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METAL MATRIX COMPOSITES REINFORCED WITH Al–Co–Cu PARTICLES

Cu- or Al-based composites reinforced with quasicrystalline Al–Co–Cu particles are produced by infiltration without applying pressure. For fabricating composites, Л62, БрОЦ 10-2 or АМг30 alloys are selected as matrix materials, and the $Al_{65}Co_{20}Cu_{15}$ alloy as reinforcement. Dissolution mechanisms are reviewed to estimate the role of the decagonal quasicrystalline and coexisting crystalline phases on interfacial structure formation. There exists a crystalline H-phase, melting temperature of which is low enough to be dissolved into the molten metal matrix during infiltration. The quasicrystalline D-phase has a higher melting temperature with better resistance to dissolution. According to the microstructural observation, a macrohetergeneous structure is achieved for Л62 matrix composite. For БрОЦ 10-2 matrix composite infiltration time and fabrication temperature should be minimized as much as possible to guarantee the macroheterogeneous composite structure. In the АМг30 matrix composites, the better quality of macroheterogeneous structure is preserved due to the lowest level of interfacial reactions.

Keywords: composite materials, metal matrix, infiltration, phase transformations.

Виготовлено композиційні матеріали на основі Cu та Al, зміцнені частинками квазікристалічного сплаву Al–Co–Cu, за допомогою методу вільного просочення. Для отримання композиційних матеріалів застосовано сплави Л62, БрОЦ 10-2 або АМг30 в якості матриць та сплав $Al_{65}Co_{20}Cu_{15}$ в якості наповнювача. Механізми розчинення розглянуто з урахуванням впливу декагональної квазікристалічної та співіснуючих кристалічних фаз на структуроутворення меж поділу між наповнювачем та матрицею. Показано, що при просоченні в розплавленій металевій матриці розчиняється кристалічна H-фаза наповнювача з відносно низькою температурою плавлення. Квазікристалічна D-фаза, що відрізняється більш високою температурою плавлення, при цьому практично не розчиняється. Металографічними дослідженнями встановлено, що композиційний матеріал з матрицею Л62 має макрогетерогенну структуру. Для отримання макрогетерогенної структури композиційного матеріалу з матрицею БрОЦ 10-2 слід мінімізувати тривалість і температуру просочення. Найкраще виражена макрогетерогенна структура композиційного матеріалу з матрицею АМг30 зберігається завдяки найнижчому рівню інтенсивності міжфазних реакцій.

Ключові слова: композиційні матеріали, металева матриця, просочення, фазові перетворення.

Изготовлены композиционные материалы на основе Cu и Al, упрочненные частицами квазикристаллического сплава Al–Co–Cu, с помощью метода свободной пропитки. Для получения композиционных материалов использованы сплавы Л62, БрОЦ 10-2 или АМг30 в качестве матриц и сплав $Al_{65}Co_{20}Cu_{15}$ в качестве наполнителя. Механизмы растворения рассмотрены с учетом влияния декагональной квазикристаллической и сосуществующих кристаллических фаз на структурообразование границ раздела между наполнителем и матрицей. Показано, что при пропитке в расплавленной металлической матрице растворяется кристаллическая H-фаза наполнителя , имеющая относительно низкую температуру плавления. Квазикристаллическая D-фаза, которая отличается более высокой температурой плавления, при этом практически не растворяется. Металлографическими исследованиями установлено, что композиционный материал с матрицей Л62 имеет макрогетерогенную структуру. Для получения макрогетерогенной структуры композиционного материала с матрицей БрОЦ 10-2 следует минимизировать продолжительность и температуру пропитки. Наиболее выраженная макрогетерогенная структура композиционного материала с матрицей АМг30 сохраняется благодаря минимальному уровню интенсивности межфазных реакций.

Ключевые слова: композиционные материалы, металлическая матрица, пропитка, фазовые превращения.

