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## HIGH PERFORMANCE COMPOSITES

Вивчено процеси контактної взаємодії, що відбуваються на границях поділу розчинно-дифузійного типу в макрогетерогенних композиційних матеріалах, отриманих способом вільного просочення. В якості наповнювачів застосовано тверді сплави, що мають мікро-, квазі- або кристалічну структуру, а в якості зв'язок – сплави на мідній або залізній основі. Описано класифікацію досліджених границь поділу з урахуванням температурно-часових залежностей кутів контактної взаємодії, вимірених за методом «затверділої краплі», і ширини зон контактної взаємодії, визначеної за допомогою металографічного аналізу. Ця класифікація дозволила виділити три типи зон контактної взаємодії залежно від часу, необхідного для досягнення квазірівноважних умов на границях поділу. Показано вплив інтенсивності процесів розчинення та дифузії на структуру зон контактної взаємодії кожного типу. Встановлено, що стабільність фаз наповнювача при дії розплавленої зв'язки під час просочення зростає в наступній послідовності: кристалічні фази → мікрокристалічні фази → квазікристалічні фази. Запропоновано керувати процесами структуроутворення композиційних матеріалів за рахунок варіювання співвідношення фаз різної стабільності у структурі наповнювача. Обґрунтовано склад композиційних матеріалів, призначених для роботи в абразивних і корозійних середовищах.

**Ключові слова:** макрогетерогенні композиційні матеріали, зв'язка, наповнювач, границі поділу, квазірівноважні умови, стабільність, високі корозійні й абразивні властивості.

Изучены процессы контактного взаимодействия, протекающие на границах раздела растворо-диффузионного типа в композиционных материалах, полученных методом свободной пропитки. В качестве наполнителей использованы твердые сплавы с микро-, квази- или кристаллической структурой, а в качестве связки – сплавы на медной или железной основе. Описана классификация изученных границ раздела с учетом температурно-временных зависимостей углов контактного взаимодействия, измеренных по методу «лежащей капли», и ширины зон контактного взаимодействия, определенной методом металлографического анализа. Данная классификация позволила выделить три типа зон контактного взаимодействия в зависимости от времени, необходимого для достижения квазиравновесных условий на границах раздела между наполнителем и затвердевшей связкой. Показано влияние интенсивности процессов растворения и диффузии, протекающих на границах раздела во время пропитки, на структуру зон контактного взаимодействия каждого типа. Установлено, что стабильность фаз наполнителя при воздействии расплавленной связки во время пропитки возрастает в следующей последовательности: кристаллические фазы → микро-кристаллические фазы → квазикристаллические фазы. Предложено управлять процессами структурообразования композиционных материалов за счет варьирования объемного соотношения фаз различной стабильности в структуре наполнителя. Обоснованы составы композиционных материалов для работы в абразивных и коррозионных средах.

**Ключевые слова:** макрогетерогенные композиционные материалы, связка, наполнитель, границы раздела, стабильность, высокие коррозионные и абразивные свойства.

The contact interaction processes at the interfaces of dissolution-and-diffusion type of macroheterogeneous composites obtained by furnace infiltration were studied. The alloys containing micro-, quasi- or crystal phases were used as fillers and copper- or iron-based alloys as binders. A classification of the investigated interfaces was proposed taking into account the dependencies of the wetting angles measured by still drop method and the depth of contact interaction zones determined metallographically on temperature and duration of infiltration. This classification allowed distinguishing three types of the interfaces depending on the time necessary for quasi-equilibrium to be achieved. The influence of dissolution-and-diffusion interfacial processes intensity on the structure of the zones of each type was shown. The stability of the filler phases effected by the molten binders during the infiltration was established to increase in the following sequence: crystal phases → microcrystal phases → quasicrystal phases. It was suggested to control structure formation of the composites by varying a volume ratio of the phases of different stability in the filler structure. The composites compositions designated for abrasion or corrosion wear applications were substantiated.

**Key words:** macroheterogeneous composites, binder, filler, interfaces, quasi-equilibrium conditions, temperature-and-time modes, high corrosive and abrasive properties.

## Introduction

Composites find the wide application as coatings to protect and restore the quick-worn parts of the equipment. These materials are characterized by a thermodynamic instability due to the presence of highly developed interfaces [1]. The instability results in intensive contact interaction which can lead to the formation of new undesirable phases at the interfaces, thus deteriorating the service characteristics. Therefore this work is dedicated to searching the ways to control interfacial reactions at the interfaces of dissolution-and-diffusion type of the macroheterogeneous composites obtained by infiltration without applying pressure.

