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THE STRUCTURE OF CENTRIFUGALLY CAST COMPOSITE CASTING

The most frequently used methods for manufacturing composite castings with an internal structure composed of a metal matrix and solid particles of the reinforcing phase are gravitational casting (into disposable or permanent moulds), pressure die casting, squeeze casting and centrifugal casting. The diphasic character of the composite suspension designed for casting leads to the fact that its gravitational casting is delimited, among others, by a minimum thickness of the casting walls. The process of casting composite suspensions using the centrifugal method is unavoidably accompanied by migration of the reinforcing phase particles. It means that during the casting process, the particles move with respect to the liquid metal matrix. Therefore, experimental tests have been made with a view to manufacturing composite castings with the method of centrifugal casting. The tests were aimed at answering whether thin-walled castings may be manufactured using this method and checking the effect of the method on the behavior of the particles present in the cast suspension. The tests have been performed using a standard composite material with an aluminum alloy matrix including silicon carbide particles. The cast part was a small turbine with a blade thickness of about 1 mm. The casting moulds were made from a gypsum mass which was poured in a device composed of an induction furnace and a mechanism, referred to as a caster, that ensured rotation of the mould around a vertical rotation axis. The castings obtained in such way were evaluated with regard to matching the required shape and achieving a uniform distribution of the reinforcing phase in the composite material samples cut from various points of the casting and its gating system. It was found that the casting conditions allow one to obtain thin-walled castings, however, migration of the reinforcing phase particles in the cast suspension is significant. Hence, further research of the conditions of applying the method appeared necessary.

Keywords: dispersion composites, centrifugal casting, gradient structure

STRUKTURA ODLEWU KOMPOZYTOWEGO WYKONANEGO ODLEWANIEM ODŚRODKOWYM

Do najczęściej stosowanych metod wytwarzania odlewów kompozytowych, których struktura wewnętrzna składa się z metalowej osnowy oraz stałych cząstek fazy zbrojącej, należą: odlewanie grawitacyjne (do form jednorazowych i trwałych), odlewanie ciśnieniowe, prasowanie w stanie ciekłym oraz odlewanie odśrodkowe. Dwufazowość zawiesiny kompozytowej przeznaczonej do odlewania sprawia, że jej grawitacyjne odlewanie limitowane jest m.in. minimalną grubością ścianek odlewów. Odlewaniu zawieszin kompozytowych metodą odśrodkową towarzyszy nieuchronna migracja cząstek fazy zbrojącej, czyli ich przemieszczanie się względem ciekłej osnowy metalowej podczas odlewania. Podjęto pilotażowe próby wytwarzania niedużych odlewów kompozytowych metodą odlewania odśrodkowego. Celem prób było sprawdzenie możliwości uzyskiwania cienkościennych odlewów oraz wpływu metody odlewania na zachowanie się cząstek w odlewanej zawieszynie kompozytowej. Do wykonania prób użyty został standardowy materiał kompozytowy na osnowie stopu aluminium, zawierający cząstki węgla krzemowego. Elementem odlewany był niewielka turbina o łopatkach grubości ok. 1 mm. Formy odlewnicze wykonano z masy gipsowej, a proces ich zalewania realizowano w urządzeniu złożonym z pieca indukcyjnego oraz mechanizmu zapewniającego wirowanie formy wokół pionowej osi obrotu. Uzyskane odlewy oceniano pod względem zachowania wymaganych kształtów oraz równomierności rozkładu fazy zbrojącej w próbkach materiału kompozytowego wyciętych z różnych miejsc odlewów i ich układów wlewowych. Stwierdzono, że stosowane warunki odlewania pozwalają na uzyskanie cienkościennych odlewów, jednak migracja cząstek fazy zbrojącej w odlewanej zawieszynie jest znaczna, a dalsze badania nad warunkami stosowania testowanej metody - konieczne.

