DETERMINATION OF TECHNOLOGICAL PARAMETERS OF SATURATED COMPOSITES BASED ON SiC BY MEANS OF A MODEL LIQUID

The paper describes a method for determining technological parameters of the formation process of saturated composites based on SiC by applying the theory of dynamic similarity. Empirical relations have been presented in terms of hydraulic analysis of the saturated liquid flow (liquid metal) and determination of the saturated composite density depending on the technological parameters of its formation process: saturation time and pressure. Adopting the method for determining the density of silumin composites reinforced with silicon carbide by means of Wood's metal as a model liquid has been described. Microscope images of the composite structure have been shown after filling it with the model liquid. Remarks have been made on the application of the method.

Key words: alloy AlSi11, casting, composites, modeling, microscopy, Reynolds number

INTRODUCTION

A continuous progress in the construction of modern ship machinery [1, 2] requires new materials [2 – 6] to be developed and composites play a very significant role among them. Currently, metal matrix composites are formed in different ways.

Formation based on technologies of liquid matrix consists in infiltrating a porous structure of the composite reinforcement phase with a liquid technical alloy (composites with infiltrated reinforcement), most often under pressure (Figure 1). Different metals and their alloys can be used as matrix [2]. However, due to technological difficulties, the casting temperature and reactivity against reinforcement phase may become an obstacle in their application.

A customer order determines the process of casting as it specifies his/her needs. The quality of casting is affected by order requirements and technological aspects. During experiments carried out at the Maritime University of Szczecin on manufacturing composite materials infiltrated with liquid matrix and having the assumed technological parameters [5 – 7], there was a problem with determining effectively the quality of filling of the reinforcement in the form of a SiC preform with AlSi11 silumin matrix. The composite density has been taken as an indicator of saturation effectiveness..

An experiment has been made on a test stand where the reinforcement SiC preform has been infiltrated with a model liquid (Wood's metal).
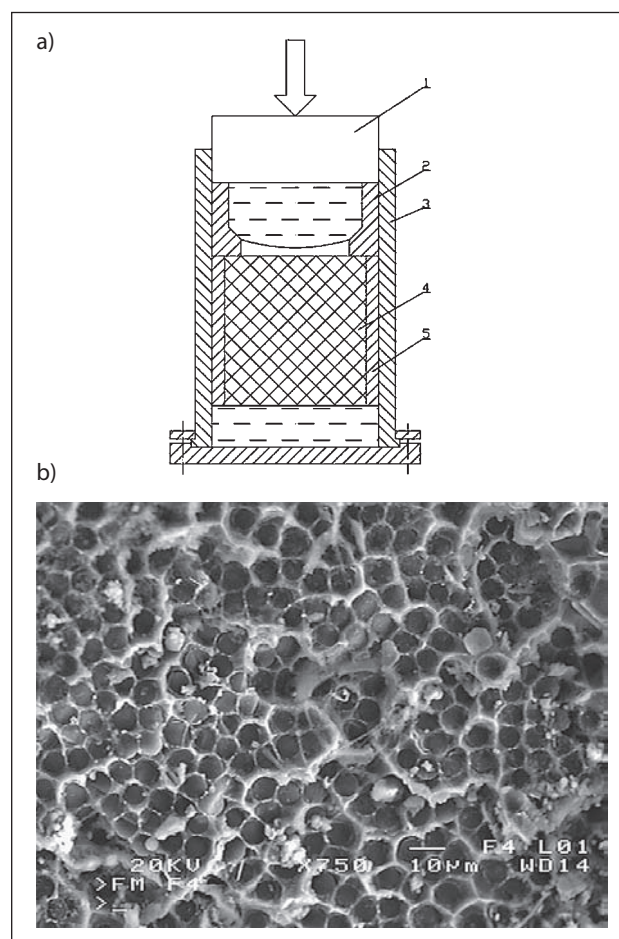

Figure 1 Making composites by infiltrating a porous structure with liquid metal of the matrix: a) mould with a preform prepared for pressurized infiltration: 1 – punch, 2 – piston, 3 – sleeve, 4 – ceramic preform, 5 – reinforcement seat; b) fracture of the composite with saturated reinforcement (Scanning Electron Microscope)

K. Gawdzińska, L. Chybowski, A. Bejger, Maritime University of Szczecin, Faculty of Marine Engineering, Szczecin, Poland
S. Krile, University of Dubrovnik, Maritime Department, Dubrovnik, Croatia

