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Development of textile-reinforced carbon fibre aluminium composites manufactured with gas pressure infiltration methods

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

[a] Institute of Lightweight Structures and Polymer Technology (ILK), Technische Universität Dresden, Germany

[b] Department of Metal Alloys and Composites, Silesian University of Technology, ul.Krasińskiego 8, 40-019 Katowice, Poland

* Corresponding author: E-mail address: acz@ilk.mw.tu-dresden.de

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ABSTRACT

Purpose: The aim of his paper is to show potential of textile-reinforced carbon fibre aluminium composite with advantage of the lightweight construction of structural components subjected to thermo-mechanical stress.

Design/methodology/approach: The manufacture of specimens of the carbon fibre-reinforced aluminium was realised with the aid of an advanced differential gas pressure infiltration technique, which was developed at ILK, TU Dresden.

Findings: The gas pressure infiltration technology enables to fabricate complex carbon aluminium composites with fibre or textile reinforcement using moulds of graphite, but in future development the optimization of infiltration process is required. The load-adapted combination of 3D reinforced semi-finished fibre products (textile preforms) made from carbon fibres (CF) with aluminium light metal alloys (Al) offers a considerable lightweight construction potential, which up to now has not been exploited.

Research limitations/implications: Gas pressure infiltration technology enables to fabricate complex carbon aluminium composites with fibre or textile reinforcement using precision moulds of graphite, but in future development the optimization of infiltration process is required.

Practical implications: Load-adapted CF/Al-MMC, due to the relatively high stiffness and strength of the metal matrix, allow the introduction of extremely high forces, thereby enabling a much better exploitation of the existing lightweight construction potential of this material in comparison to other composite materials.

Originality/value: Constantly rising demands on extremely stressed lightweight structures, particularly in traffic engineering as well as in machine building and plant engineering, increasingly require the use of endless fibre-reinforced composite materials which, due to their selectively adaptable characteristics profiles, are clearly superior to conventional monolithic materials.

Keywords: Composites; Carbon fibre-reinforced aluminium; Pressure infiltration

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1. Introduction

Constantly rising demands on extremely stressed lightweight structures, particularly in traffic engineering as well as in machine building and plant engineering, increasingly require the use of endless fibre-reinforced composite materials which, due to their selectively adaptable characteristics profiles, are clearly superior to conventional monolithic materials. Especially composites with textile reinforcement offer the highest flexibility for the adaptation of the reinforcing structure with regard to complex loading conditions.

The load-adapted combination of three-dimensional reinforced semi-finished fibre products (textile preforms) made from carbon fibres (CF) with aluminium light metal alloys (Al) offers a considerable lightweight construction potential, which up to now has not been exploited. The textile CF reinforcements embedded in the light metal matrix offers improved properties of these metal matrix composites (MMC), thus causing better creep resistance, especially at high operating temperatures, and good energy absorption behaviour, as well as increased stiffness and strength. For instance, aluminium composites with "tailored textile reinforcements" are virtually predestined for use in highly stressed components under complex mechanical and superposed thermal loading conditions. Such textile-reinforced metal-matrix composites offer extraordinary lightweight construction properties, even at higher permanent operating temperatures, and thus are clearly superior to classic fibre or textile-reinforced synthetic composites. In addition, load-adapted CF/Al-MMC, due to the relatively high stiffness and strength of the metal matrix, allow the introduction of extremely high forces, thereby enabling a much better exploitation of the existing lightweight construction potential of this material in comparison to other composite materials.

However, a broad, seminal utilisation of this young group of CF/Al-MMC for lightweight structures is currently strongly inhibited by materials scientific obstacles as well as a lack of calculation methods, design principles and processes suitable for serial production.

In the development of composite components made from CF/Al-MMC it is important to match the metal matrix alloy and the fibre as well as the textile reinforcement and the component structure to one another in optimal fashion, which inevitably leads to close interlocking of processes relevant to material and structure [1-13].

2. Choice of matrix and reinforcement system

Good mechanical properties of carbon fibre reinforced aluminium are highly dominated by the control and the enhancement of the interfaces between the aluminium matrix and the carbon fibres. The poor wettability between carbon fibre and aluminium matrix is a major problem in fabricating CF/A1 composite with attractive mechanical properties. This is further complicated by the possibility of a fibre-matrix interfacial reaction that can lead to a degradation of the fibre, and hence the properties of the composite.