Słowa kluczowe: kompozyty zbrojone dyspersyjnie, odlewanie odśrodkowe, struktura gradientowa

INTRODUCTORY REMARKS

The advantageous properties of composite materials are conducive to their growing application in various structures. In the case of metal composite castings, their preparation is constrained, on the one hand, by the characteristic properties of the processed material and, on the other hand, by its possible shaping with the use of selected foundry technology.

A remarkable portion of composite castings with a metal matrix is manufactured by casting suspensions composed of technical alloys and solid particles of the reinforcing phase. The diphasic character of the suspension causes behavior different than conventional casting alloys, both while pouring into the moulds and cooling. Since the quality of suspension composite castings

strongly depends on their structure, which, in turn, depends on the conditions of casting, cooling, and solidification of the cast suspension, research of the relationship between these factors is justified.

INTRODUCTION

The process of casting metal composite suspensions is used in the production (also of mass character) of castings such as automotive brake disks, pistons, sleeves, etc. [1, 2]. These parts are usually manufactured from the suspensions whose matrix includes aluminum alloys, while the reinforcing phase includes ceramic particles of Al_2O_3 , SiC and others. The composite suspension may be obtained in foundries from components prepared in their own capacity (i.e. the matrix and reinforcing phase) or by melting composite pig sows delivered by an external supplier.

The behavior of the composite suspension designed for casting depends, irrespective of the source of the charge materials, on the properties of the liquid matrix (its chemical composition, viscosity, surface properties) and the particles of the reinforcing phase (their kind, size, shape, density, surface properties, and contents in the suspension), whereas the internal structure of the composite casting is additionally determined by the suspension behavior during its casting and the course of cooling in a liquid state and solidification. In practice, it depends mostly on the factors related to:

1. the casting (its dimensions, mass, thickness of the walls)
2. the casting mould (its material, design, thermo-physical properties)
3. the casting method (gravitational, under pressure, centrifugal)

Gravitational casting into permanent moulds and pressurized casting are among the most frequently employed techniques of composite casting production for casting composite suspensions. Gravitational casting into permanent moulds constraints the possible minimum thickness of casting walls to be obtained. In the case of manufacturing massive thick-walled castings, the uniformity of the reinforcing phase distribution in the casting material may be worsened as a result of the gravitation force or development of the structural phases of the composite matrix [3, 4]. On the other hand, a drawback of pressurized casting of a composite suspension, which guarantees achievement of a thin-walled casting, consists in faster wearing of the working parts of the machines (cylinder of the chamber, piston) and pressure moulds.

The possibility of obtaining composite castings of a gradient structure has created interest in the centrifugal casting of composite suspensions [5-7].

The different density of the components (i.e. matrix and reinforcing phase) is conducive, due to the fact that during the centrifugal casting process the particles of the reinforcing phase migrate. In consequence, the

structure of the centrifugal casting becomes locally diversified. In result, proper selection of the components and casting conditions may be used with a view to control the internal structure of the casting according to the imposed requirements [8, 9].

The reasons mentioned above led to the idea of checking the results obtained while casting a composite suspension in a precise ceramic mould, aided by centrifugal force.

EXPERIMENTAL PROCEDURE

The experiments were carried out with the following materials:

- a standard composite material made by the DURALCAN company and marked as A359/20SiCp (sub-eutectic silumin + 21,6% silicon carbide particles)
- disposable models of a small turbine (Fig. 1) 70.9 mm in diameter with thin (1 mm), curved blades made of poly(methyl methacrylate) - PMMA using the 3D printing method [10].



Fig. 1. Image of turbine (\varnothing 70.9 mm)

Rys. 1. Rysunek konstrukcyjny turbiny (\varnothing 70,9 mm)

For the purpose of composite charge melting, a laboratory chamber resistance furnace by NABERTHERM was used. The charge was melted in a graphite crucible inside a larger crucible made of Al_2O_3 . The composite pig sows were melted without a fluxing agent.

