Archives of Materials Science and Engineering

Volume 39
Issue 1
September 2009
Pages 29-37

International Scientific Journal published monthly by the World Academy of Materials and Manufacturing Engineering

Design, manufacture and technological verification of SiC/C composite stirrer

A. Dolata-Grosz [a,*], W. Hufenbach [b], J. Śleziona [a], M. Gude [b], A. Czulak [b]

[a] Department of Alloys and Composite Materials Technology,
Faculty of Materials Science and Metallurgy,
Silesian University of Technology, ul. Krasińskiego 8, 40-019 Katowice, Poland

[b] Institut für Leichtbau und Kunststofftechnik (ILK),
Technische Universität Dresden, 01062 Dresden, Germany

* Corresponding author: E-mail address: anna.dolata-grosz@polsl.pl

Received 02.03.2009; published in revised form 01.09.2009

ABSTRACT

Purpose: In article were presented assumptions and choose results of investigations connected with material selection and technology production of prototype's ceramic stirrer with destination to work in environment of liquid metal. In the research work the result of the design, manufacture and technological verification of SiC/C composite stirrer have been presented.

Design/methodology/approach: The design of the stirrer (2D and 3D models) and strength tests on the blade and fragment of the composite axle was prepared in the programme Solid Works and the FEM, using COSMOS software. Polymer infiltration and pyrolysis (PIP) technique was used for fabrication SiC/C stirrer. Examination of wettability and suitability of the SiC/C composite for application in a liquid metal with sessile drop wettability was conducted. The surface geometry, conducted using a non-contact optical profilometer, FRT Micro'Prof.

Findings: Further laboratory tests of the SiC/C composite stirrer, designed and developed in the Institute of Lightweight Engineering and Polymer Technology at TU Dresden have confirmed rightness of the design, assumptions regarding the thermal, mechanical and chemical resistance of the stirrer.

Practical implications: The technological tests have proven a considerable reduction of the turbulence flow, which with an unchanged system of controlling the stirrer ensured stability of the liquid metal whirl and repeatability of the process.

Originality/value: The application of this new material will enable not only the expansion of laboratory research, but it may also facilitate the implementation of liquid/phase technologies of obtaining MMC composites for the industry and thus, contribute to increasing the durability of stirrers in comparison with the solutions applied so far.

Keywords: Composites; Solidification; Thermovision; Structure

Reference to this paper should be given in the following way:

A. Dolata-Grosz, W. Hufenbach, J. Śleziona, M. Gude, A. Czulak, Design, manufacture and technological verification of SiC/C composite stirrer, Archives of Materials Science and Engineering 39/1 (2009) 29-37.

MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

A need for new materials and technological solutions emerged, due to durability and wear-related problems, duringprocessing of graphite stirrers, so far used in the process of liquid metal mixing and production of composite suspensions, [1,2]. An alternative solution, consisting in application of the composite belonging to the CMC group of

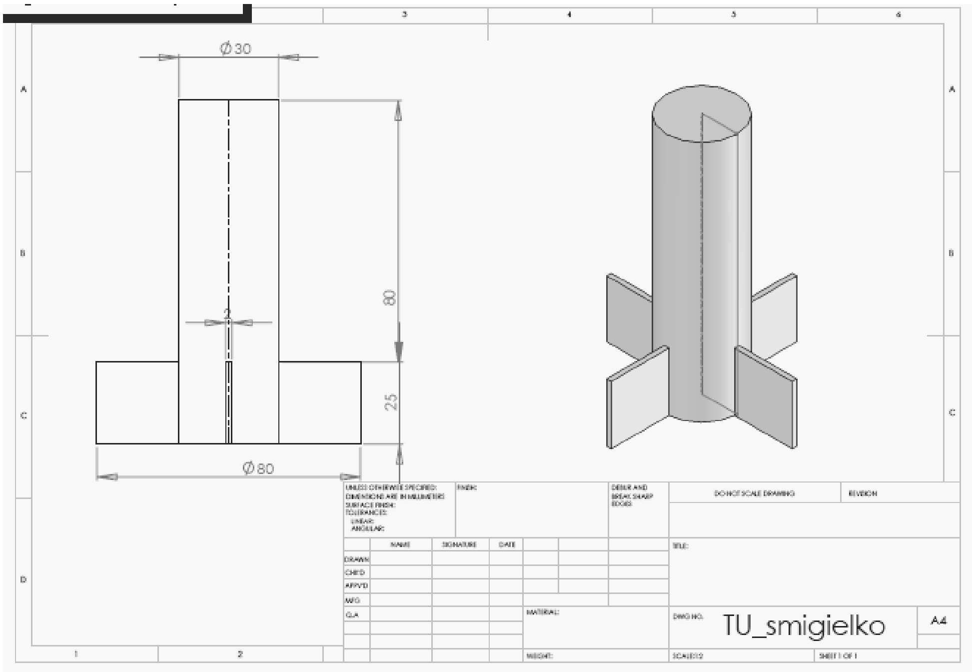


Fig. 1. Technical drawing of SiC/C composite stirrer prepared in the program Solid Works

materials, was proposed in the researches. The components selection for the designed stirrer was based on common advantages of ceramic materials: low density, high durability and rigidity, good temperature stability, good fatigue strength, resistance to thermal shock, very good tribological properties, shape stability and chemical resistance, [1-10,16,17]. It was assumed that the above-mentioned properties of ceramic materials, SiC/C in particular, shall enable application of ceramic materials in the structure of mixing system operating in the liquid metal environment. Taking into account the above premises, a stirrer was designed and fabricated from a composite material with a SiC ceramic matrix reinforced with a continuous carbon fibre (SiC/C).

