A R C H I V E S O F M E T A L L U R G Y A N D M A T E R I A L S
Volume 58 2013 Issue 3
DOI: 10.2478/amm-2013-0109

Z. KONOPKA*, M. ŁĄGIEWKA*, M. NADOLSKI*, A. ZYSKA*

DETERMINATION OF THE STRENGTHENING COEFFICIENT OF PRESSURE CAST AlSi13Cu2/CHOPPED CARBON FIBRE COMPOSITE

WYZNACZENIE WSPÓŁCZYNNIKA UMOCNIENIA KOMPOZYTU AlSi13Cu2-CIĘTE WŁÓKNA WĘGLOWE ODLEWANEGO CIŚNIENIOWO

The purpose of the work is the determination of the strengthening coefficient for the AlSi13Cu2 alloy matrix composite reinforced with chopped carbon fibre and produced by high-pressure casting method. This coefficient was determined during the static tensile test using the Ramberg-Osgood equation. The regression relationships between strain and stress were established, serving as a basis for finding the strengthening coefficient values. The measurements and calculations were performed also for the matrix alloy itself, for the purpose of comparison. The examined coefficient decreased with an increase of fibre fraction in the composite. Its value for composite containing 15 vol. % of chopped fibre was found to be lower by 30% than the value determined for matrix alloy, what means the strengthening of the alloy to such a degree.

Keywords: metal matrix composites, pressure die casting, strengthening

Celem pracy jest wyznaczenie współczynnika umocnienia kompozytu na osnowie stopu AlSi13Cu2 zbrojonego ciętymi włóknami węglowymi wytworzonego metodą ciśnieniowego odlewania. Współczynnik ten wyznaczono w statycznej próbie rozciągania korzystając z równania Ramberga-Osgooda. Opracowano regresyjne zależności odkształcenia i naprężenia, na podstawie których wyznaczono współczynnik umocnienia. Dla porównania wykonano pomiary dla stopu osnowy bez włókien. Stwierdzono zmniejszenie się tego współczynnika ze wzrostem udziału włókien w kompozycie. Jego wartość dla kompozytu zawierającego 15% obj. ciętych włókien jest o około 30% niższa od wartości wyznaczonej dla stopu osnowy, co oznacza, że materiał został w takim stopniu umocniony.

1. Introduction

Silumin matrix composites reinforced with carbon fibre are the highly appreciated structural material due to their high specific strength, high elastic modulus, distinctive fracture toughness, good creep resistance in elevated temperature, low thermal expansion coefficient, and excellent corrosion resistance. Fibre as a reinforcing phase can improve the cracking resistance and strengthen the relatively brittle casting aluminium alloys containing silicon [1, 2].

Carbon fibre applied in production of composites is practically non-wettable by aluminium and its alloys [3, 4] at the temperature range below 1100°C, and during the prolonged contact it reacts with the molten metal, precipitating the brittle and hygroscopic Al_4C_3 carbide [5, 6] which can significantly weaken or destroy the composite. The mentioned factors lead to the segregation of fibre in the composite slurry and the resulting structural non-uniformity of castings. A variety of preparation methods is applied to the surface of the reinforcement in order to improve the wetting conditions and protect the carbon fibre. They consist in producing the technological coatings (e.g. of Ni, Cu), the barrier coatings (e.g. of SiC, B_4C, TiC, SiO_2), or special coatings (e.g. of Na, $Na_2B_4O_7$, B_2O_3) [7, 8].

The further technological problem is high viscosity and low castability of composite slurries. The viscosity increases with an increase in the reinforcing phase fraction and depends on its shape and the surface phenomena taking place at the metal/reinforcement boundary (wetting, work of adhesion) [9, 10]. The dynamic coefficient of viscosity of AlSi matrix composite reinforced with chopped carbon fibre is ten times greater than this coefficient for the liquid alloy itself. The proper filling of the die cavity is therefore obtained only under the conditions of increased or high external pressure, and by the same the choice of casting method is inevitably restricted. The particularly effective methods are those of pressure or squeeze casting, the latter applied either for liquid or for semi-solid material. In pressure casting method the proper filling of the die cavity depends mainly on the injection velocity in the second phase of injection. This parameter can be precisely controlled and changed by proper setting the piston velocity during the II phase of die filling and by the appropriate selection of the gate area, and being more precise – by selection of the gate width, as its thickness depends on the wall thickness of a

* CZĘSTOCHOWA UNIVERSITY OF TECHNOLOGY, CZĘSTOCHOWA, POLAND

casting and is equal to 75% of this thickness as a rule. The time of die filling (the injection time) depends on the casting solidification time (its reduced wall thickness) and should be the same for castings of different volume produced in one shot in the multi-cavity die. It is obvious that the thinner the casting wall, the greater the injection speed should be, and for most pressure castings the die filling is of turbulent character.