1. Introduction

Quasicrystals exhibit exclusive properties, such as high hardness, low friction coefficient, high wear resistance etc. [1]. However, quasicrystals are extremely brittle at room temperature. Therefore, quaisicrystalline alloys could be used as reinforcement particles in metal matrix composites in order to circumvent their intrinsic brittleness [2]. The first successful application of quasicrystals is the production of Al composites reinforced by Al–Cu–Fe particles [3–5]. The metal matrix and the reinforcement particles are blended using mechanical milling technique, and later extruded to produce a composite material, which increases the hardness of the composite. But attempts should be made to preserve the quasicrystalline icosahedral phase during heating, for instance by pre-oxidizing or using Ni-coated reinforcement particles in order to place a diffusion barrier at the matrix-particle interface and block diffusion of aluminum during annealing [6,7]. These measures successfully increase the content of the quasicrystalline phase in the resulting composite materials. Further enhancements are expected with using a gas-pressure infiltration technique to produce composite materials with Al-based matrix reinforced by Al–Cu–Fe particles, which applies a device that injects under the pressure the matrix in the liquid state into a preform of reinforcement particles [8, 9]. This procedure leads to rather complex composite materials containing a variety of phases that are in the vicinity of the icosahedral phase in the Al–Cu–Fe phase diagram.

Meanwhile, the investigations performed on conventionally solidified Al–Co–Cu alloys confirm that the alloy system forms decagonal quasicrystalline phase that is stable up to ~ 1000°C [10]. Thus, the use of Al–Co–Cu particles to produce metal matrix composites constitutes a promising challenge.

Taking into account the higher stability of the decagonal quasicrystalline phase observed in the Al–Co–Cu alloys compared with the icosahedral phase of Al–Cu–Fe alloys, the aim of the paper is to investigate the reactions proceeding at the matrix-particle interfaces of the composites reinforced with Al–Co–Cu particles.

2. Experimental procedure

The particle-reinforced metal matrix composite materials were produced with using infiltration technique without applying pressure [11]. The composites were fabricated by melting the metal matrix with a superheat of 50°C and infiltrating reinforcing particles during 40 – 60 minutes. The particles were prepared from Al–Co–Cu ingots by hammer milling. The ingots were basically of the decagonal quasicrystalline phase (D-phase), but also contain a small amount of crystal phases. The final particle size was ranging between 500 μm and 1500 μm. Cu- or Al-based alloys, namely Л62, БрОЦ 10-2 or АМг30 alloys, were used as metal matrixes. Different matrix compositions were selected for the following reasons:

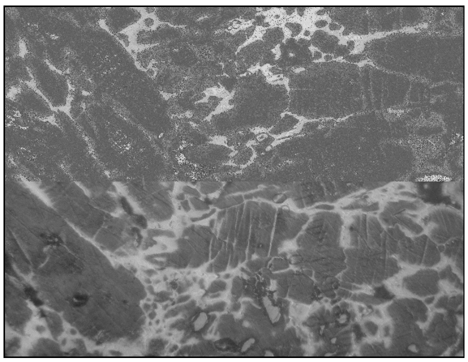
- Л62 alloy because it exhibits high anticorrosive properties;
- БрОЦ 10-2 alloy because it has been reported as alloy with low friction coefficient;
- АМг30 alloy because it has lower melting temperature as compared to pure Al.

For all composites, the quasicrystalline particles were adjusted to correspond to a volume fraction of about 50 vol. pct. of the total composite volume. The cooling time to room temperature was nearly 3 hours.

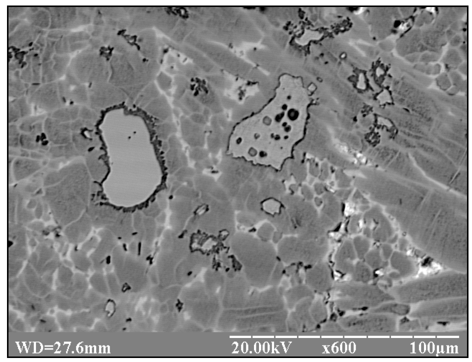
The instruments used in the microstructural characterization of the investigated composite materials were optical microscopes (OM) *Neophot* and *GX-51*, quantitative analyzer *Epiquant*, scanning electron microscope (SEM) *РЭМА 102-02*. The alloys were also studied by powder X-ray diffraction (XRD) using CuK_{α} radiation. The local phase compositions were determined in SEM by energy dispersive X-ray (EDX) analysis. The usual scattering of the measurements was about ± 0.2 at. pct. The porosity level was determined by image analysis to be approximately 3 pct.