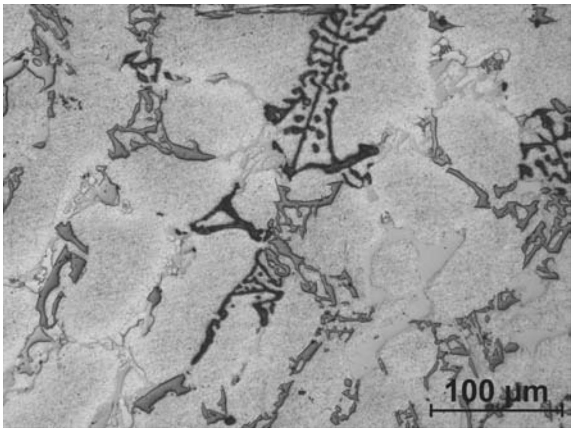
For aluminium alloys as matrix, wetting may be improved by a chemical reaction with the reinforcement which lowers the interfacial energy. Also the disruption of the oxide skin covering the liquid aluminium may improve the wetting behaviour. The parameters that are further influencing the wetting of carbon fibres by liquid aluminium alloys are the temperature, the contact time, and the pressure of the surrounding atmosphere. In literature four means of enhancing the generally poor wetting [2]:

- matrix alloy modifications,
- reinforcement coating,
- reinforcement pre-treatment,
- mechanical means.

The characteristic profile of fibre-reinforced aluminium is influenced by the selection of reinforcing fibres and their interface in a controlled way by the variation of alloy compositions and process parameters during the production of the composite [3,4].

Here a modified 226D aluminium alloy was used in the manufactures process. The alloy was prepared and modified in the Silesian University of Technology. For the modification of the initial alloy magnesium and strontium additions, in the amount of the 0.03 % Sr and 1 % Mg were used. The selected alloy composition are assures good technological properties especially castability and viscosity, moreover they improvement of the carbon fibres' surface wettability, [14-17].

a)



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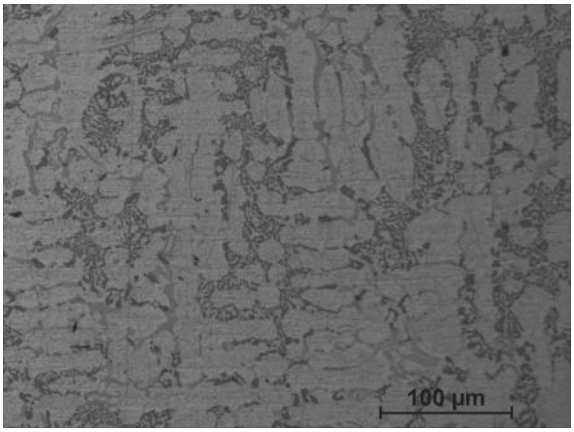


Fig. 1. Microstructure of aluminium alloy after solidification process: a) 226D alloy without modification, b) 226D alloy modified by 1%Mg and 0.03% Sr alloying additions

The microstructures of modified and non-modified aluminium alloy after solidification process have been presented in Figure 1.

Depending on the chemical composition, the silumin structure can be built in various proportions, from a mixture of grains of α solid solution, silicon crystals and aluminium-silicon eutectic, and precipitates of intermetallic compounds' phases (e.g. $CuAl_3$). The eutectic - Si size and morphology of non-modified aluminium cast alloy and modified cast alloy observed by the optical microscope, (Fig. 1) [14].

Due to general poor wetting between aluminium and carbon fibres, Ni coating of carbon fibres and extremely high infiltration pressures and short time are required in the manufacture of carbon fibre aluminium composites. Therefore, gas pressure infiltration techniques have proven to be a particularly effective manufacture process, which allows sufficiently high infiltration pressures at the required high processing temperatures [19-21].