The models were impregnated with paraffin in order to ensure low roughness of their surfaces. The models were provided with wax models of the gating systems with two ingates (Fig. 2). The compactness of the thus formed models was imposed by the constrained dimensions of the molding boxes, which had the form of sleeves, with an inside diameter equal to 70.9 mm.

The moulds were made of KERR casting gypsum. The models were filled with the gypsum mass and afterwards subjected to negative pressure treatment in order to remove the gas bubbles from it. Once the mass was bound, the moulds were dried and burned at the temperature of 720°C for 12 hours.



Fig. 2. Disposable turbine models
Rys. 2. Jednorazowe modele turbiny

Before pouring, the mould temperature was reduced to 300°C. To fill the moulds, the Italian casting machine GIACETTI was used. It included a furnace with a crucible capacity allowing for the filling of a single cavity turbine mould. Prior to collection of the suspension from the NABERTHERM furnace, the layer of oxides was removed from the surface while the crucible contents were gently mixed. The portion was poured into the crucible of the casting machine furnace and, once its temperature stabilized (720°C), the mould was clamped with the furnace casing and the casting process started. The rotational speed was always constant, equal to 270 rpm. The radius from the axis of rotation to the crucible-mould set amounted about to 180 mm. The duration of the rotation stage exceeded the time of total solidification of the suspension.

Once the rotation was finished, the filled mould was disassembled and the gypsum mass was separated from the casting using a water jet. All the castings were free of shape flaws, e.g. in the form of misruns (Fig. 3a). In order to conduct a metallographic test, one randomly selected casting was cut so as to make polished sections of some selected parts of the gating system (Fig. 3b) and the casting itself (Fig. 4a), with special attention paid to the blade cross sections (Fig. 4b).

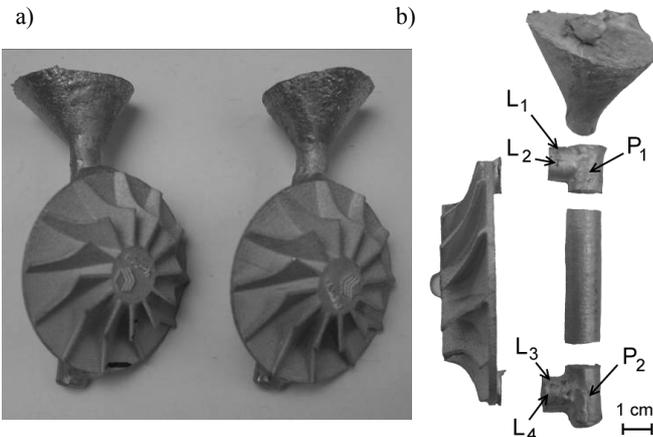


Fig. 3. Raw composite castings: a) view; b) after initial cutting
Rys. 3. Surowe odlewy kompozytowe: a) widok, b) po wstępnym pocięciu

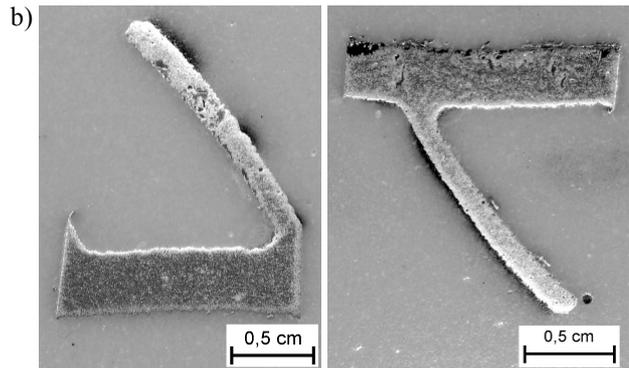
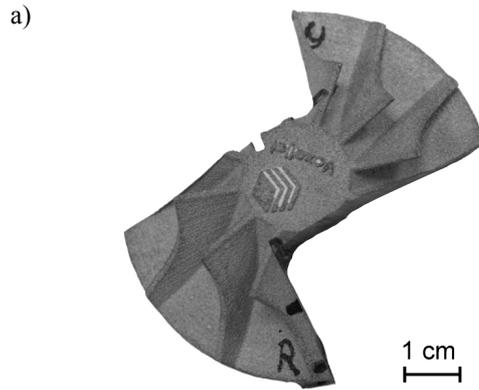