3. Results and discussion

Fig. 1 shows the representative solidification microstructure of $Al_{65}Co_{20}Cu_{15}$ particles formed during the preparation process. In Fig. 1, a where cooling rate of 100 K/s was imposed during solidification, there exist three different phases, discernible by the image contrast as mottled dark and light grey in the rather white region. According to phase identification of EDX, the mottled dark region consists of quasicrystalline decagonal D-phase that volume fraction is about 65 pct. Light grey inclusions embedded in D-phase correspond to $Al_4(Co,Cu)_3$ phase (β′-phase). The rather white region corresponds to the $Al_3(Cu,Co)_2$ phase (H-phase).



(a)

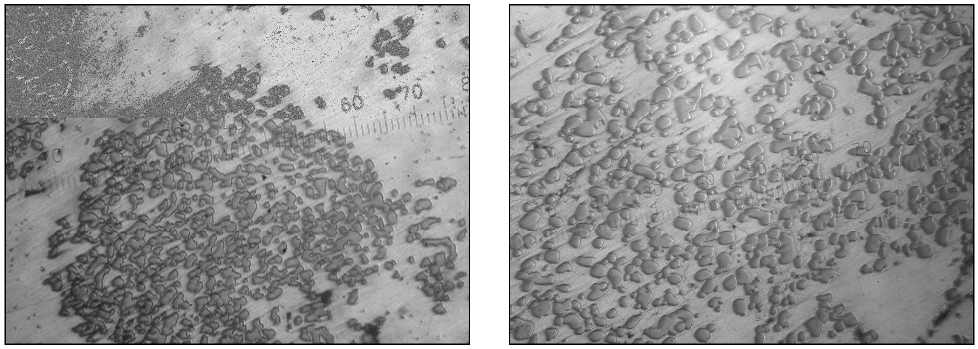


(b)

Fig. 1. Microstructure of $Al_{65}Co_{20}Cu_{15}$ alloy: a – optical micrograph, ×400; b – SEM micrograph, ×600.

After infiltration, all composite materials contain reinforcing particles embedded in the matrix. Quasicrystalline phases of the particles are present in the final materials. Fig. 2, a shows the Л62 matrix composite material, where due to the complete dissolution of crystalline H-phase the quasicrystalline D-phases are seen to be distributed throughout the metal matrix nonuniformly. They are observed preliminary in the places where reinforcing particles should be located. The quasicrystals are not decomposed. The size of quasicrystalline phase decreases to ~ 20 – 40 µm. Scanning electron microscopy shows the absence of segregated phases around the particles in the structure. The wettability of the matrix and D-phase is good. No evidence of the presence of cavities at interfaces nor in the matrix is found with optical microscopy, which shows that full infiltration of reinforcement particles is obtained with using the present infiltration process. The best bonded interfaces should give rise to the high level of mechanical properties.

In Fig. 2, b most quasicrystalline phases are normally observed to be uniformly distributed in the БрОЦ 10-2 matrix alloy. Here, it is noticed that crystalline H-phase, which had been formed during casting Al–Co–Cu alloy, was also dissolved into the БрОЦ 10-2 matrix. A closer observation at higher magnification revealed that a relatively good bonding between the quasicrystalline phases and the matrix has been achieved during fabrication. However, special attention should be paid to minimizing the contact time between the molten metal and reinforcement particles, in order to reduce the interphase reactions which could lead to composite strength degradation as a result of non-macroheterogeneous structure of the composite.



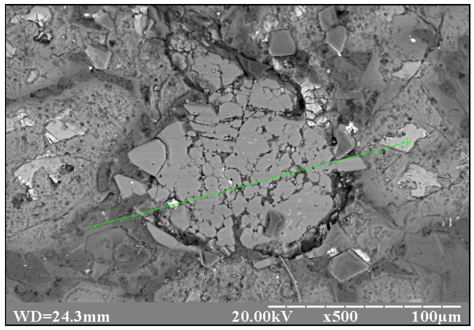
(a) (b)

Fig. 2. Microstructure of composites reinforced with Al–Co–Cu particles infiltrated by : a – Л62 alloy, ×400; b – БрОЦ 10-2 alloy, ×600.