As shown in literature [22-32] the use of fibres with Ni-coating significantly improves the wetting of carbon fibres, having an impact on surface of phase division. In first experiments, commercial fibres were used, signed Toho Tenax HTS40 A23 12K MC from TENAX Company with Ni coating. The fibres were processed manually to woven fabrics (Fig. 2)

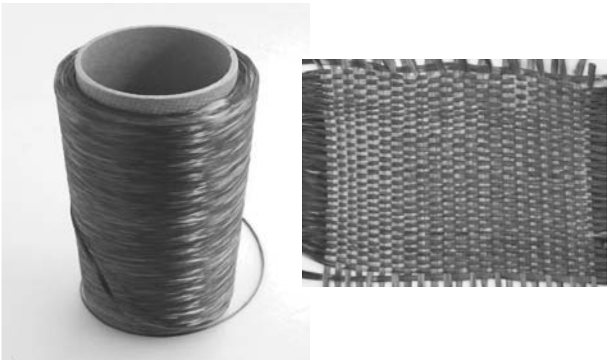


Fig. 2. CF-Fibres and woven perform

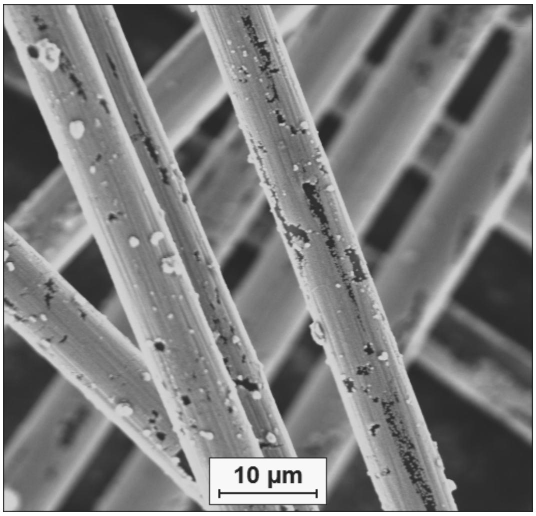


Fig. 3. CF-Fibres before removal of sizing

The used Toho Tenax HTS40 A23 12K MC fibres contained a sizing based on epoxy resin. During gas infiltration the temperatures reach 700°C, which cause evaporating of the layer. In Fig. 3 the image of SEM microscope was depicted on which sizing grains are visible.

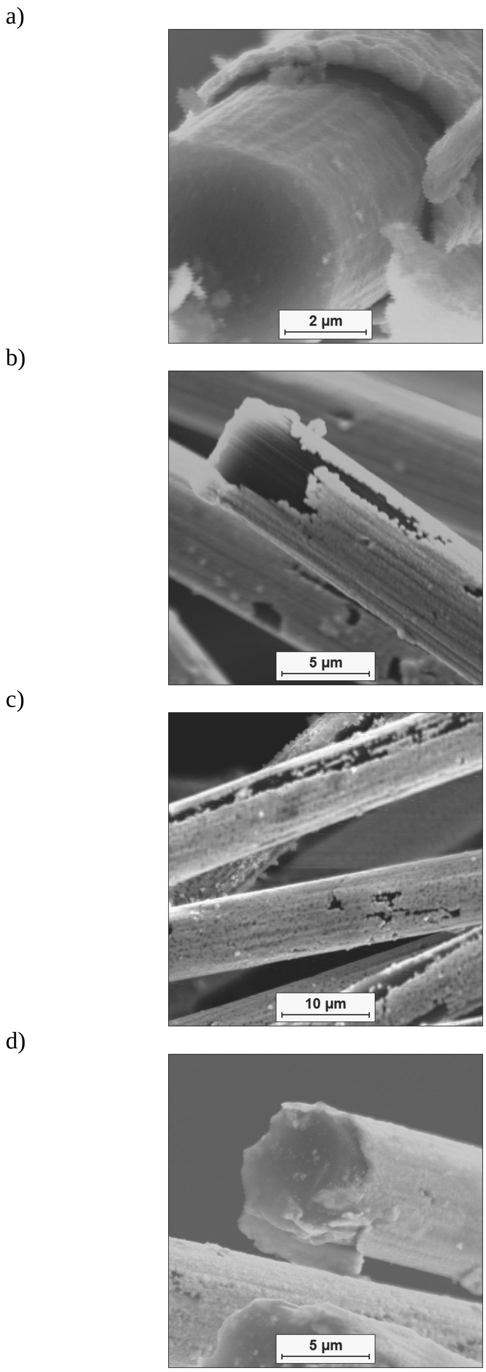


Fig. 4. CF-Fibres after removal of sizing depend on different atmosphere, temperature and duration; a) 450°/1h, b) argon 350°/1h, c) argon 450°/1h, d) argon 700°C/30min