Fig. 4. Cut-up composite casting (a) and parts of occluded blades (b)
Rys. 4. Pocięty odlew kompozytowy (a) oraz fragmenty zokludowanych łopatek (b)

RESULTS OF METALLOGRAPHIC TESTS

The metallographic tests were aimed at improving the inner structure of the obtained casting, with particular attention paid to the distribution of the reinforcing phase particles of the metal matrix. Tests were performed particularly on the material of the thin-walled turbine blades and various parts of the gating system. The observations were carried out with the use of a metallographic microscope, Neophot 2 by Carl Zeiss Jena, equipped with a BRESSER camera. In order to determine the share of the reinforcing phase in the observed polished sections, the IMAGE J. program was used. Moreover, macroscopic tests were performed on the polished cross-section of the pouring cup casting. As a reference for comparative tests, the structure found on polished sections of samples cut from a composite pig sow (Fig. 5) was used.

The pictures in Figure 6 show the microstructures found in various locations of the pouring cup casting. The polished sections were made in the areas L1, L2, L3, L4, P1, and P2 marked in Figure 3b (connection of main ingate to upper and bottom ingate). The photomicrographs in the left-hand column of Figure 6 present the structure of the bottom zone of the ingates. In the middle column, structures are shown that exist in the solidified main ingate at the level of the supplying ingates. Finally, the right-hand column of Figure 6 shows the structure of the upper zones of the supplying ingates.

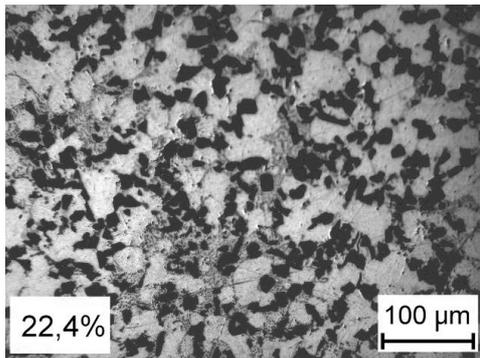


Fig. 5. Structure of composite pig sows used for tests
Rys. 5. Struktura materiału gąski kompozytowej użytego do badań

The structures found in various areas of the obtained composite casting are shown in Figures 7 and 8. Figure 7 illustrates the structure occurring in the material of the corners of the blades. The corners most distant from the turbine disk plane are shown in Figures 7a and 7b, while the corners at the base of the blade are shown in Figures 7c and 7d. The pictures in Figures 7a and 7c are related to the blade nearest the upper ingate, while the pictures in Figures 7b and 7d - nearest the bottom ingate (Fig. 4b).

The pictures in Figure 8 present the microstructures sporadically occurring in the structures of the casting disk from the side opposite the blade root.