## Experimental procedure and results

The composite materials were produced from copper- or iron-based binders and reinforcing particles made of alloys containing micro-, quasi- or crystal phases. A cooling rate of the particulate was from 10 to  $10^3$  K/s. Then the reinforcing particles were mixed in proportion, put in the mold, and infiltrated by metal binder at 1000 – 1200 °C. The temperature range was selected with a view to infiltrating effectively and avoiding destruction of the original reinforcing particles. While infiltrating, the holding time ranged from 30 to 60 minutes.

Corrosion resistance was examined using gravimetric and potentiostatic methods. Aggressive media were chosen in order to investigate corrosion processes proceeding with oxygen and hydrogen depolarization. The specimens were corroded in the following aqueous solutions: 3 % NaCl, 3 %  $\text{Na}_2\text{SO}_4$ , 2N  $\text{CH}_3\text{COOH}$ , 1N HCl, 5N  $\text{H}_3\text{PO}_4$ , 0,5N  $\text{H}_2\text{SO}_4$ , 5 %  $\text{HNO}_3$ . Tests of 4 hours and 5 days in the acid and neutral media, respectively, were run at  $22 \pm 2$  °C. Silver-chloride electrode was used as the reference specimen, the auxiliary electrode being one of platinum. Abrasive wear tests were carried out by means of a rotary tester in ambient air at 20 °C. Specimens were fixed on the rotary disk and ran 413 m on the abrasive cloth. Relative wear resistance was calculated against 40 X13 steel. Methods of metallographic, X-ray, micro-X-ray analyses were used. Fractographs of all the studied specimens were studied on SEM.

The structure of the composites studied features filler particles of irregular or spherical shape depending on cooling rate embedded in metal matrix. Particles size is from 0.5 to 2 mm. The interfacial zones between the filler and the matrix (i.e. solidified binder) are produced as a result of dissolution and diffusion processes (Fig. 1).

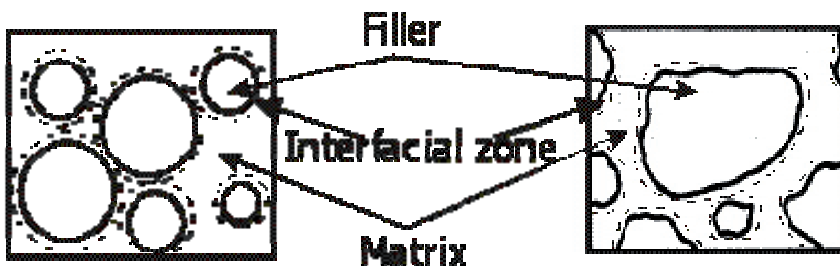


Fig.1. Schematic structure of the studied macroheterogeneous composites

To estimate phase stability the time dependencies of the wetting angles and the width of interfacial zones have been used. These dependencies make it possible to evaluate time interval necessary for setting quasi-equilibrium conditions at the interfaces. Quasi-equilibrium is assumed to be reached on the expiry of interval  $t$  when no visible changes in the values of wetting angles and interfacial zones width can be revealed. Comparing the time interval  $t$  with the infiltration duration  $\tau$  three types of interfacial zones of

diffusion-and-dissolution type at the interfaces of the investigated composites can be distinguished [2]. The first type of the interfacial zone structure is observed when quasi-equilibrium at the interfaces is set within 5 to 10 minutes, i.e.  $t \ll \tau$ . In this case the filler phases dissolve at the minimal rate, mainly, due to diffusion of the atoms from filler to molten binder. Therefore, interfacial zones are viewed only from the matrix side.

When quasi-equilibrium at the interfaces can be reached on the expiry of the period that is comparable to the infiltration duration, i.e.  $t \approx \tau$  the second type of interfacial zone structure is seen, as quasi-equilibrium at the interfaces sets within 30 to 60 minutes. A filler dissolution rate increases compared with that for the previous case  $t < \tau$ . Diffusion of the atoms from the molten binder to the filler intensifies. An interfacial zone width increases and a layer that dissolves and re-solidifies during the infiltration appears in the structure of the interfaces. Diffusion zones are seen on either side of this layer.