Sizing removal was conducted outside the autoclave, in diverse gases and by diverse temperatures. The results of a SEM analysis are shown in Fig. 4. In each case removal of sizing was observed, but in case of heating in the air for one hour in the temperature 450°C (Fig. 4a), as well as in argon for 30 min in temperature 700°C (Fig. 4d), huge damages of the fibre structure and Ni-coating were observed. Thus for within further processing the reinforcement material preparation the sizing was removed in temperatures under 350°C in 30 min.

3. Manufacture studies

The manufacture of specimens of the carbon fibre-reinforced aluminium was realised with the aid of an advanced differential gas pressure infiltration technique (Fig. 5), which was developed at the ILK [4] for carbon fibre-reinforced magnesium.

Fig. 5. High temperature and pressure autoclave in ILK

The advantage of this technique is that, in contrast to hot pressing, the atmosphere in the fibre preform is reduced during the infiltration. The solidification takes place with a high gas pressure, so that significantly fewer pores are created during the infiltration procedure. Additionally, in gas pressure infiltration the decisive process parameters, such as temperature, pressure and infiltration as well as cooling times can be adjusted selectively, allowing optimisation of the infiltration sequence.

In combination with adapted precision mould of graphite the gas pressure infiltration enables the manufacture of CF-Al composites. The advantage of the infiltration techniques compared to conventional techniques like hot-pressing is that very thin-walled infiltration tools can be applied, witch results in a better controllable process.

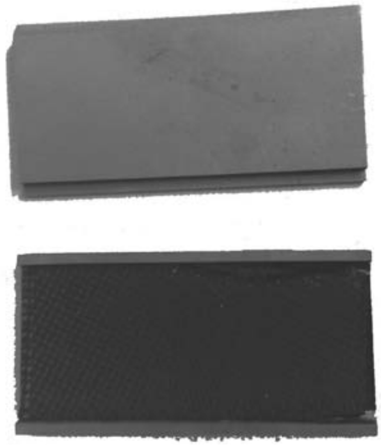
A laboratory autoclave (Fig. 5), designed to process pressure of 100 bar at temperatures up to 1200°C, was initially used for the fabrication of CF-Al composites.

The autoclave, which is equipped with two independently controlled heating zones from graphite, offers a capacity with a diameter of 150 mm and a height of 400 mm. The extraordinarily great bandwidth of variable material and process parameters in the manufacture of carbon fibre-reinforced aluminium by means of gas pressure infiltration methods requires a systematic approach in the selection of optimal parameters [4]. In the course of these efforts, the material parameters of fibre type and textile reinforcement and magnesium matrix were varied with respect to parameters: heating of pre-mould, mould and casting temperature as and infiltration pressure.

The manufacture of specimens and components requires the conception, design and manufacture of precision moulds. Based on adapted requirement specifications of graphite moulds were selected. The moulds for plain specimen (Fig. 6a) enable the manufacture of plates with a length of 150 mm, a width of 65 mm and a thickness of 0.5 to 2 mm.

The prepared preform was put into the graphite inner mould after a treatment with separating. Over the inner mould inside the outer mould (Fig. 6b) the exact amount of modified Al-alloy was evenly arranged and the whole mould was placed into the autoclave (Fig. 5).

a)



b)

Fig. 6. Mould for plain specimen a) graphite inner mould, b) graphite outer mould

In the first process step, the preform, mould and aluminium were heated to the temperature exceeding liquidus temperature of the modified aluminium alloy in vacuum condition. Applying neutral gas, it was supposed to prevent creating detrimental oxides during infiltration. After exceeding the liquidus temperature and initial infiltrating of the preform, high pressure was applied (Fig. 7c). The last step consisted in relative fast cooling of the autoclave chamber by ventilation with cooled protective gas. The course of process, registered by the autoclave equipment is shown in Fig. 8.

