IMPACT OF COOLING TIME ON THE STRUCTURE
AND TRIBOLOGICAL PROPERTIES
OF METAL MATRIX COMPOSITE CASTINGS

The article presents the influence of cooling time on the structure of metal matrix composites (MMC) castings. The examination covered two types of composites manufactured by mechanical mixing. Composite reinforcement consisted of SiC particles, and the matrix consisted of AlSi9 alloy in the first case and AlSi11 in the second. Comparison covered samples cooled in sand moulds and gravity dies by presenting their cooling curves and their abrasive resistance.

Key words: metal matrix composites, casting, cooling curves

1. INTRODUCTION

In recent years, metal and non-metal composites have been rapidly developing as construction materials of various applications in different industries.

One of major composite advantages is the possibility of obtaining desired usable properties. This involves, among others, the use of relevant fabrication methods. Composites with hard particles reinforcement (SiC, Al2O3, and BC) are frequently used as elements comprising tribological pairs [4–5]. Methods used to test their wear enable assessing relative resilience of the materials. Tribological phenomena depend mainly on the status of surface layers at interfaces between interacting elements of machines [3–4]. For this reason, it is important to examine the impact of the composite structure, which comprises at least two different materials [9], on the wear and tear. The wear and tear of such elements involves a number of processes that accompany friction and apply to the surface layer and change in mass, surface geometry, and shape. The objective of the paper is to present findings of the research focusing on resistance to wear and

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tear of composites which structures were determined by different cooling conditions (sand mould and gravity die).

2. METHODOLOGY

The examination covered MMCs fabricated using mechanical mixing. It is an intermediary method also known as ex-situ [2, 3]. The method involves introducing reinforcement particles (or fibers) to liquid metal (alloy) and their mechanical spreading in the matrix as shown in Fig. 1 (suspension composites) [9].

The research covered two types of materials which differed as regards their matrix:

- composite of AlSi11 matrix and 15% SiC particle reinforcement. The material was fabricated in the Chair of Metal Alloy and Composites Technologies at the Silesian University of Technology in Katowice, Poland,
- composite of AlSi9 matrix and 15% SiC particle reinforcement fabricated by ALCAN Canada.

The composite input was prepared by cutting pig sows. It was then melted in a graphite crucible, moulds were filled and temperature changes registered during liquid metal cooling, solidification and cooling of casting. Trial castings were made of each of the materials. Their shape and dimensions are presented in Fig. 2.
3. COOLING CURVES

Solidification conditions were based on solidification time [7–8], determined according to cooling curves using a set of K type thermocouples and Eurotherm 5100 V. The hot end of the thermocouple was placed in the geometric center of perpendicular samples. Cooling curves and their first derivatives for the sand mould and gravity die are shown in Fig. 3a for the AlSi9 + 15% SiC alloy and in Fig. 3b for AlSi11 + 15% SiC alloy. Solidification times for trial castings are shown in Table 1.

Fig. 3. Cooling curves and theirs first derivatives: a) AlSi9 + 15% SiC, b) AlSi11 + 15% SiC
Rys. 3. Krzywe stygnięcia i ich pierwsze pochodne: a) AlSi9 + 15% SiC, b) AlSi11 + 15% SiC
In the case of AlSi9+15%SiC composite casting, α phase nucleation in sand mould and gravity die did not show visible recalescence of temperature on the cooling curve \((A_p, A_k – \text{Fig. 3a})\). The α phase nucleation in the AlSi11+15%SiC casting involved recalescence of temperature in both forms \((A_p, A_k – \text{Fig. 3b})\).

The \(\alpha + \text{Si}\) eutectic nucleation occurred at about 567°C in the casting which solidified in a sand mould without temperature recalescence \((B_p – \text{Fig. 3a})\), and in a gravity die with temperature recalescence \((B_k – \text{Fig. 3a})\). Crystallizing eutectic \(\alpha + \text{Si}\) surrounded SiC particles (Fig. 4a, magnification 500). Triple eutectic \(\alpha + \text{Mg}_2\text{Si} + \text{Si}\) in the shape of Chinese writing crystallized at 556÷545°C (Fig. 4b, magnification 500). The ratio of solidification time for composites in the sand mould and in the gravity die is 1.80 and 2.84 respectively for AlSi9+15%SiC and AlSi11+15%SiC.