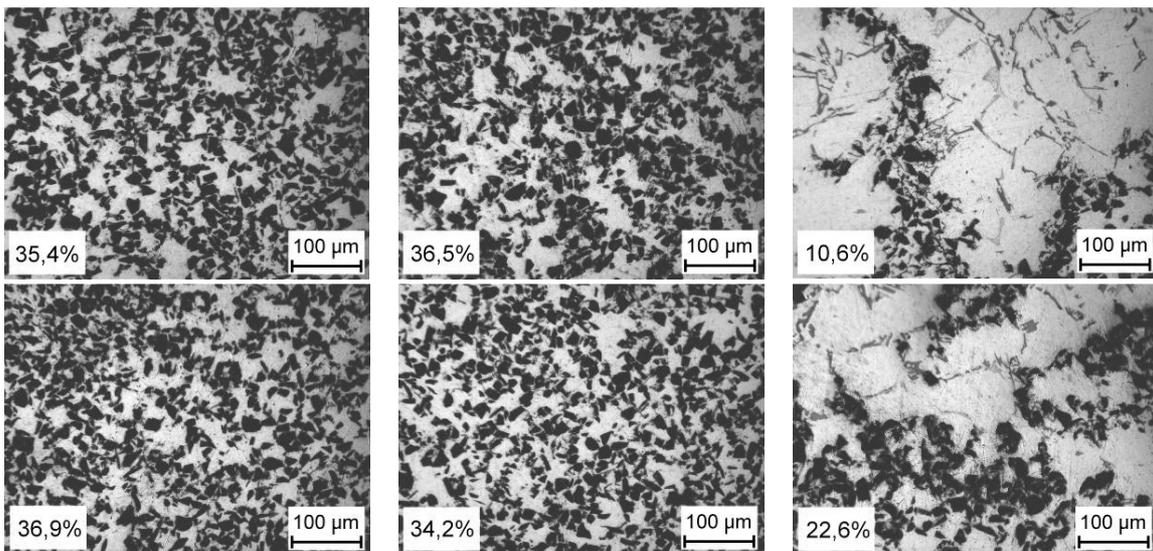


Fig. 6. Composite material structures in different areas of the casting gating system
Rys. 6. Struktury materiału kompozytowego w różnych obszarach odlewu układu wlewowego

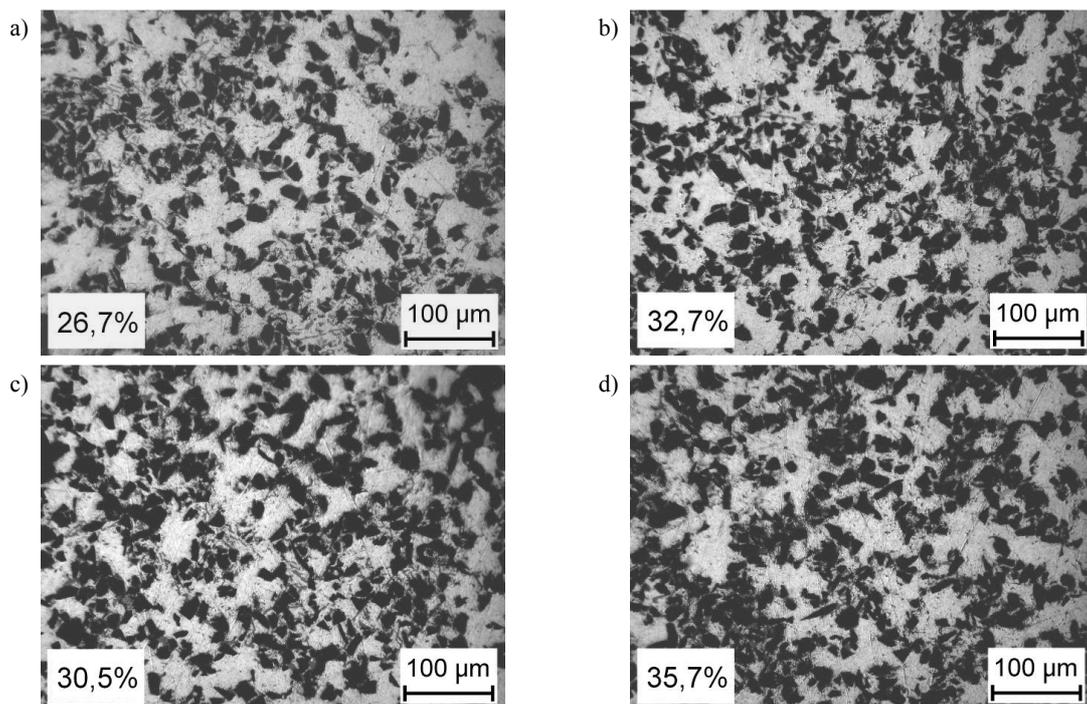


Fig. 7. Structure of composite casting in various locations
Rys. 7. Struktura materiału odlewu kompozytowego w różnych jego obszarach