The third type of interfacial zone structure is observed when quasi-equilibrium does not set during the infiltration ( $t \gg \tau$ ). The dissolution rate and the interfacial zones width are of maximal value. At that, the interface width increases at the expense of the layer that dissolves and re-solidifies during the infiltration. Diffusion of the atoms from the binders to the filler reaches the maximal level.

The period of the time necessary to reach quasi-equilibrium increases in the following sequence depending on the filler structure: crystal → microcrystal → quasicrystal. Accordingly the interfacial reactions between the filler and the matrix intensify. Having revealed the regulations in the structure formation of the interfaces of diffusion-and-dissolution type it is possible to combine phases of different stability in the structure of the fillers. When infiltrated the filler phases dissolve in the molten binder non-uniformly. Naturally the phases of less stability dissolve at the higher rate. For the fillers having crystal or microcrystal phases in the structure the dissolution of the grain boundaries by the molten binders prevails during the infiltration. Inside the fillers containing quasicrystal and crystal phases the molten binders penetrate along the interphase boundaries dissolving mainly crystal phases.

Table 1

**High-performance macroheterogeneous composites for various applications**

Properties	Composites			Interface type	Application
	Filler		Binder		
	Alloy	Structure			
Corrosion-resistant	W-C	Crystal	Cu-Zn	I, II	Metallurgy, machine-building, mining, chemical industry, power industry
	W-C	Microcrystal	Fe-B-C		
	W-C	Crystal	Fe-B-C-Si-Mn-P		
	Cr-Ti-C	Crystal	Cu-Ni-Mn		
	Cr-Ti-C	Crystal	Fe-B-C-Ti		
	Cr-Ti-C	Crystal	Fe-B-C-Cr		
	Al-Co-Ni	Quasicrystal	Cu-Zn		
	Al-Co-Cu	Quasicrystal	Cu-Zn		
Abrasive-resistant	Al-Cu-Fe	Quasicrystal	Cu-Zn	II, III	Metallurgy, machine-building, mining
	Fe-B	Crystal	Cu-Zn		
	Fe-B	Crystal	Cu-Ni-Mn		
	Fe-B-C	Crystal	Cu-Zn		
	Fe-B-C	Crystal	Cu-Ni-Mn		
	Fe-Cr-B-C	Crystal	Cu-Zn		
Gas-abrasive-resistant	Fe-Cr-Nb-Mo-V-C	Crystal	Cu-Ni-Mn	II, III	Metallurgy, machine-building
	W-C	Crystal	Fe-B-C-Si-Mn-P		
	Fe-P-B	Crystal	Cu-Zn		
	Fe-B-C	Microcrystal	Cu-Ni-Mn		
	Fe-Cr-B-C	Microcrystal	Cu-Zn		
	Fe-Cr-Nb-Mo-V-C	Microcrystal	Cu-Ni-Mn		

The results obtained make it possible to develop new high-performance composite materials. In Table 1 are given just a few of them that boast high corrosive and abrasive resistance. The metallographic study shows that in the corrosive media the filler/matrix interfaces corrode heavier than surrounding areas. This phenomenon results in the subsequent crumbling of the filler from the matrix. As a result, interfacial reactions should assure, on the one hand, adhesion between the composite constituents, but on the other hand, the interfacial zones width should be as small as possible. These conditions imply the formation of I- or II-type interfaces. Therefore, for maximum resistance to corrosion the filler should contain microcrystal or quasicrystal phases.

Maximum resistance to wear in abrasive or gas-abrasive media ensures microcrystal or crystal structure of the filler and II- or III-type interfaces. In this case the problem is that metal matrices are too weak to support the filler particles. Due to intensification of dissolution and diffusion processes at the interfaces the alloying elements from filler are delivered to matrix which makes it stronger.

### Conclusions

The idea used in this work is to select such composites constituents that allow combining the phases of different stability at the composites interfaces. To estimate phase stability the criterion that takes into account the time interval necessary for setting quasi-equilibrium conditions at the interfaces is suggested. Its evaluation is based on studying time dependencies of the wetting angles and the width of interfacial zones. These dependencies make it possible to predict performance characteristics and enhance their level due to strict control of interfacial reactions during infiltration.

Developed metal-matrix macroheterogeneous composites obtained by furnace infiltration feature high strength, toughness, impact properties and so on. Technology of furnace infiltration allows fabricating one-layer or multilayer composites for various applications. Layers of the composites may differ in the filler or the matrix compositions or structure type. They can be utilized for excellent abrasive or corrosive resistance.

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