![Composite structure: a) SiC particles surrounded by \(\alpha + \text{Si}\) eutectic, b) triple eutectic \(\alpha + \text{Mg}_2\text{Si} + \text{Si}\)](image)

Rys. 4. Struktura kompozytu: a) cząstki SiC otoczone eutektyką \(\alpha + \text{Si}\), b) eutektyka potrójna \(\alpha + \text{Mg}_2\text{Si} + \text{Si}\)

SiC particles are unevenly distributed in the structure of castings examined. The uneven distribution is higher in castings which solidified in sand moulds (Fig. 5).
Systematic scanning was used to determine homogeneity of dispersed phase distribution in the composite. According to the method, the binary picture of a microstructure of the material examined is divided into identical interosculant square fields [3, 6]. The surface content of analyzed $A_{\text{ij}}$ phase is measured for each field and results are used to calculate the following:

- average value of surface content:

$$\bar{A}_A = \frac{1}{n^2} \sum \sum A_{\text{ij}}$$

(1)

($n^2$ – number of measurement frame uses),

- standard deviation:

$$s(A_A) = \left[ \frac{\sum \sum (A_{\text{ij}} - \bar{A}_A)^2}{n^2 - 1} \right]^{0.5}$$

(2)
– particle distribution coefficient:

\[ v(A_d) = \frac{s(A_d)}{A_d} \cdot 100 \]  

(3)

Results have been shown in Table 2.

**Table 2**

Quantitative analysis of particle distribution coefficient for SiC in AlSi9 and AlSi11 matrix

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Mould/die</th>
<th>Average SiC surface share $\overline{T}_s$ (equation 1)</th>
<th>Standard deviation $s(A_d)$ (equation 2)</th>
<th>Particle distribution coefficient $v(A_d)$ [%] (equation 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AlSi9 +15%SiC</td>
<td>Sand mould</td>
<td>7.05</td>
<td>2.08</td>
<td>29.35</td>
</tr>
<tr>
<td>Gravity die</td>
<td>16.88</td>
<td>4.86</td>
<td>28.81</td>
<td></td>
</tr>
<tr>
<td>AlSi11 +15%SiC</td>
<td>Sand mould</td>
<td>18.40</td>
<td>3.85</td>
<td>20.94</td>
</tr>
<tr>
<td>Gravity die</td>
<td>19.97</td>
<td>4.21</td>
<td>21.05</td>
<td></td>
</tr>
</tbody>
</table>

4. ABRASIVE RESISTANCE OF METAL COMPOSITES

Abrasive tests on composites have been performed in the Chair of Ship Material Engineering, Institute of Basic Sciences at the Maritime University in Szczecin, Poland. The tests used a weight method described in greater detail in [1, 4]. Tests involved rectangular prism samples of $10 \times 10 \times 5$ mm and counter samples made of grey ductile ferritic-pearlitic cast iron of $90 \times 19 \times 3$ mm. Weight measurements were performed every 1800 s, whereas the total test time was 21600 s. Each time three samples made of the same material were tested. Average results are presented in Fig. 6 (figures show the loss of weight in time in materials tested excluding the preliminary phase of placing a mould).

5. CONCLUSIONS

It has been established that:

– different mass loss appears between materials cooled in a sand mould and in a gravity die (Fig. 6a and 6b);

– in both cases (composites based on AlSi9 and AlSi11 matrixes), mass loss was larger in the case of composites cooled in a sand mould;

– mass loss during analysis was higher in the case of a AlSi9 composite.
This resulted from a lower content of silica in the matrix and uneven distribution of SiC particles in the cast structure. The latter is confirmed by the particle distribution coefficient (Table 2).

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Wpływ szybkości chłodzenia
na strukturę i właściwości tribologiczne metalowych odlewów kompozytowych

Streszczenie

W prezentowanym artykule przedstawiono wpływ szybkości chłodzenia na strukturę odlewów z metalowych materiałów kompozytowych. Badano dwa rodzaje kompozytów wytworzonych metodą mechanicznego mieszania. Zbrojenie kompozytu stanowiły cząstki SiC, osnovę w pierwszym przypadku stop AlSi9, w drugim AlSi11. Porównano materiały chłodzone w formie piaskowej i kokili i przedstawiono ich krzywe krzepnięcia oraz odporność na ścieranie.

Słowa kluczowe: metalowe materiały kompozytowe, odlewy, krzywe krzepnięcia