

Energetic conditions of effective recycling of composite castings

J. Jackowski

Department of Foundry, Institute of Material Technology, Poznan University of Technology,
ul. Piotrowo 3, 61-138 Poznań, Poland

Corresponding author. E-mail address: jacek.jackowski@put.poznan.pl

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Abstract

The most reasonable way of recycling the metal composite materials consists in separation of the components. In case of the composites with saturated reinforcement it is the only recycling method. The process of separation of the components always undergoes in the presence of an additional liquid phase called a recycling medium. In a three-phase system including the material of composite reinforcement – liquid composite matrix – liquid recycling medium, an important role for the recycling process is played by the changes in energy values at the interfacial surfaces. Proper choice of the recycling medium enables simultaneous process of transition of the reinforcing phase particles into the environment (the suspension composites) or also simultaneous outflow of the metal matrix from the reinforcement capillaries (the composites with saturated reinforcement). Moreover, a very important role in recycling of composite materials with saturated reinforcement is played by geometry of the reinforcement material capillaries. Energetic conditions render impossible simultaneous outflow of the matrix from the capillaries of varying and irregular geometry. It means that a choice of proper recycling medium is necessary condition for the recycling process, although not always a sufficient one.

Keywords: Metal composites, Recycling, Surface energy

1. Introduction

Among the metal composite materials obtained with foundry methods two groups predominate, the classification of which is a result of the method of their obtaining. The suspension composite materials are obtained by formulation of a suspension of the reinforcing phase particles in a liquid composite matrix and, afterwards, casting it into previously prepared moulds. On the other hand, the materials of the other group are made by saturation of a rigid and porous reinforcing profile with liquid metal or alloy. Dimensions and shape of the profile may be entirely or partially consistent with the casting to be obtained. Growing use of the composite materials (of suspension type or with saturated reinforcement) justifies the attempts to search reasonable recycling methods of these products.

Recycling of the suspension composite materials, consisting in remelting of the composite scrap and repeated casting of the suspension so obtained, is particularly advantageous but rare case of the use of composite scrap [1,2,3]. In most cases the recycling of suspension composite materials consists in separation of the material components. Moreover, separation of the components is a sole recycling way of the composite materials with saturated reinforcement [4].

In case of the recycling with components separation of both composite materials discussed here, a recycling system containing another liquid phase must be generated [4,5]. The environment, as being a mixture of melted salts, intercepts the particles of the reinforcing phase from the recycled composite suspension (in case of a suspension composite) or replaces the liquid composite matrix in the pores (capillaries) of the material reinforcing the composite materials (in case of a saturated reinforcement composite). Very important role in these processes is played by

the changes in surface energy that undergo in the recycling systems composed of one solid phase (the reinforcement material) and two liquid phases (the melted matrix and medium).

2. Mechanism of separation of the composite suspension components

The composite materials mentioned above (the suspension and saturated reinforcement ones) differ each from other both in their manufacturing and recycling (components separation) methods. Therefore the course of their recycling processes should be presented accordingly.

2.1. Mechanism of separation of the composite suspension components

The composite suspension designed for the recycling process may be obtained by melting a composite scrap of various forms and origin (the production or after-amortization scrap). The second liquid phase of the recycling system is the recycling medium, i.e. A melted salt mixture [4]. Diagram of the process is shown in Fig. 1.

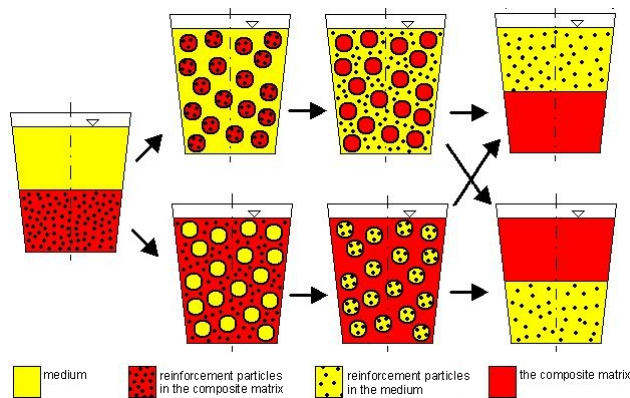


Fig. 1. Diagram of the recycling process of composite materials with separation of the components [6]

Since the particles of the reinforcing phase have higher density than the composite matrix (the matrix – Al alloy) the sedimentation process, although undergoing slowly, is conducive to their removing from the liquid metal surface and from the metal matrix – medium interphase. For the phase of the liquid medium to be able to intercept the reinforcing phase particles both liquid phases (i.e. the composite suspension and the medium) must emulsify. The fact which one of the phases is continuous or dispersed remains unimportant. The only significant fact is emulsification of the system that enables transition of the solid reinforcement phase particles from the matrix suspension state to the medium suspension state. Once the composite suspension is converted and the matrix and medium particle suspension drop coagulated, the system is subject to clarification. Location of its particular layers depends on their densities. The mechanism has been many times verified [7]. Its effectiveness depends on the

ability of the particles of the solid reinforcing phase to cross the metal matrix – medium interphase.