2. Design of the stirrer

The design of the stirrer (2D and 3D models) was prepared in the programme Solid Works. Manufacture of stirrer individual components, blades and handle was based on a production drawing with dimensioning SiC/C system (Fig.1).

An optimal shape of the stirrer, blades and axles was designed within the technological capacity of the Institute of Lightweight Engineering and Polymer Technology, considering the manufacture conditions and technical restrictions of the laboratory stand in the Department of Alloys and Composite Materials Technology for mixing alloys and for the production of composite suspensions. During the stirrer design, special attention was paid to the metal stream and its flow. In a real system, the mixing of a liquid alloy produces so called: central whirl and potential whirl, both responsible for introduction and uniform distribution of ceramic particles in a liquid metal matrix during the production of a composite suspension.

2.1. State of stress analysis

As a part of the investigations, strength tests on the blade and fragment of the composite axle were conducted at ILK. For this purpose FEM, using COSMOS software and Solid Works program, was applied. Two production variants of stirrer, taken from a book „Mixing multiphase systems“ by prof. J. Kamienski, were considered, [11]. Stirrer with and without a notch are shown in Fig.2,3.

a) b)

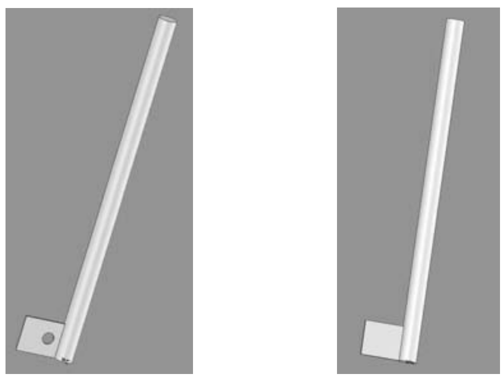
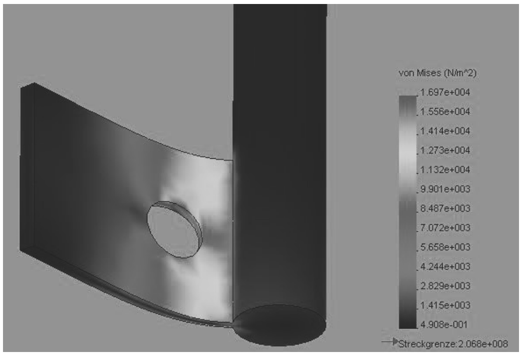


Fig. 2. Model of SiC/C composite stirrer prepared in the program Solid Works

The aim of the study is identification of highest stress areas and possible damage to finished element of a stirrer. The load results in calculating density of liquid aluminium in 650°C with a single blade (Fig. 3).

a)



b)

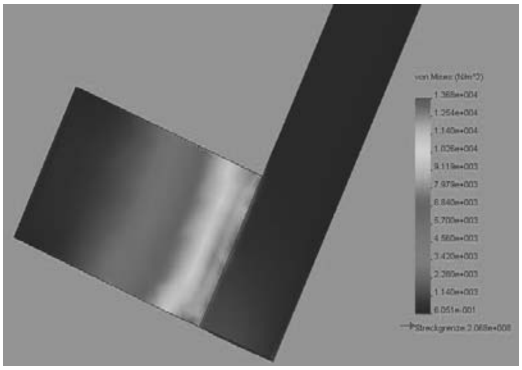


Fig. 3. Stress pattern in the blade with round hole and without any hole

The analysis results show that higher value stresses occur in notch blade with total 16970 N/m2 (Fig 3a). Nonetheless, high values are concentrated near indentations, whereas at the contact points with an axle stresses are reduced to 9900 N/m^2. For blades without a notch stresses total up to 13680 N/m^2 and high stresses are concentrated near blade-axle body connection (Fig 3b). Significant is relatively low stress value in comparison to the durability of the designed material and its connections, which substantially differ from critical values. In addition, the increase of axle diameter, during production process enables further value reduction.

3. Development of the production technology of CMC composite stirrers

For manufacture of ceramic axle stirrer, reinforced with carbon fibres, a modified winding method was applied at the ILK, (Fig.4), [12,13]. The method enables: manufacture of ceramic materials, reinforced with a carbon fibre <45°, a uniform connection of fibres and matrix with preserving of the winding structure, precise fibre arrangement with a programmable tension, high fibres fraction in elements for transferring high loads, pressure and resistance of flow.

