites. Table 2 shows the average value of CrSi phase and Al_3Ni phase when infiltration temperature at 700°C, 750°C, 800°C and 850°C.

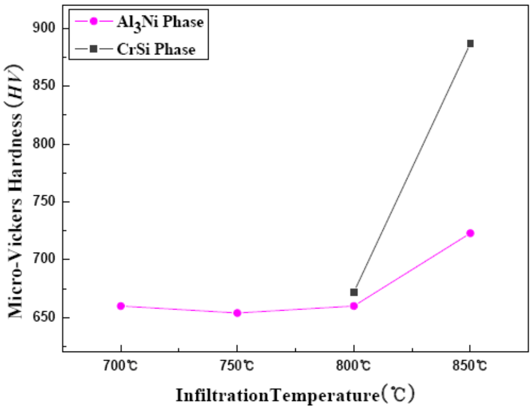


Fig. 7. Micro-Vickers hardness of Al_3Ni and CrSi phase in Ni-Cr/AC8A composites.

We can see that the hardness value of Al_3Ni phase is higher with infiltration temperature increased; minimum average value is 654 HV with infiltration temperature at 750°C and maximum average value is 723 HV at 850°C. CrSi phase has the same tendency, minimum average value is 672 HV at 800°C and maximum average value is 887 HV at 850°C. To observe directly, Fig. 7 shows the trend curve of hardness based on Table 2. We can easily see that Vickers hardness value of CrSi phase is higher than Al_3Ni phase at each infiltration temperatures, respectively. Usually hardness of Al-alloy (AC8A) is about 100 HV, and hardness of composites with intermetallic compounds is higher than AC8A. Ni-Cr/AC8A composites with the existence of intermetallic compounds can improve the hardness.

4. Conclusions

In this paper, we manufactured Ni-Cr/AC8A composites at different infiltration temperatures. The microstructure and hardness were studied, and we obtained the conclusion as follows:

(1) Al_3Ni and CrSi intermetallic compounds are new formed phase in Ni-Cr composites during low pressure infiltration process.

(2) Through EPMA analysis, it can be seen that gray colour phase is Al_3Ni and deep colour phase is CrSi in micrograph.

(3) As the infiltration temperature increased, hardness value of intermetallic compounds became higher, infiltration temperature at 850°C, the hardness value of Al_3Ni and CrSi phases reached their maximum, which are 723HV and 887 HV.

Acknowledgment

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