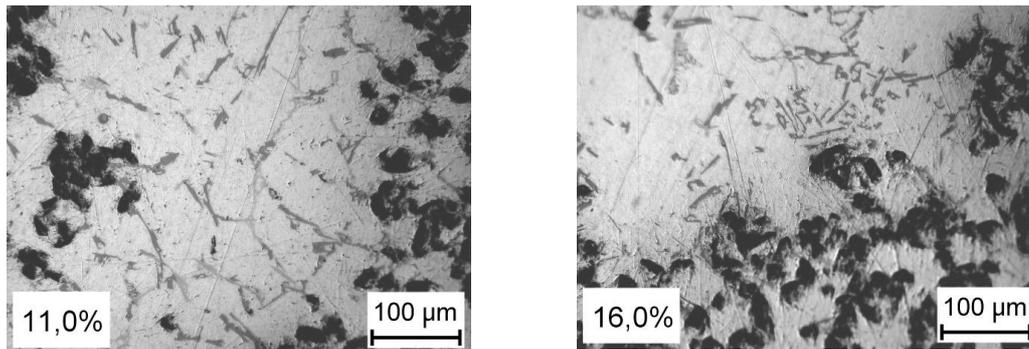


Fig. 8. Structure anomalies found in parts of composite casting

Rys. 8. Anomalie struktury spotykane we fragmentach odlewu kompozytowego

Figure 9 shows the macrostructure of the pouring cup casting, with a clearly visible boundary between the concentrated suspension and sedimentation composite matrix.

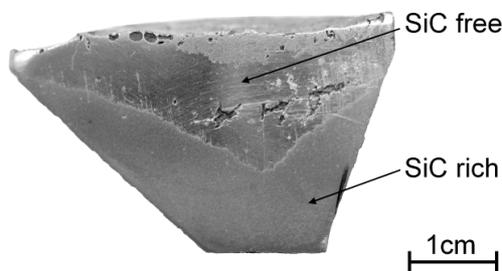


Fig. 9. Macrostructure of cross-section of pouring cup casting

Rys. 9. Makrostruktura przekroju odlewu zbiornika wlewowego

DISCUSSION OF RESULTS AND CONCLUSIONS

The experiments performed together with metallographic tests have shown that centrifugal pressure aiding the filling process of precise moulds with a composite suspension allows one to obtain thin-walled castings (Fig. 3a) but, at the same time, is conducive to evident migration of the reinforcing particles in the cast suspension. The number of reinforcing phase particles in most of the presented polished sections is considerably higher than in the polished section of the material sample used for making the castings is a phenomenon that draws particular attention. Clear sedimentation of the particles is visible in the cross-section of the pouring cup casting of the mould (Fig. 9) - it is a fact that could be expected. Nevertheless, the prepared polished sections give evidence to surprisingly large differences in the numbers of particles in the cross-sections of the solidified gates (Fig. 6). It means that in relatively large cross-sections (Fig. 3b), where the axes of symmetry are perpendicular to the radius of rotation of the mould being poured, the particles are in intensive motion with respect to the liquid matrix. The large dimensions of the ingates are a cause of the fact that the duration of the liquid state of the suspension contained in them is long enough to lead to the appearance of (centrifugal)

sedimentation, as opposed to the thin-walled sections of the castings.

The reasons for areas of lowered contents of reinforcing phase particles occurring in the polished sections (Fig. 8) have not been explained. It is probable that such areas present in the casting structure (the turbine) are a result of the complicated motion of the stream of the suspension in the mould. The geometry of the mould cavity does not preclude variations of the suspension stream directions with respect to the direction of the centrifugal force acting on particular particles.

In order to verify this hypothesis, additional research is recommended (under conditions identical or similar to the above-mentioned) but with the use of moulds with much simpler cavity geometries in order to find such thermal conditions of cooling and solidification of the cast suspension that would reduce migration (or migration feasibility) of the particles it is composed of.

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