AN EXPERIMENTAL WORK

To identify the flow similarity which determine the saturation process and are characteristic for the applied reinforcement, the value of the Reynolds number Re was calculated [6-8]:

$$\text{Re} = \frac{d\,u}{v} \qquad (1)$$

where: d / mm – the characteristic dimension (capilary diameter), u / mm/s – the characteristic velocity of the fluid, v / cSt – the kinematic viscosity and on the formula for the velocity of the fluid $\hat{f}_1$ / mm/s in the capillary as a pressure function p / MPa described in [7, 8]:

$$\hat{f}_1(p) = 8{,}201 + 1{,}938 \cdot 10^{-3}\,p \qquad (2)$$

taking into account that the kinematic viscosity n is expressed as a ratio of the dynamic viscosity of the fluid m / MPa·s and the density of the fluid r / kg/m³, there is a relation:

$$\text{Re} = \frac{\rho\,p\,d^3}{32\mu^2\,l} \qquad (3)$$
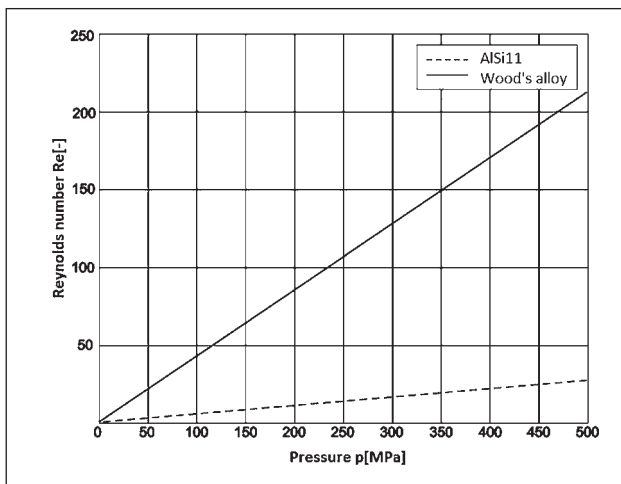
where: l / mm – the capillary length.

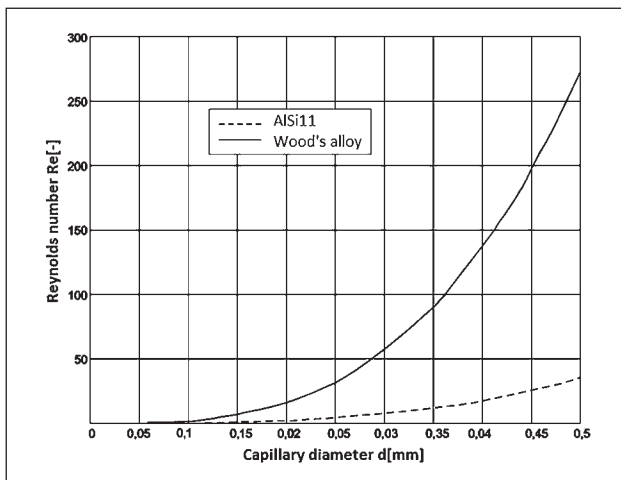**Figure 2** The value of the Reynolds number as a function of saturation pressure

Figure 3 The value of the Reynolds number as a function of capillary diameter

For the assumed simplified boundary geometrical conditions: the capillary diameter $d < 0{,}5$ mm, capillary length $l < 50$ mm, pressure $p < 50$ MPa and test and technical alloy properties given in Table 1, the calculated Reynolds numbers as a function of pressure and cappillary diameter are shown in Figures 2 and 3 respectively.

Taking the value of Re = 2340 (below which the flow of the liquid should be laminar [5, 9]), alloy AlSi11 taken as a matrix of a technical composite shows a similarity of the flow characteristic with reference to the test liquid i.e. Wood's metal – in both cases the flow is laminar.

DETERMINATION OF THE COMPOSITE DENSITY

The composite density $r\,(p,t)$ estimated by applying the test liquid is the basic principle of predicting the parameters of the saturation process p_k (pressure of saturation) and τ_k (time of saturation) for any metal used as a matrix metal of the composite material being developed (Figure 4).

The composite density $\rho_k(p_k,\tau_k)$ / kg/m³ for any metal, when the reinforcement properties are known as shown in Figure 4, was determined according to formula (4) [3]:

$$\rho(p,\tau) = \beta\,\rho_{max} + \frac{(1-\beta)\rho_{max}}{p_{max}\,\tau_{max}}\,p\,\tau \qquad (4)$$

where: b – the coefficient of density expansion, ρ_{max} / kg/m³ – the maximum density, τ_{max} / s – the maximum time.