Blade elements were manufactured using a modified manual laminating method; whereas angle of mat reinforcement is [0,90]. The mats were coated with carbon. Placing a mat on a steel mould ensures proper plate thickness 2mm. For mat impregnation special rolls were used, (Fig.5). Proper pressure ensures abstraction of excessive impregnate, thus guarantees exact fibre content. Next elements were moulded by jet cutting.

a)

b)

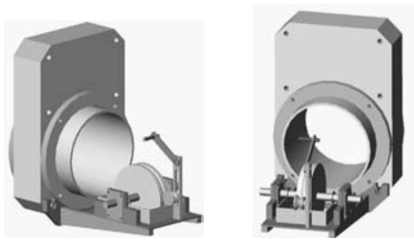


Fig. 4. a) Five axis of winder applied in ILK, b) Magnification a modified of winder's element

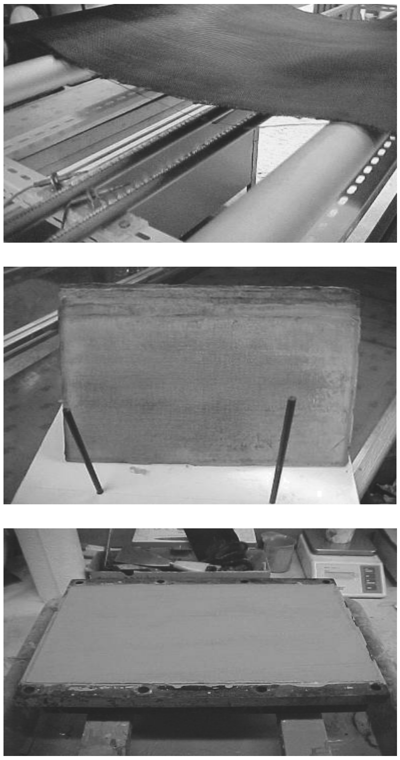


Fig. 5. SiC/C blade of stirrer fabrication via polymer infiltration and pyrolysis (PIP) technique

3.1. Manufacture SiC/C axle of stirrer via PIP technique

The high performance carbon fibre surface with pyrolitic carbon is a precondition for the manufacture of damage tolerant SiC/C composites. During the thermolysis, pyC layer is a barrier of carbon fibres and ceramic matrix and provides adhesion between fibres and matrix in the finished composites, whereby ductile fracture behaviour is generated. The coating process is realized by AP-CVD technique. Thereby, the continuous deposition of the coating components is performed by a cold-wall reactor using inert gas enriched with the coating precursor. For fibre surface wetting the fibre strand is heated in the reactor up to glow (Fig. 6).

Fig. 6. Glowing carbon fibre into a cold-wall reactor.

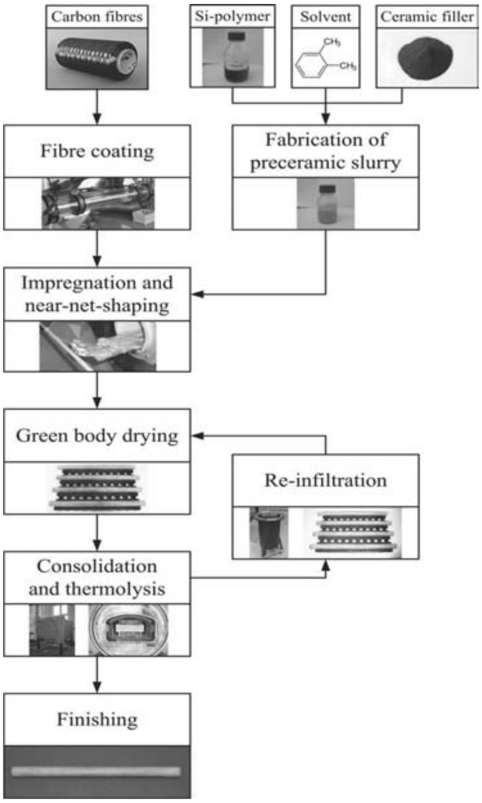


Fig. 7. Fabrication of SiC/C composite axle via polymer infiltration pyrolysis (PIP) technique

The near-net-shaping of the composite axle were achieved by the liquid impregnation of the coated carbon roving with preceramic slurry. This slurry is a powder-endowed polymer suspension composed of an organosilicon precursor such as polycarbosilane, suitable dissolver and inert ceramic fillers. After the green body drying and consolidation, the polymeric educts underwent a thermal decomposition in an oxygen-free muffle kiln atmosphere. Thus, a ceramic solid, composed predominantly of amorphous silicon carbide, is generated. During that direct synthesis a densification is induced, what results in an irreversible volume shrinkage with a simultaneous pore formation inside the silicon carbide matrix. To reduce that porosity, the brown body is filled with the matrix precursor using several re-infiltration and ceramisation steps before the finishing begins, (Fig.7).