The manufactured composite specimens (Fig. 9a) with dimensions 65 x 150 x 2 mm is characterized by a smooth outer surface with visible roving fragments from the carbon preform. Using computer tomography (Fig. 9b), and microscope analysis (Fig. 9c), fragment of the specimen was examined. The analysis showed acceptable quality however with minor areas of insufficient infiltration. Moreover, one can see growth of Al-alloy grains, which reduce mechanical properties of the composite material. Using ultrasonic methods (Fig. 10), quality of the whole specimen was examined. The analysis showed also acceptable quality of manufactured plates. The next step of the investigation is preparing of specimens from examined materials and carrying out strength test, which can determine the influence of individual process parameters on strength of manufactured material. The strength analysis is planned together with determination of fibre arrangement influence on material strength.

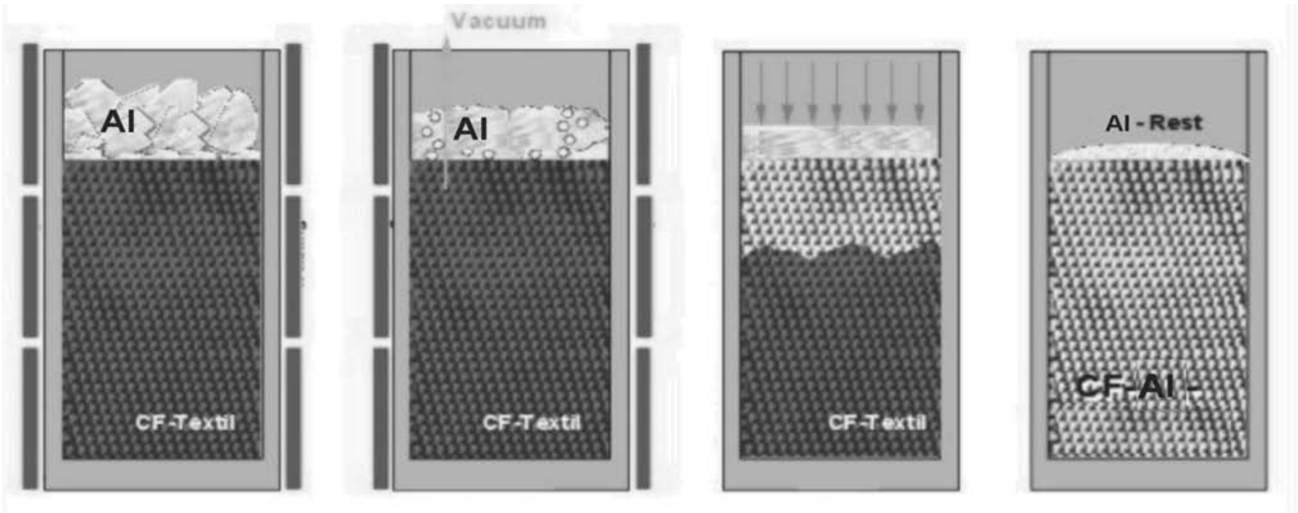


Fig. 7. Gas pressure infiltration technique - procedural principle

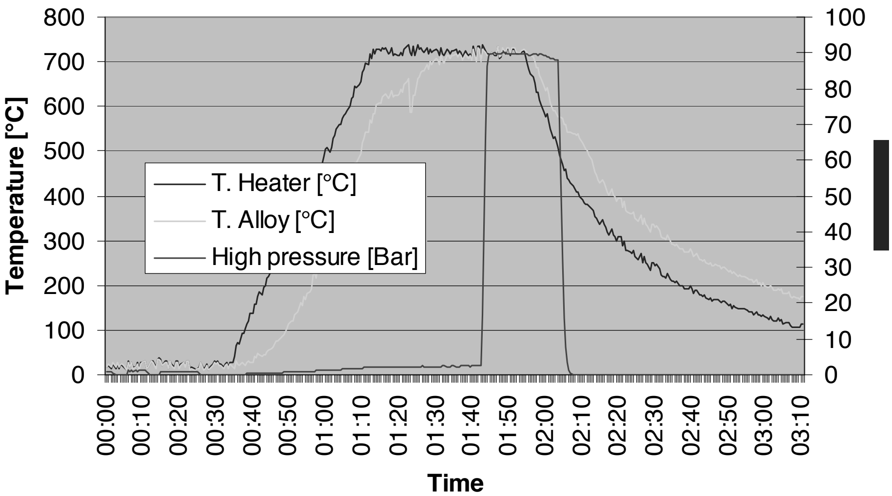


Fig. 8. Temperature-Time-Pressure-Cycle of gas pressure infiltration process

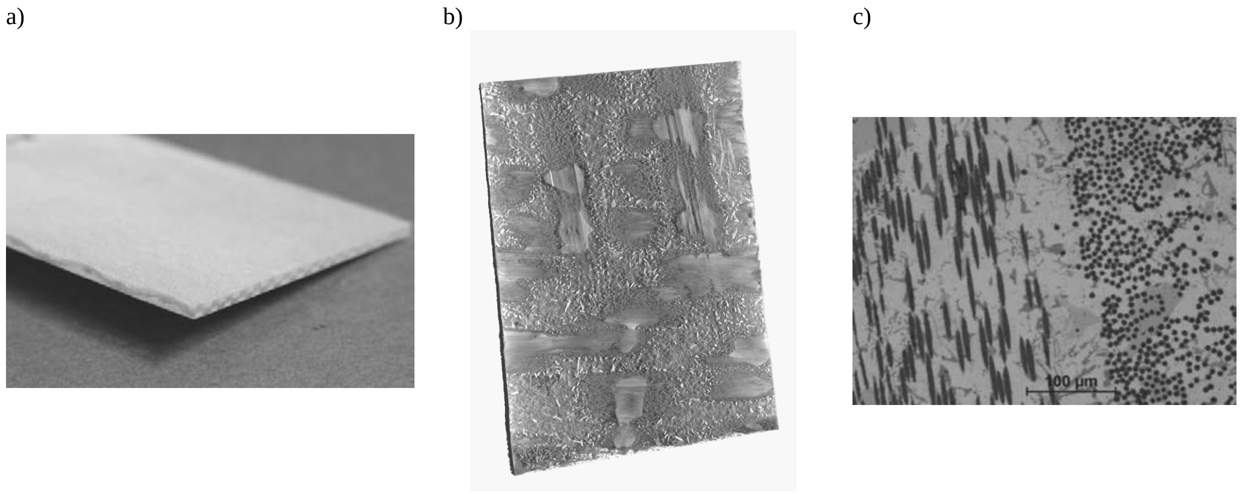


Fig. 9. a) Manufactured CF/AL-MMC specimen b), CT-analysis of CF/AL-MMC specimen, c) Microscopic analysis of CF/AL-MMC specimen

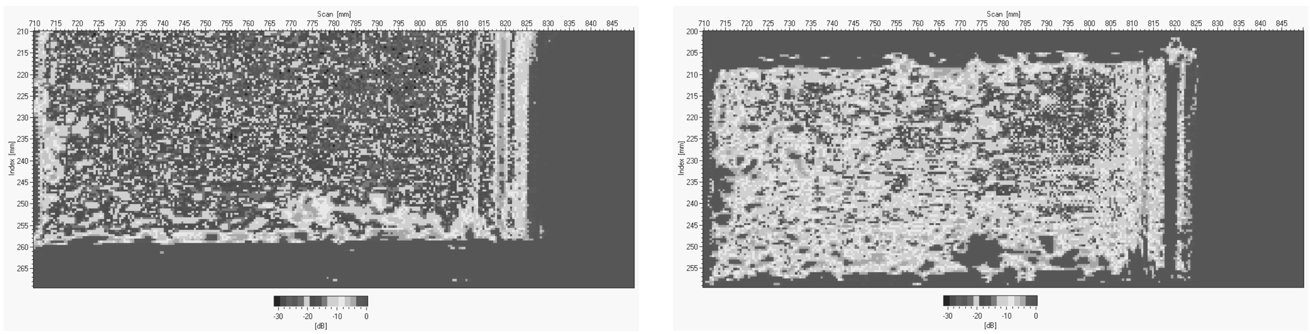


Fig. 10. Ultrasonic analysis of manufactured CF/AL-MMC plates

4. Conclusions

The first positive results of application of the gas pressure infiltration methods for manufacture of carbon fibres-reinforced aluminium are shown. The manufactured specimens are characterized by the homogenous structures and good surfaces quality.