The examinations of fracture toughness of metal matrix composite materials exhibiting small plastic deformation are held under the plane stress conditions. The experimental analysis is based on three parameters of fracture mechanics, i.e. the stress intensity factor K, the J integral, and the crack tip opening displacement (CTOD). The degree of composite strengthening is most frequently described by the Ramberg-Osgood equation, which in the logarithmic form takes the following shape [11, 12, 13]:

$$\log \varepsilon_{pl} = N \cdot \log \sigma - \log F \tag{1}$$

where σ – the stress recorded in static tensile test between the yield point and tensile strength ($R_e \leqslant \sigma \leqslant R_m$), N – the strengthening coefficient taking a value between zero and infinity, F – a constant.

The N parameter characterises the 'degree' of material strengthening. It takes a value of 1 for ideally elastic materials, and tends to infinity ($N \to \infty$) for ideally plastic ones.

2. Methods and results of investigation

The alloy selected for examination concerning the metal matrix composite pressure casting was AlSi13Cu2 matrix alloy of chemical composition: Si=11.0-12.5%, Cu=1.75-2.50, Fe=0.7-1.0 with permitted contaminants: Zn=0.8-1.0, Mn=0.5, Mg=0.2. It is the alloy commonly used in pressure casting. The reinforcing phase was composed of chopped carbon fibre (C_f) of HTA family produced by Tenax Fibre company, 7 μm in diameter and 7 mm long, coated with 0.25 μm thick nickel layer.

The composite slurry was prepared by mixing the liquid matrix alloy and the assumed volume amount of carbon fibre. The parameters were as follows: mixing time – 300 s, angular velocity of propeller mixer equal to 10 s^{-1}. Composite slurries containing carbon fibre volume fraction in the amounts of 5, 10, or 15% were prepared. Then tensile test specimens were cast of each of these slurries by the high pressure casting method. The parameters of pressure casting were chosen on the basis of castability examination of composites. Free of defects composite castings were achieved at the injection velocity equal to 60 m/s and the gate width of 1 mm, and these values of pressure casting process parameters were applied during the experiment. The prepared slurries were cast in the multi-cavity die installed in the horizontal cold chamber pressure casting machine of clamping force 1.6 MN. Four specimens intended for mechanical properties testing and a test piece for examination of the die filling (the castability) were cast during a single shot in the die. The piston velocity in the second stage of injection was 3 m/s, and the intensification pressure – 40 MPa.

The value of the strengthening coefficient N for the examined composite was determined from the Ramberg-Osgood equation (1), taking into account the data recorded during the static tensile test. The standardized round tensile specimens with gauge length to diameter ratio of 10:1 and the diameter of 6.1 mm were examined. The tensile test was performed by means of suitably equipped hydraulic testing machine of Zwick production. The applied force was recorded by receiving signals from the tensometric sensor of the machine, and the elongation from the indications of extensometer made by Zwick. The recorded signals were converted into the stress-strain system, indicating the total strain ε_{cal} versus the stress σ. The examined composite exhibited the yield point. Points falling within the stress range from the yield point to the tensile strength were selected for calculations. They were transferred to the stress σ – plastic deformation ε_{pl} system, then the data were logarithmized and there were found equations of straight lines, the slopes of which represent the required values of the strengthening coefficient N.

The arrangement of chopped carbon fibres in examined composites was shown in Figs. 1-3. The graphic presentation of the performed calculations including the equations describing the plotted lines can be found in Fig. 4. The values of the strengthening coefficient N were calculated for lines exhibiting the correlation coefficient $R > 0.96$. The values of the N parameter found in this way for all variations of the examined pressure cast composite are gathered in Table 1.

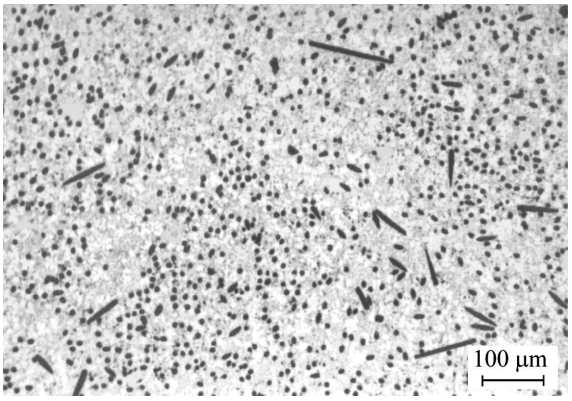


Fig. 1. Arrangement of chopped carbon fibres in composite containing 5% vol.reinforcing phase