4. Stirrer materials assessment in aluminium alloys contact

4.1. Examination of the stirrer surface material wettability with a liquid metal

Examination of wettability and suitability of the SiC/C composite for application in a liquid metal with sessile drop wettability was conducted (Fig. 8,9)(Tab 1). The wettability tests were curried out by the using different testing procedures. One of them CH method where contact heating of Al and substrate samples up to the test temperature, [14] and the other CP test consist in capillary purification technique which allows the separate heating of the samples while a drop is produced by squeezing a metal through capillary directly at the test temperature, [15].

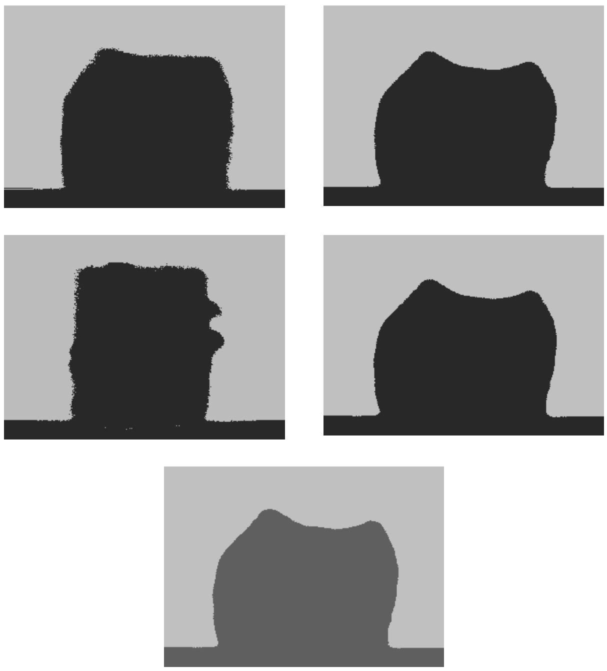


Fig. 8. Photographs of AlSi9Cu droop on SiC/C composite plate, sessile drop wettability CH method: a) T=580^{0}C; b) T=640^{0}C; c) T=820^{0}C,, $\Theta = 114^0$; d) T=900^{0}C, $\Theta = 112^0$; e) T=1000^{0}C, $\Theta = 110^0$,[2]

Table 1.
Measurement results of the contact angle

	AlSi9Cu alloy – SiC/C			Pure Al – SiC/C		
	Θ left	Θ right	Θ mean	Θ left	Θ right	Θ mean
0	137,602	149,443	144	107,322	136,601	122
1	138,127	149,151	144	106,291	137,28	122
2	137,694	149,367	144	103,103	137,544	120
3	137,951	149,718	144	102,685	138,008	120
4	138,376	149,133	144	98,993	138,477	119
5	138,344	148,871	144	97,758	138,362	118
6	137,654	148,616	143	95,394	138,522	117
7	84,04	148,64	116	94,902	138,162	117
8	89,451	147,943	119	93,576	138,027	116
9	88,266	148,103	118	93,89	138,213	116
10	90,906	148,246	120	93,367	136,211	115

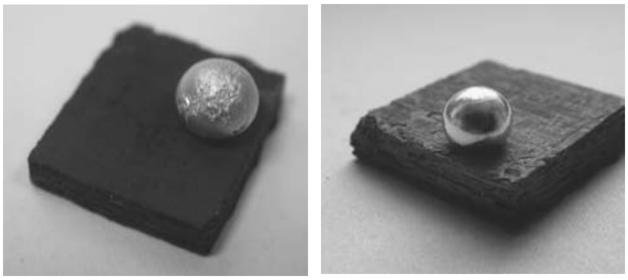


Fig. 9. Photographs of AlSi9Cu droop on SiC/C composite plate, sessile drop wettability method, CP, [2]

Bonding of metal drops with the substrate was not identified, after the tests. The results indicate suitability of the applied composite for its operation in a liquid metal environment, the composite being specifically intended for a mechanical stirrer.

4.2. Profilographometric tests

Apart from numerous factors, the condition of the surface of a stirrer operating in a liquid metal environment also affects its durability. Characteristic features of the surface geometry, conducted using a non-contact optical profilometer, FRT Micro'Prof., were determined in profilographometric tests, (Figs. 10-17). Selected fragments of the stirrer blade surface were investigated. The blade surfaces marked as A and B in the tests reveal significant macroscopic differences. One of them (marked as A) is a smooth with few cracks located on the edges, (Figs. 10-13) while surface B is characterized by distinct bands of reinforcing fibres (Figs. 14-17).

As a result of the production process (PIP), some cracks appeared on surface A, which can be observed in Fig. 10. Those cracks are distributed in different directions, with their lengths not exceeding 0.5 mm and the depth measured not exceeding 45 mm (Figs. 11-13).