The gas pressure infiltration technology enables to fabricate complex carbon aluminium composites with fibre or textile reinforcement using precision moulds of graphite, but in future development the optimization of infiltration process is required.

Reduces of the temperature and time of the gas infiltration process have a meaningful influence on the quality of the manufactured composite materials, because long stay of carbon fibres in temperature over the liquidus temperature of the aluminium can lead to the degradation of the fibre, and hence the properties of the composite. Significant task of following investigations will be choosing of strengthening material and coating.

Extensive efforts should be expanded by different investigators in the development of fibre surface coatings to improve the wetting properties of the carbon fibres and to serve as a diffusion barrier to prevent possible degradation of carbon fibres.

Application of carbon fibre is planned, reinforcing the manufactured structure in 3 directions - 3 D. Weave and bending of roving significantly hinder correct infiltration through aluminium alloy and application of the coating on carbon fibre. From this reason, it is crucial to make new investigations to choose proper 3D carbon fibre structure, allowing easy coats spread on carbon fibres as well as unproblematic carrying out of the gas infiltration process.

References

[1] W. Hufenbach; A. Langkamp, M. Andrich, Novel fabrication technologies for carbon fibre reinforced magnesium, Composites 3/7 (2003) 271-274.

[2] Training in Aluminium Application Technologies (TALAT), Version 2.0 – CD-ROM, 199, EAA, Brussels.

[3] M. Adamiak, Selected properties of the aluminium alloy base composites reinforced with intermetallic particles, Journal of Achievements in Materials and Manufacturing Engineering 14 (2006) 43-47.

[4] G. Palumbo, L. Tricarico, Numerical and experimental investigations on the warm deep drawing process of circular aluminium alloy specimens, Journal of Achievements in Materials and Manufacturing Engineering 14 (2006) 111-118.

[5] J. Wieczorek, A. Dolata-Grosz, M. Dyzia, J. Śleziona, Tribological properties of aluminium matrix composites reinforcement with intermetallic phases, Journal of Achievements in Materials and Manufacturing Engineering 15 (2006) 58-62.

[6] M. Kciuk, The influence of heat treatment on the structure, mechanical properties and corrosion resistance of aluminium alloy AlMg1Si1, Journal of Achievements in Materials and Manufacturing Engineering 16 (2006) 51-56.

[7] M. Kciuk, Structure, mechanical properties and corrosion resistance of AlMg5 alloy, Journal of Achievements in Materials and Manufacturing Engineering 17 (2006) 185-188.

[8] L.A. Dobrzański, T. Tański, L. Cizek, Influence of Al addition on structure of magnesium casting alloys, Journal of Achievements in Materials and Manufacturing Engineering 17 (2006) 221-224.

[9] L.A. Dobrzański, T. Tański, L. Cizek, Influence of Al addition on structure of magnesium casting alloys, Journal of Achievements in Materials and Manufacturing Engineering 19/2 (2006) 49-55.

[10] W. Hufenbach, L.A. Dobrzański, M. Gude, J. Konieczny, A. Czulak, Optimisation of the rivet joints of the CFRP composite material and aluminium alloy, Journal of Achievements in Materials and Manufacturing Engineering 20 (2007) 119-122.

[11] J. Szajnar, T. Wróbel, Inoculation of primary structure of pure aluminium, Journal of Achievements in Materials and Manufacturing Engineering 20 (2007) 51-54.

[12] A. Fayza, A. Zghal, E. Bayraktar, Analytic and experimental study for light alloy aluminium panels under compression, Journal of Achievements in Materials and Manufacturing Engineering 25/1 (2007) 19-22.

[13] J. Szajnar, T. Wróbel, Methods of inoculation of pure aluminium structure, Journal of Achievements in Materials and Manufacturing Engineering 27/1 (2008) 95-98.