As a result of transforming relation (4), the following is obtained:

$$\rho_k(p_k,\tau_k) = \beta\,\rho_{k_{max}} + \frac{(1-\beta)\rho_{k_{max}}}{p_{k_{max}}\,\tau_{k_{max}}}\,p_k\tau_k \qquad (5)$$

where:

$\rho_{k\,max} @ \rho_{k\,t}$ / kg/m³ – the composite maximum density, determined according to formula (6) for the composite theoretical density $\rho_{k\,t}$ / kg/m³ considering the volume of empty spaces in the material $V_{por} = 0$, for the matrix density ρ_m / kg/m³, the reinforcement density ρ_z / kg/m³ and reinforcement porosity P / % :
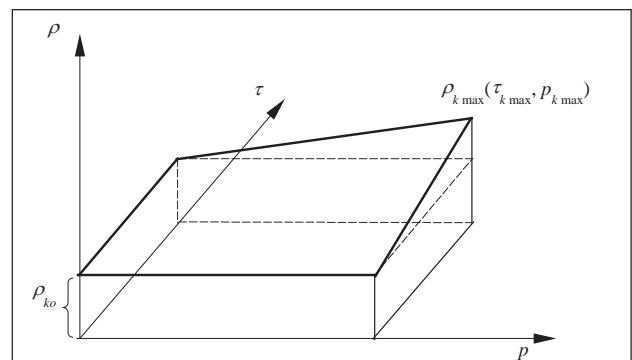

Figure 4 Relation $\rho_k(p_k,\tau_k)$ for a composite infiltrated with another test metal [3]

$$\rho_t = \rho_m \frac{P}{100} + \rho_z\left(1 - \frac{P}{100}\right) \qquad (6)$$

$p_{k\,\text{max}}$ /MPa – the maximum pressure of infiltrating the composite with matrix metal determined according to the formula:

$$p_{k_{\text{max}}} = p_{\text{max}} \frac{\sigma_k \cos\theta_k}{\sigma \cos\theta} \qquad (7)$$

p_{max} / MPa – the maximum pressure of infiltration by the test liquid selected by experiments;

s / N/m – the surface tension of the test liquid;

σ_k / N/m – the surface tension of the composite matrix metal;

q / deg – the contact angle between the reinforcement material and the test liquid;

θ_k / deg – the contact angle between the reinforcement material and the matrix metal;

$\tau_{k\,\text{max}}$ / s – the maximum time to full saturation of the reinforcement preform /s determined according to the formula:

$$\tau_{k_{\text{max}}} = \tau_{\text{max}} \frac{\mu_k \; p_{\text{max}}}{\mu \; p_{k_{\text{max}}}} \qquad (8)$$

μ_k/ MPa·s − the composite dynamic viscosity.

Time $\tau_{k\,\text{max}}$ is determined for another metal after integration within the boundaries of 0 to l of the formula:

$$\frac{\mathrm{d}l}{\mathrm{d}\tau} = -\frac{p\,d^2}{32\mu\,l} \qquad (9)$$

Relation (5) after substitution of $p_{k\,\text{max}}$ and $\tau_{k\,\text{max}}$ determined by relations: (6), (7) and (8) produces:

$$\rho_k(p_k, \tau_k) = \beta\, \rho_{k_{\text{max}}} + \frac{(1-\beta)\,\rho_{k_{\text{max}}}}{p_{\text{max}}\, \tau_{\text{max}}} \frac{\mu}{\mu_k} p_k\, \tau_k \qquad (10)$$

Formula (10) enables one of three parameters of the saturation process to be determined (ρ_k, p_k, τ_k), after assuming the two others.

THE DENSITY FUNCTION FOR ALLOY AlSi11

The process of testing the assumed reinforcement with Wood's metal according to the above mentioned procedure is fundamental to determine the values of p_{max}, τ_{max}, ρ_{max} and to determine coefficient b. They amount to: $p_{\text{max}} = 11{,}3$ MPa, $\tau_{\text{max}} = 300$ s, $\rho_{\text{max}} = 8\,420$ kg/m³, $b = 0{,}9726$.

The method described above for the density determination $\rho_k(p_k, \tau_k)$ of the composite with another matrix and reinforcement metal whose characteristics were determined by means of a test liquid [8-14], involves the knowledge of a number of parameters. These parameters and their values for the considered composite according to [3, 8, 14-15] are shown in Table 1.