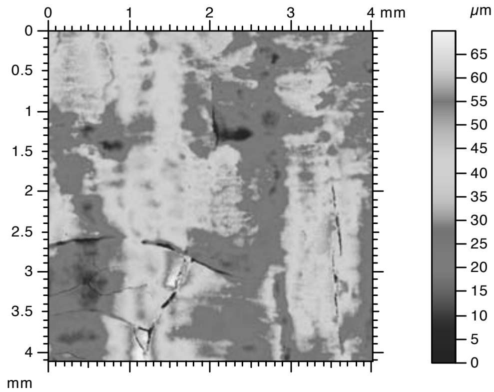


Fig. 10. Surface A: 2D isometric view

a)

b)

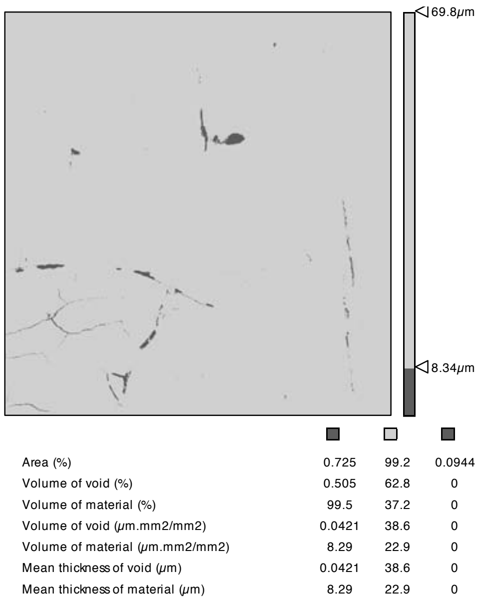
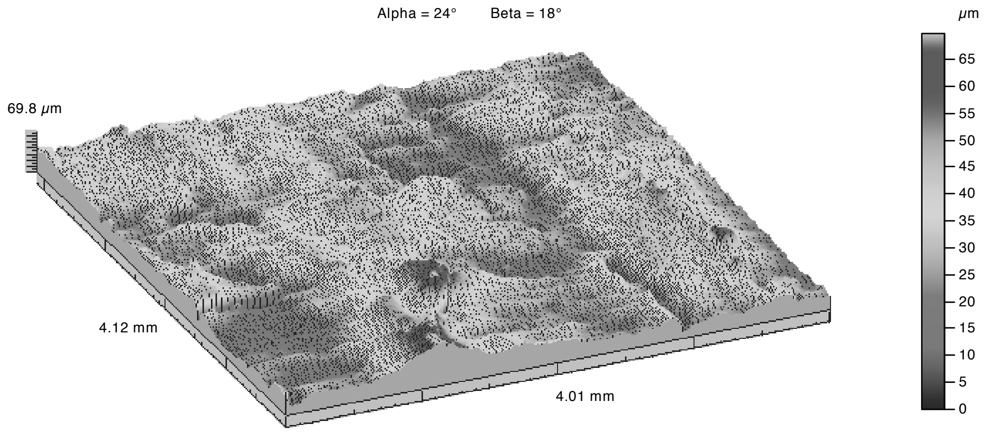


Fig. 11. a) Numerical pictures and b) superficial volume of void, %

a)



b)

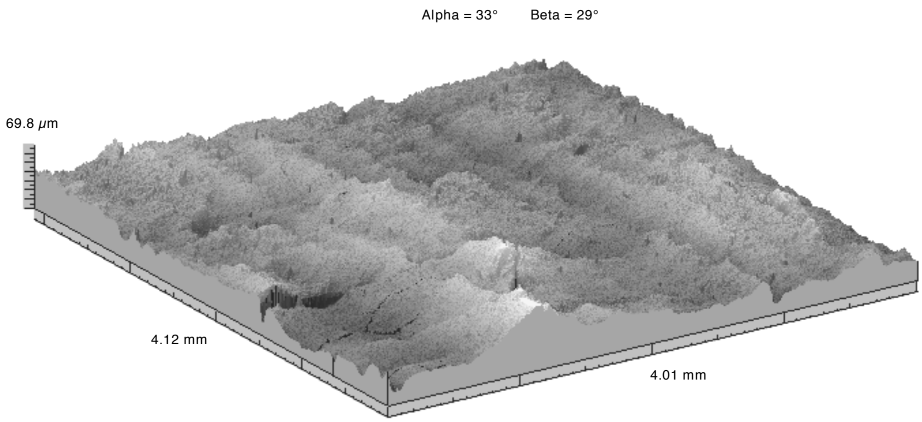
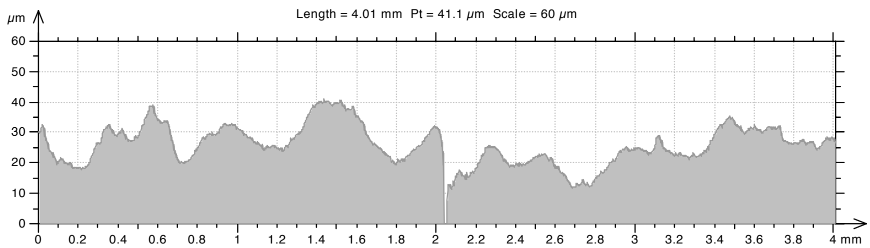