Calculation of the surface energy changes of the system composed of the solid phase particle (S) at the metal matrix (M) and medium (O) interphase has shown that for spontaneous course of the process the following inequality should be fulfilled [8]:

$$\omega_{M-G} \cos \theta_{S-M} - \omega_{O-G} \cos \theta_{S-O} + \omega_{M-O} < 0 \quad (1)$$

where:

- ω - value of the surface energy at the following boundaries:
- M-G - liquid metal – gas interphase
- O-G - liquid medium – gas interphase
- M-O - liquid metal – liquid medium interphase
- θ - value of the extreme wetting angle of the solid phase material in the gas atmosphere:
- $\frac{S-M}{G}$ - by the liquid metal matrix
- $\frac{S-O}{G}$ - by the liquid recycling medium

2.2. Mechanism of matrix outflow from the reinforcement capillaries

It was found experimentally that separation of the components of the composite material with saturated reinforcement consisting in liquid matrix outflow from the reinforcement capillaries in gas (air) atmosphere does not occur [4]. Nevertheless, such a process might undergo in the environment of a specially selected medium [4,5,2]. In result of such a process the metal composite matrix of the reinforcement capillaries is replaced by a liquid recycling medium. The studies preceded by analysis of the capillary pressure values in the composite reinforcement pores (capillaries) made of various materials of differentiated structures (fibrous, sintered), have shown that the process of the composite matrix outflow from the reinforcement capillaries depends, among others, on the geometry of these capillaries [9].

Calculation of the changes in surface energy of a system composed of a cylindrical capillary filled with liquid composite matrix in a liquid medium environment [10] shows that fulfillment of the inequality identical with the one presented by the expression (1) is a condition for spontaneous matrix outflow from the capillary and its replacement by the liquid medium.

Since a cylindrical capillary is a very particular geometric case of the composite reinforcement structure, further calculation has been carried out for an irregular capillary presented in Fig. 2.

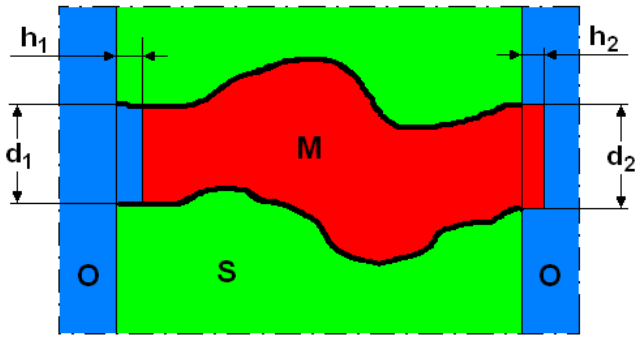


Fig. 2. Calculation scheme of the surface energy during the outflow of liquid composite matrix from an irregular capillary in the liquid medium environment

The calculation is conducive to the relationship considering the ratio of extreme diameters in irregular capillary, the liquid composite matrix of which may be replaced by a liquid medium [11]. The relationship has a form:

$$\frac{d_1}{d_2} < \frac{-(\omega_{M-G} \cos \theta_{S-M} - \omega_{O-G} \cos \theta_{S-O})}{\omega_{M-O}} \quad (2)$$

with the same denotations as the ones used in the inequality (1) and corresponding to Fig. 2. (d_1 and d_2). It may be easily noticed that the relationship (2) differs from (1) only by occurrence of the ratio d_1/d_2 before the ω_{M-O} value that is presented by the inequality (3):

$$\omega_{M-G} \cos \theta_{S-M} - \omega_{O-G} \cos \theta_{S-O} + \frac{d_1}{d_2} \omega_{M-O} < 0 \quad (3)$$

3. Recycling effectiveness

The presented schemes of the course of separation of the composite material (the suspended ones and the ones with saturated reinforcement) in the presence of an additional liquid phase (the medium) and calculated changes in surface energy accompanying the processes allow for:

- determining the possibility (or impossibility) of the composite material recycling;
- the choice of the medium of the properties enabling effective recycling;
- determination of limiting geometric parameters of the reinforcement capillaries that allow for free outflow of the melted composite matrix

Possibility of separation of the components of the composite suspension and the composite material with saturated reinforcement is determined by the relationships (1) and (3). They show that fulfillment of the inequality is favoured by the following factors:

- high surface energy (surface tension) of the composite matrix in the gas atmosphere, accompanied by high value of the extreme wetting angle (poor wettability) of the reinforcement material by liquid matrix in the gas atmosphere;

- high surface energy (surface tension) of the medium in the gas atmosphere, accompanied by perfect wetting of the reinforcement material;
- possibly low value of the surface energy (adhesion tension) at the boundary between the liquid composite matrix and the liquid medium.