[14] A. Włodarczyk-Fligier, L.A. Dobrzański, M. Kremzer, M. Adamiak, Manufacturing of aluminium matrix composite materials reinforced by Al_2O_3 particles, Journal of Achievements in Materials and Manufacturing Engineering 27/1 (2008) 99-102.

[15] M. Dyzia, A. Dolata-Grosz, J. Śleziona, Influence of modification on structure, fluidity and strength of 226D aluminium alloy, Archives of Foundry Engineering 8/3 (2008) 13-16.

[16] M. Dyzia, A. Dolata-Grosz, J. Śleziona, Infiltration test of carbon fibres textile by modified AlSi9Cu(Fe) alloy, Composites (2009) (in print).

[17] M. Dyzia, A. Dolata-Grosz, J. Śleziona, Fabrication and structure of Al-carbon fibres composites obtained by infiltration, Materials Engineering (2009) (in print).

[18] M. Dyzia, A. Dolata-Grosz, J. Śleziona, Technological aspects of Al-carbon fibres composites fabrication-selection of matrix material, Materials Engineering (2009) (in print).

[19] W. Hufenbach, M. Andrich, A. Langkamp, A. Czulak, Precision moulds of graphite for fabrication of carbon fibre reinforced magnesium, Proceedings of the 12th Scientific International Conference „Achievements in Mechanical and Materials Engineering" AMME'2003, Gliwice–Zakopane, 2003, 381-384.

[20] H.-M. Cheng, B.-L. Zhou, A. Kitahara, S. Akiyama, K. Kobayashi, Effect of silicon additions on characteristics of carbon fibre reinforced aluminum composites during thermal exposure, Journal of Materials Research 11/5 (1996) 1284-1292.

[21] T. Etter, M. Papakyriacou, P. Schulz, P.J. Uggowitzer, Physical properties of graphite / aluminium composites produced by Gas Pressure Infiltration method, Carbon 41/5 (2003) 1017-1024.

[22] A. Daoud, Microstructure and tensile properties of 2014 Al alloy reinforced with continuous carbon fibres manufactured by gas pressure infiltration, Materials Science and Engineering A 391/1-2 (2005) 114-120.

[23] S.N. Patankar, C. Suryanarayana, D. Blackketter, F.H. Froes, Thermally induced residual stresses in carbon fibre-reinforced aluminium-matrix composites, Journal of Materials Science Letters 11 (1992) 947-949.

[24] J.W. Kaczmar, K. Pietrzak, W. Włosiński, The production and application of metal matrix composite materials, Journal of Materials Processing Technology 106 (2000) 58-67.

[25] S. Kumar, V. Santhosh Bai, V. Seshu, T. Rajasekharan, Aluminium matrix composites by pressureless infiltration: the metallurgical and physical properties, Journal of Physics D: Applied Physics 41/10 (2008) 105403.

[26] K.U. Kainer, Alloying Effects on the Properties of Alumina-Magnesium- Composites, in: Metal Matrix Composites – Processing Microstructure and Properties, Risø National Laboratory, Roskilde, 1991, 429-434.

[27] R.F. Tressler, Interfaces in Oxide Reinforced Metals, in: Interfaces in Metal Matrix Composites, Academic Press, New York, 1974, 285.

[28] L.J. Ebert, P.K. Wright, Mechanical Aspects of the Interface, in: Interfaces in Metal Matrix Composites, Academic Press, New York, 1974, 31.

[29] K.K. Chawla, Composite Materials: Science and Engineering, Springer-Verlag, New York, 1998.

[30] C.M. Friend, The effect of matrix properties on reinforcement in short Alumina fibre-aluminum metal matrix composites, Journal of Materials Science 22 (1987) 3005-3010.

[31] F.J. Humphreys, Deformation and annealing mechanisms in discontinuously reinforced metal-matrix composites, Mechanical and Physical Behavior of Metallic and Ceramic Composites, Proceedings of the 9th Risø International Symposium "Metallurgy and Materials Science", Risø, 1988.

[32] F.J. Humphreys, A. Basu, M.R. Djazeb, The microstructure and strength of particulate metal-matrix composites, Proceedings of the 12th Risø International Symposium "Materials Science, Metal-Matrix Composites – Processing, Microstructure and Properties", Roskilde, 1991, 51-66.