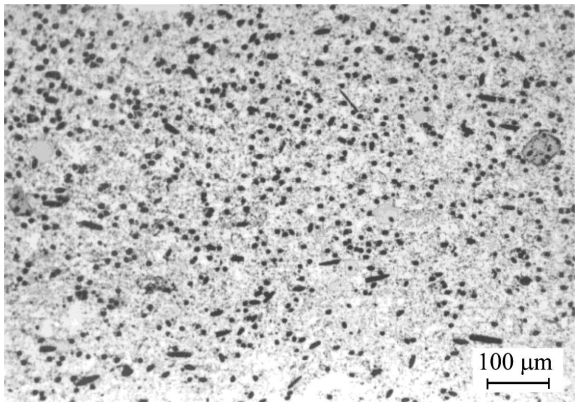


Fig. 2. Arrangement of chopped carbon fibres in composite containing 10% vol.reinforcing phase

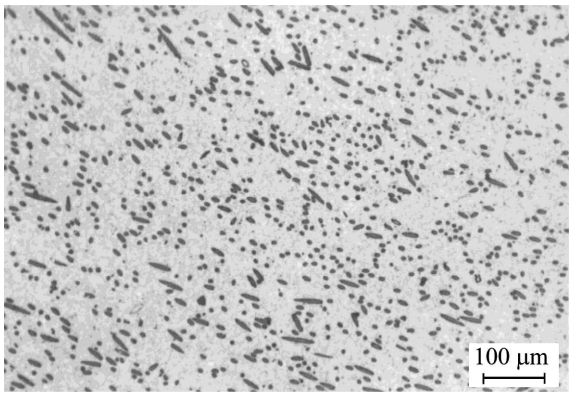
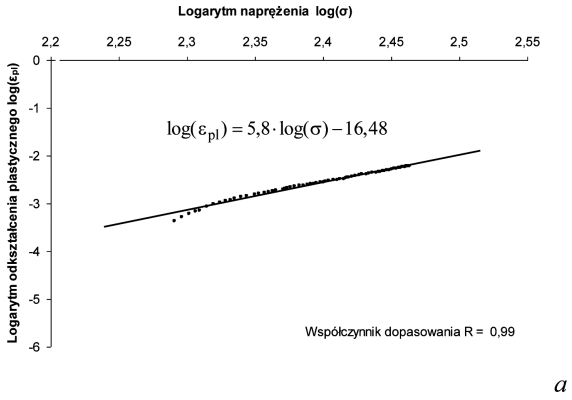
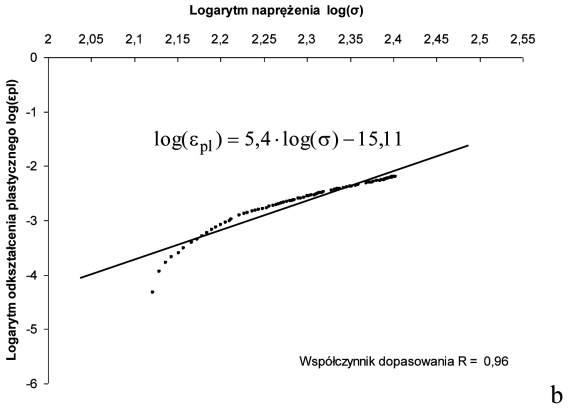


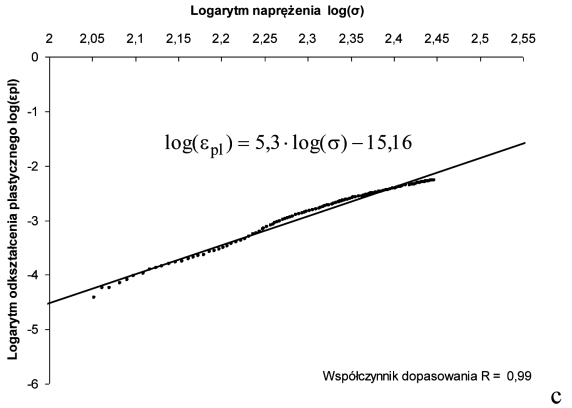
Fig. 3. Arrangement of chopped carbon fibres in composite containing 15% vol.reinforcing phase