Wood's metal (Lipowitz's Alloy) melts in the temperature of between 66 – 72 °C. But it was overheated up to 100 – 120 °C because the composite materials could not have been made due to an insufficient saturation of the reinforcement structure with the alloy of 70 °C as shown in Figure 5.

Table 1 **A specification of parameter values for configurations SiC-Wood's metal and SiC-AlSi11**

Parameter name and symbol		Unit	Value
Reinforcement porosity	P	%	54[1], 63[2]
Density of reinforcement material	ρ_z	kg/m³	3 000
Contact angle between the reinforcement material and test liquid	q	deg	110
Kinematic viscosity of the test liquid	n	cSt	0,127
Surface tension of the test liquid	s	N/m	0,465
Density of the composite matrix metal	ρ_m	kg/m³	2 650
Contact angle between the reinforcement material and matrix metal	θ_k	deg	134
Kinematic viscosity of the composite matrix metal	ν_k	cSt	0,650
Surface tension of the composite matrix metal	σ_k	N/m	0,900

[1] for SiC of F40 granulation
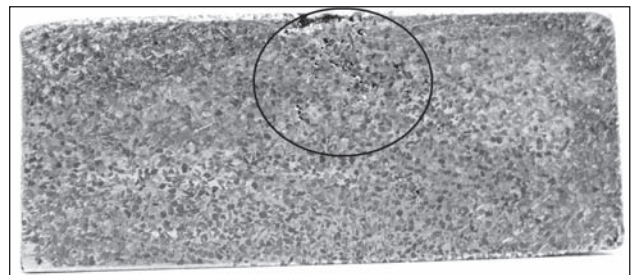[2] for SiC of F120 granulation

Figure 5 Insufficient saturation of the reinforcement preform (SiC of F40 granulation) with Wood's metal of 70 °C (macroscopic examination)
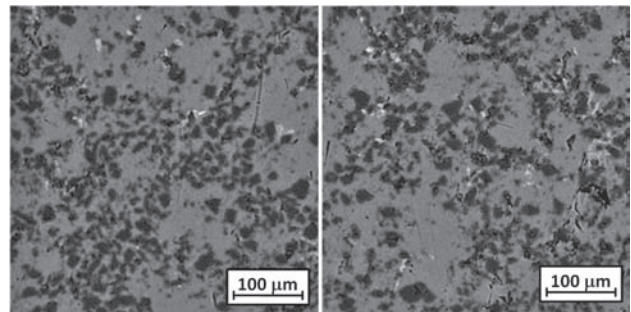

Figure 6 A microstructure of composite SiC/Wood's metal. Particles of F40 (a) and F120 (b) granulation (optical microscopy)

The saturation pressure in the case of SiC preforms (of different granulation F40 and F120) amounted to 15 – 20 MPa. Figure 6 show microstructures of castings.

In further calculations (for the composite with the AlSi11 matrix) it is necessary to determine: $\rho_{k\,\text{max}}$ ac-

Table 2 **Optimal technological parameters for composite AlSi11/SiC**

Composite AlSi11/SiC (of F40 granulation)	Composite AlSi11/SiC (of F120 granulation)
composite density $\rho_{k\,\text{max}} = 2\,890$ kg/m³	composite density $\rho_{k\,\text{max}} = 2\,820$ kg/m³
saturation pressure $p_{k\,\text{max}} = 17{,}0$ MPa	saturation pressure $p_{k\,\text{max}} = 16{,}5$ MPa
saturation time $\tau_{k\,\text{max}} = 500$ s	saturation time $\tau_{k\,\text{max}} = 500$ s

cording to formula (6) for $V_{por} @ 0$ and $\rho_{k\,max} @ \rho_{k\,t}$, then $p_{k\,max}$ according to formula (7), $\tau_{k\,max}$ to (8) and function $\rho_k(p_k, \tau_k)$ based on (10). The values for these parameters are shown in Table 2.

CONCLUSIONS

Based on determined technological characteristics of the assumed reinforcement composed of unordered particles and considering the flow similarity, conclusions can be made as for infiltrating this reinforcement with any other metal whose physical and chemical properties are known. Similarly to the case of making the composite with a test matrix, the composite density may be considered as the measure of effectiveness for saturation.

To fulfill the requirements for the flow of the saturating liquid it is advisable that the Reynolds number should be below 2 340, when turbulent flows are not observed [5].

The microscope images show the level up to which the reinforcement should be filled with the saturating liquid which proves the usefulness of the whole method.

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