Fig. 12. Surface A: a)image and b) 3D view

a)



b)

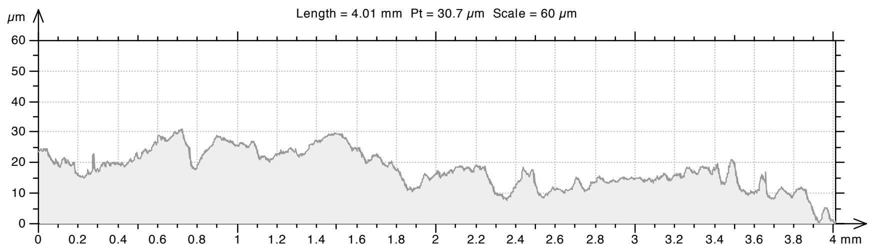


Fig. 13. Profile roughness: a) in chosen section (through the crack); b) in the non crack section.

Surface B (less smooth, with visible traces of fibres)

a) b)

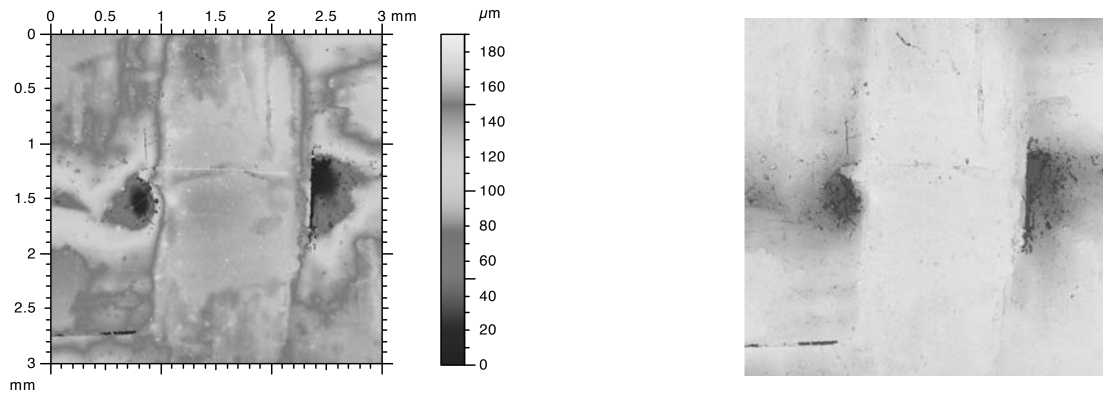


Fig. 14. Surface B: a) 2D isometric view; visible fiber bundle of 1,2 mm diameter; b) numerical pictures