It should be emphasized that fulfillment of the inequalities (1) and (3) is impossible in case of good wetting of the reinforcement material by liquid composite matrix. It means that, for example, preparation of the solid phase particles designed for composite suspensions with a view to ensure good wettability by the liquid matrix metal precludes their recycling afterwards, i.e. separation of the matrix. This concerns also the technology of the reinforcement profiles of saturated composites. The inequality (2) explains and specifies the reasons of ineffective recycling of some composite materials with saturated reinforcement [9], e.g. made of sintered granulates.

In order to illustrate the problem an example of behaviour of the liquid composite matrix in the capillary of variable diameter is presented. Assumption of the values approximating the real recycling system allows for calculating, based on the relationship (2), the limiting value of the d_1/d_2 ratio, restraining the matrix motion in the capillary in the medium environment. For the values of: $\omega_{M-G} = 1000$ mN/m; $\omega_{O-G} = 100$ mN/m; $\omega_{M-O} = 600$ mN/m, and $\theta_{S-M} = 150^\circ$ i $\theta_{S-O} = 0^\circ$, the ratio amounts to 1.6.

Meaning of the fact in case of the outflow of the composite matrix from a regular but non-parallel capillary shaped as a double truncated cone is shown in Fig. 3.

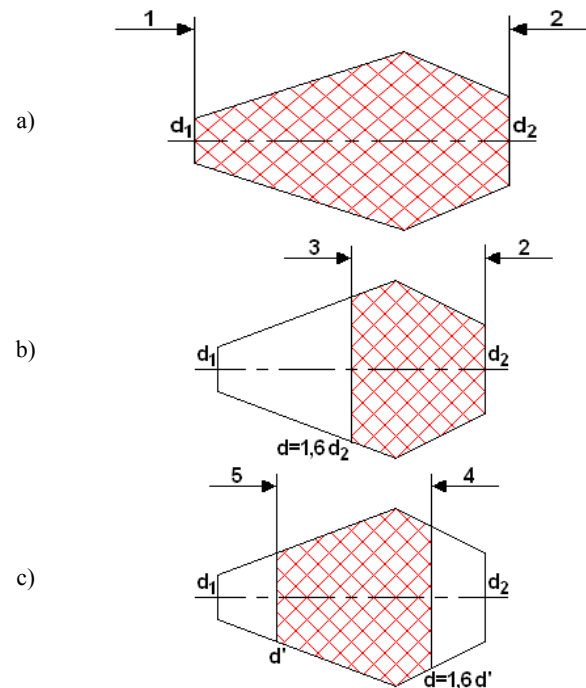


Fig. 3. The scheme of behaviour of the liquid composite matrix in the capillary of varying diameter under the conditions of recycling in a liquid medium

In the first stage of the process, once the composite matrix metal is melted, it flows out from the capillary through the whole of d_2 diameter. This is a consequence of the difference in capillary pressures acting at the capillary ends (Fig. 3a). The motion of the liquid matrix stops when the surface of its contact with the liquid medium inside the capillary achieves the equilibrium defined by the relationship $d=1.6 d_2$. (Fig. 3b). Once the motion inside the capillary stops, the difference in pressures at the fronts of a horizontal column of the matrix gives rise to metal motion in the opposite direction, i.e. inside the capillary. The motion stops again when equilibrium shown in Fig. 3c is achieved. Further motion of the composite matrix will be induced again by the difference in capillary pressures, leading to the condition depicted in Fig. 3b. Such a reciprocating matrix motion will last until cooling of the system and solidification of the media it is composed of.

4. Conclusions

1. The calculations presented here indicate that the computed surface energy changes undergoing in the recycling systems provide an important information for purposes of designing the recycling process of the composite materials with saturated reinforcement. Fulfillment of the inequality (1) is a basic condition of effectiveness of the recycling.
2. It should be noticed that fulfillment of the inequality (1) is a first and necessary condition for effective recycling of composite materials with saturated reinforcement that, in case of the reinforcement of extremely disadvantageous geometry of the capillaries, may be insufficient.
3. At the same time, the computation indicates important role of the geometry of the capillaries of the saturated reinforcement for the recycling process (inequality (2) and Fig. 3). Results of the calculations explain the observed fact of ineffectiveness of recycling of some of the composite materials. This concerns the materials the reinforcement of which includes capillaries of irregular shapes (e.g. made of sintered granulates).
4. The lack of spontaneous matrix outflow from the capillaries of the material reinforcing the recycled composite material means that another methods of recycling are necessary, e.g. through disintegration of the recycled material or the use of dynamical forcing of the liquid matrix motion in the capillaries.

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