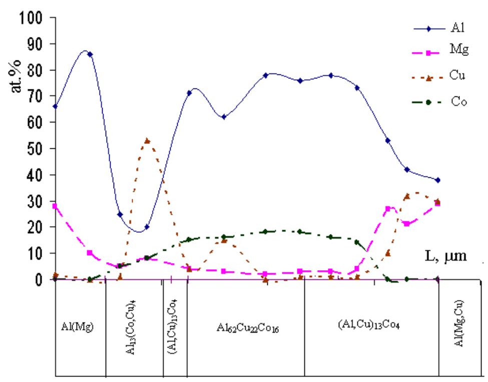
The infiltration by АМг30 alloy affects composite material microstructure and the dissolution kinetics (Fig. 3). The reinforcing particles slightly dissolve into the matrix. The complete dissolution of crystalline H-phase is not observed. Therefore, the molten matrix does not penetrate along the boundaries of quasicrystalline D-phase. The most reinforcing particles during solidification process are finally dispersed in the matrix. The interfacial zones composed of several layers with different aluminum, cobalt and copper contents are observed around the reinforcing particles. The first layer directly adjacent to the particle contains D-phase inclusions imbedded in $Al_{13}(Co,Cu)_4$ (M-phase). From the particle outward, Cu is detected in the layers with a content that varies from place to place for a given composite, but which does not exceed 6.97 at. %. Correspondingly, cobalt content increases from 33.13 % to 38.1 % and aluminum content decreases from 65.87 % to 53.99 %. Mg diffusion out of the matrix is obvious, since up to 1 at. % of this element is present in the outer layer between the particle and matrix. It is interesting to point out that there are no distinct boundaries between the layers. In the metallic matrix two solid solutions are seen. They differ in composition as follows: 85.27 – 87.86 % Al; 7.82 – 10.35% Mg; 1.79 – 6.91 % Cu for first solution and 13.58 – 23.54 % Mg; 39.73 – 50.90 % Al; 25.56 – 46.78 % Cu for second one. All phase transformations can be coherently explained by Cu and Co depletion of the Al–Co–Cu reinforcing particles and Al fluxes from the particles to the matrixes and/or vice versa.

Taking into account the above considerations, the reactions occurring during the infiltration process may be described by the following scenario. The origin of the formation of the interfacial zones is related to a partial dissolution of the particles during infiltration in the molten matrixes. This process enriches small areas of matrix melt with constituent components of the particles. According to the phase diagrams, during solidification, the enriched liquid forms corresponding interfacial zones around the particles. For the Л62 or БрОЦ 10-2 matrix composites the H-phase dissolves completely, but for the АМг30 matrix composite it does only partially.

Macroheterogeneous structure of the composite materials is preserved only for the Л62 and АМг30 matrix composites. In the АМг30 matrix composite, the reinforcing particles have an M-phase shell that results from partial dissolution of H-phase. The interface reactions are at the lowest level, which certainly favored the stability of the quasicrystalline D-phase.



(a)



(b)

Fig. 3. Composite reinforced with Al–Co–Cu particles infiltrated by АМг30 alloy: a – SEM micrograph, ×500; b – distribution of Al, Mg, Cu, Co across the interfacial zone between the particle and the matrix.

5. Conclusions

In this study, three composite materials with Cu- and Al-based matrix reinforced with Al–Co–Cu particles initially of quasicrystalline decagonal phase are produced by infiltration without applying pressure. It is shown that such a fabrication technique leads to formation of flawless interfacial zones between the particle and matrix resulting from specific dissolution and diffusion processes. The morphology and spatial distribution of the quasicrystalline D-phase depend on the composite material. In the Л62 or БрОЦ 10-2 matrix composites crystalline H-phase of the particles dissolves completely, and the quasicrystalline phase is dispersed with different degree of uniformity in the metal matrix. This degree depends on interphase reactions and increases for БрОЦ 10-2 matrix composite material. In the АМг30 matrix composite the M-phase encircles reinforcing

Al–Co–Cu particles due to partial dissolution of H-phase that is located, mainly, close to the interface.

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