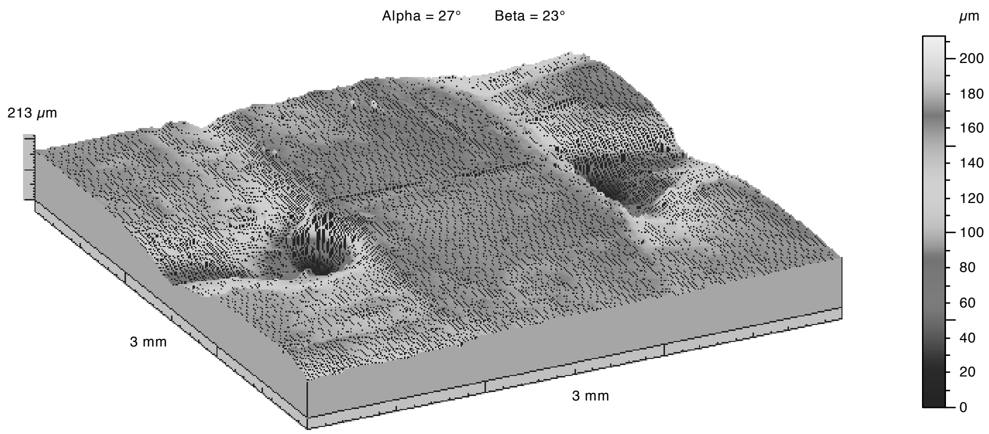


Fig. 15. Image of surface B

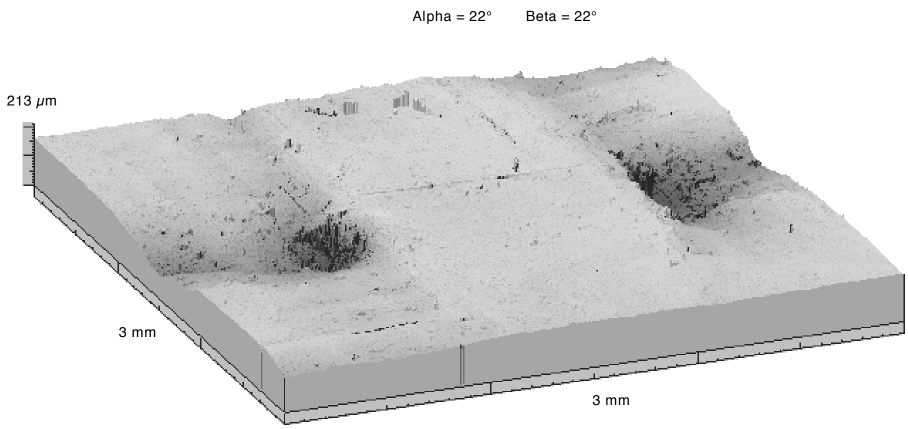


Fig. 16. 3D view of surface B

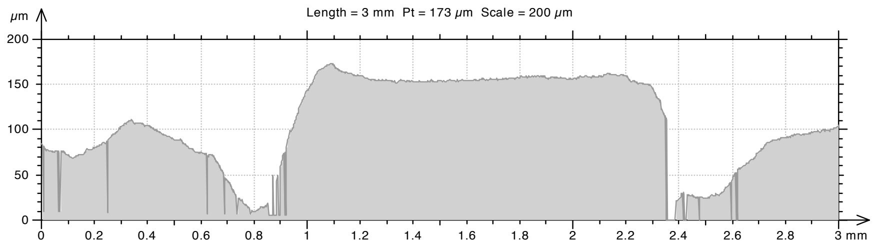


Fig. 17. Example of roughness profile, surface B

5. The concept of methods of connecting the blades with the stirrer axle

Based on the results of the FEM strength analysis, two methods for connecting the blades with the stirrer axle were proposed. The first solution was a lap joint made without using a glue or a solder. It is a mechanical joint obtained by means of a properly prepared system of cut-outs in the stirrer axle. After inserting the second plate, the blades are fastened inside the axle, which prevents them from slipping out during operation, (Fig. 18). An advantage of the mechanical joint is replaceability of the blades.

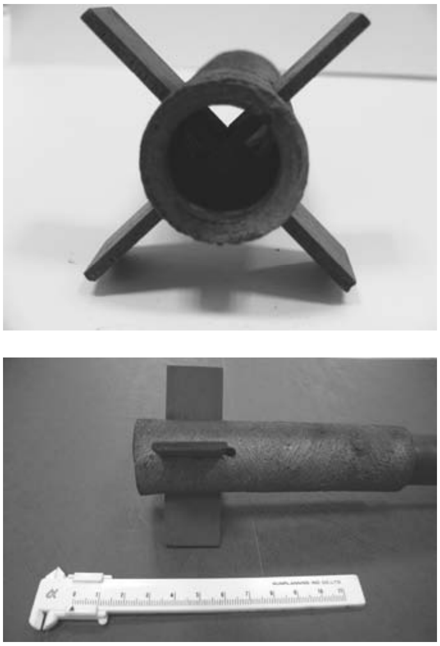


Fig. 18. Prototype of composite stirrer with mechanical joint

The other method of joining blades with the stirrer axle is based on the concept of using a SiC powder suspension in a water solution of sodium silicates, (Fig. 19). An advantage of a glue joint is simplicity of its making and tightness of such system, which reduces penetration of a liquid metal into clear spaces of the stirrer.

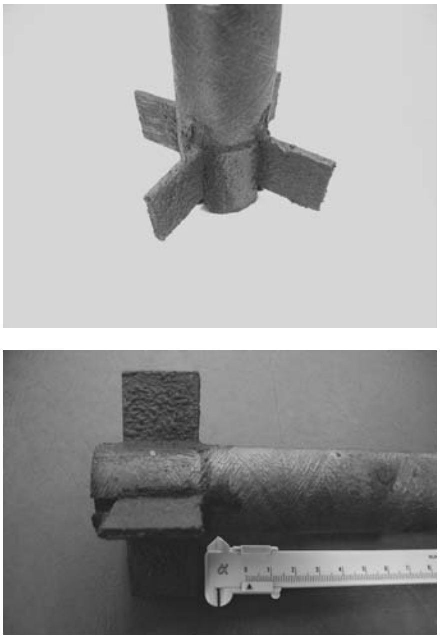


Fig. 19. Prototype of composite stirrer with glue joint.

6. Conclusion and experimental verification the SiC/C prototype stirrers

A optimal selected material and shape of the stirrer was experimentally verified in the Department of Alloys and Composite Materials Technology at the Silesian University of Technology during technological tests consisting of mixing composite suspensions Fig. 20.

The technological tests have proven a considerable reduction of the turbulence flow, which with an unchanged system of controlling the stirrer ensured stability of the liquid metal whirl and repeatability of the process.