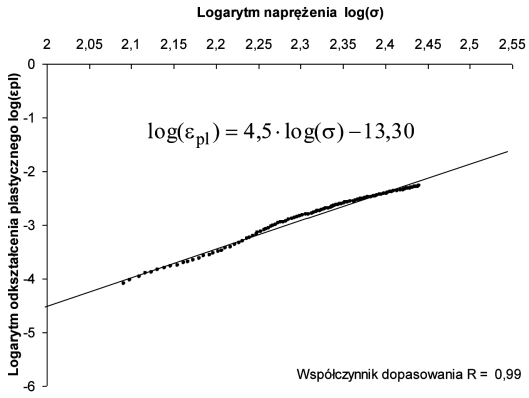
a



b



c



d

Fig. 4. The determination of the strengthening coefficient N for the AlSi13Cu2 alloy (a), for the AlSi13Cu2/5 vol. % of carbon fibre composite (b), for the AlSi13Cu2/10 vol. % of carbon fibre composite (c), for the AlSi13Cu2/15 vol. % of carbon fibre composite (d)

TABLE 1
Results of examinations of the strengthening coefficient *N*

Designation of composition	Gauge diameter d_o	Strength indicators			The strengthening coefficient
		R_e	R_m	A_c	*N*
	[mm]	[MPa]	[MPa]	[%]	-
AlSi13Cu2	6.1	233.8	291.5	0.55	5.8
AlSi13Cu2/5% C_f	6.1	195.5	261.3	0.60	5.4
AlSi13Cu2/10% C_f	6.1	225.2	279.2	0.48	5.3
AlSi13Cu2/15% C_f	6.1	213.5	286.5	0.64	4.5

3. Conclusion

The technology of pressure casting allows to produce composite materials containing carbon fibre uniformly distributed in the volume of AlSi13Cu2 alloy matrix. The presence of carbon fibre distinctly strengthen the examined alloy (eq.1) mainly due to the rise of plastic properties of composites (A_c). Other mechanical properties of examined composites (R_e,R_m) are slighty lower in comparison to matrix alloy. The strengthening coefficient *N* decreases with an increase of their volume fraction, what indicates that the material properties shift towards more elastic behaviour. The strengthening coefficient at 15 vol. % of carbon fibre fraction is by 30% lower than for the non-reinforced AlSi13Cu2 alloy.

REFERENCES

[1] Z. K o n o p k a, Metalowe kompozyty odlewane. Wyd. Politechnika Częstochowska, Częstochowa (2011).
[2] M.F. A s h b y, Dobór materiałów w projektowaniu inżynierskim. WNT, Warszawa (1998).
[3] K. L a n d r y, Characteristic contact angles in the aluminium/vitreous carbon system, Scripta Materialia **34**, 841-846 (1996).

[4] J. Hashim, L. Looney, M.S.J. Hashmi, The wettability of SiC particles by molten aluminium alloy, J. of Mater. Proc. Technology **119**, 324-328 (2001).
[5] B. Wielage, A. Dorner, Corrosion studies on aluminium reinforced with uncoated and coated carbon fibres, Composites Sc. Techn. **59**, 1239-1245 (1999).
[6] J. Rams, A. Ureña, M.D. Escalera, M. Sánchez, Electroless nickel coated short carbon fibres in aluminium matrix composites, Composites A **38**, 566-575 (2007).
[7] Y.D. Huang, N. Hort, H. Dieringa, Microstructural investigations of interfaces in short fiber reinforced AlSi12CuMgNi composites, Acta Materialia **53**, 3913-3923 (2005).
[8] D. Doutre, Foundry Experience in Casting Aluminium Metal Matrix Composites, Trans. Amer. Found. Soc. **101**, 1070-1076 (1993).
[9] J. Campbell, Review of Fluidity Concepts in Casting, Cast Metals **7**, 227-237 (1994).
[10] Z. Konopka, A. Zyska, M. Cisowska, Badanie wypełniania wnęki formy ciśnieniowej suspensją kompozytową, Archiwum Odlewnictwa **4**, 14, 229-236 (2004).
[11] M.H. Alibaldi, Numerical Fracture Mechanics. Dordrecht, Kluwer Academic Publishers, 2 (1991).
[12] D. Stouffer, L.T. Dame, Inelastic Deformation of Metals. Models, Mechanical Properties and Metallurgy. New York, Jon Wiley & Sons Inc., 66 (1996).
[13] A. Bochenek, Inicjacja i podkrytyczny rozwój szczeliny w stalach mikro-stopowych w ujęciu metod numerycznych i doświadczalnych. Częstochowa, Wydaw. Politechniki Częstochowskiej (1990).

This article was first presented at the VI International Conference "DEVELOPMENT TRENDS IN MECHANIZATION OF FOUNDRY PROCESSES", Inwałd, 5-7.09.2013

Received: 20 January 2013.