Further laboratory tests of the SiC/C composite stirrer, designed and developed in the Institute of Lightweight Engineering and Polymer Technology at TU Dresden have confirmed rightness of the design, assumptions regarding the thermal, mechanical and chemical resistance of the stirrer. Figure 21 demonstrates the stirrer after sixteen 30-minute mixing cycles. The metal visible on the stirrer blades does not exhibit any adhesive reactions (this is the effect of solidifying contraction), which enables easy cleaning of their surface. It should be therefore assumed that application of this new material will enable not only the expansion of laboratory research, but it may also facilitate the implementation of liquid/phase technologies of obtaining MMC composites for the industry and thus, contribute to increasing the durability of stirrers in comparison with the solutions applied so far.

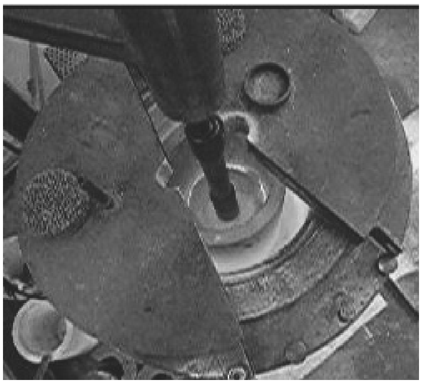


Fig. 20. Tests of composite suspensions manufacture with prototype of SiC/C composite stirrer

a)

b)

a

Fig. 21. View of the stirrer: a) after sixteen 30-minute mixing cycles, b) view of the stirrer after clean

Acknowledgements

Investigation was made within the confines of German –Polish cooperation between Institute of Lightweight Engineering and Polymer Technology in TU Dresden and Department of Alloys and Composite Materials Technology in the Silesian University of Technology. Presented researches are part of Joint Project „Konzeption und Fertigung eines Rührers aus textilverstärkter Keramik zur Herstellung partikelverstärkter Metalllegierungen", financed by Herbert Quandt Germany Foundation in 2008 year.

References

[1] A. Dolata-Grosz, W. Hufenbach, J. Śleziona, A. Czulak, M. Gude, M. Dyzia, J. Wieczorek: Possibility of realization of CMC composite stirrer for suspension method obtaining MMC Composites 8/4 (2008) 429-431.

[2] A. Dolata-Grosz, W. Hufenbach, J. Śleziona, M. Gude, A. Czulak: Application of SiC/C composite stirrer in suspension mixing systems, Composites 9/4 (2009) 373-379.

[3] A. Mühlratzer, Production, Properties and Applications of Ceramic Matrix Composites, Deutsche Keramische Gesellschaft, 76/4 (1999) 30–35.

[4] H. Schneider, High Temperature Ceramic Matrix Composites. Wiley-VCH, Weinheim, Germany, 2001, 802–808.

[5] R. Kochend¨orfer, W. Krenkel, High-temperature ceramic–matrix composites I: Design durability and performance, Ceramic Transactions 57 (1995) 13–22.

[6] W. Krenkel, B. Heidenreich, R. Renz, C/C-SiC composites for advanced friction systems, Advanced Engineering Materials 4/8 (2002) 427–436.

[7] J. Hashim, L. Looney, M.S.J Hashmi: Metal matrix composites: production by the stir casting method, Journal of Materials Processing Technology 92-93 (1999) 1-7.

[8] M. Kok. Production and mechanical properties of Al_2O_3 particle-reinforced 2024 aluminium alloy composites, Journal of Materials Processing Technology 161 (2005) 381–387.

[9] S. Naher, D. Brabazon, L. Looney, Simulation of the stir casting process, Journal of Materials Processing Technology 143-144 (2003) 567-571.

[10] W. Hufenbach, C. Weimann, H. Richter, A. Langkamp, T. Behnisch, Development of textile reinforced CMC lightweight modules for high performance automotive damping systems, Revue**,** Interceram 56/2 (2007) 92-97.

[11] F. Stręk, Mixing and mixers. WNT, Warsaw, 1981.

[12] W. Błażejewski, W. Hufenbach, A. Czulak, R. Böhm, Manufacture and test of composite tube specimens with braided glass fiber reinforcement, Composites 5/4 (2005) 67-71.

[13] G. Ziegler, I. Richter, D. Suttor, Fiber-reinforced composites with polymer-derived matrix: processing, matrix formation and properties, Composites Part A: Applied Science and Manufacturing 30/4 (1999) 411-417.

[14] G. Siwiec, J. Botor, The surface tension determination through the estimation of the parameters of the sessile drop equation, Archives of Metallurgy 48/2 (2003) 209-221.

[15] N. Sobczak, Wetting, structure and properties Al/Al_2O_3 interfaces, Composites 3 (2003) 7 301-312.

[16] A. Dolata-Grosz, M. Dyzia, J. Śleziona, Solidification analysis of AMMCs with ceramic particles, Archives of Materials Science and Engineering 28/7 (2007) 401-404.

[17] J. Myalski, J. Wieczorek, A. Dolata-Grosz, Tribological properties of heterophase composites with an aluminium matrix, Journal of Achievements in Materials and Manufacturing Engineering 15 (2006) 53-57.