EFECT OF CHEMICAL COMPOSITION OF THE ALLOY ON ALUMINIUM/CARBON FIBRES COMPOSITE STRUCTURE

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Keywords: *alumina alloys, carbon fibres, composites, infiltration methods*

1 Introduction

Aluminium matrix composites reinforced with carbon fibres offers very high specific thermal properties (low coefficient of thermal expansion, high thermal/electrical conductivity), mechanical properties (high specific strength, youngôs modulus, stiffness) and high design flexibility for lightweight applications. Therefore Al/CF composites have the most potential to be applied as structural and functional materials in the future [1].

On the other hand, the lack wettability of surface carbon fibres by liquid aluminium alloys and reactivity of aluminium-carbon fibres system (problem with unstable Al_4C_3) effectively hindered the development of Al/CF composites and limited their industrial application [2-5].

Therefore the production of Al-based composites reinforced with carbon fibres requires a proper selection of chemical composition of the alloy, as well as specific preparation of the reinforcing fibres. Appropriate wettability within the Al/CF system is of a considerable significance for obtaining a good bonding on the matrix-fibre boundary (acquired by modifying the matrix alloy and the physicochemical state of the reinforcement surface). Equally important is a reduction of reactivity between the liquid aluminium and the carbon fibre (coatings, protective barriers). These problems are solved by the coatings applied on carbon fibers (Ni, Cu, SiC or pyrolytic carbon), [2,4]. However, it is not possible to forget about important role of chemical composition of matrix alloy [6-10]. For preparing alloy as the matrix of composites reinforced with carbon fibre it is necessary to analysis not only physical-chemical phenomena in liquid Al ï carbon fibre but also specific character of selected fabrication processes.

The basic technology production of fiber reinforced composites based on the liquid-phase processes. Most commonly used methods are of pressure infiltration and pressing of the liquid crystal state (squeeze casting), [3,6-9,11-17]. Squeeze casting process requires special presses to produce very high compression pressures (~200 MPa). Such high pressure may still lead to fiber damage or non-uniform distribution of reinforcement in the composite. It does not prevent the formation of air voids, resulting from gas entrapment in the porous preform during the infiltration of molten metal. In the case of gas pressure infiltration process, it is possible to avoid these disadvantageous phenomena by reducing the pressure in the mould and using the gas pressure on liquid metal which is helpful in carbon fibre infiltration [11-17]. However in this case the contact time between liquid metal and reinforcement it is important too. Also the properties of metal matrix alloy which depends on its chemical composition. For these processes the aluminium matrix should characterized high strength, possibility to heat treatment and good technological properties (high castability, good wettability on carbon fibre surface, low viscosity). Based on literature data and our own experience, it was assumed that such properties provide the alloys containing Si, Cu, Mg, Ti additions. In this paper, the effect of the chemical composition of the matrix alloy and technological aspects (process parameters) on the structure of Al/CF have been presented.

2 Experimental procedures

Based on the results of castability tests, strength tests and microstructure observation, presented in different own articles [6-10], as the matrix of composites used aluminum alloy with silicon and cupper - AlSi9Cu(Fe) as well as silicon and manganese alloy - AlSi9Mn (trimal 37-TR37). Table 1 shows the chemical composition of aluminium alloys.

Table 1 Chemical composition of aluminium alloys

Alloy	Element (wt %)									
	Si	Fe	Cu	Mn	Mg	Zn	Cr	Ni	Ti	Al
AlSi9Cu(Fe)	9.9	0.9	2.2	0.21	0.44	-	-	-	0.03	Bal.
AlSi9Mn	9.57	0.07	0.14	0.5	0.04	0.01	0.004	0.006	0.033	Bal.

The AlSi9Cu(Fe) alloy was modified with 1% Mg and 0,03% Sr. The typical microstructure of the applied matrix alloys are presented in Fig. 1.

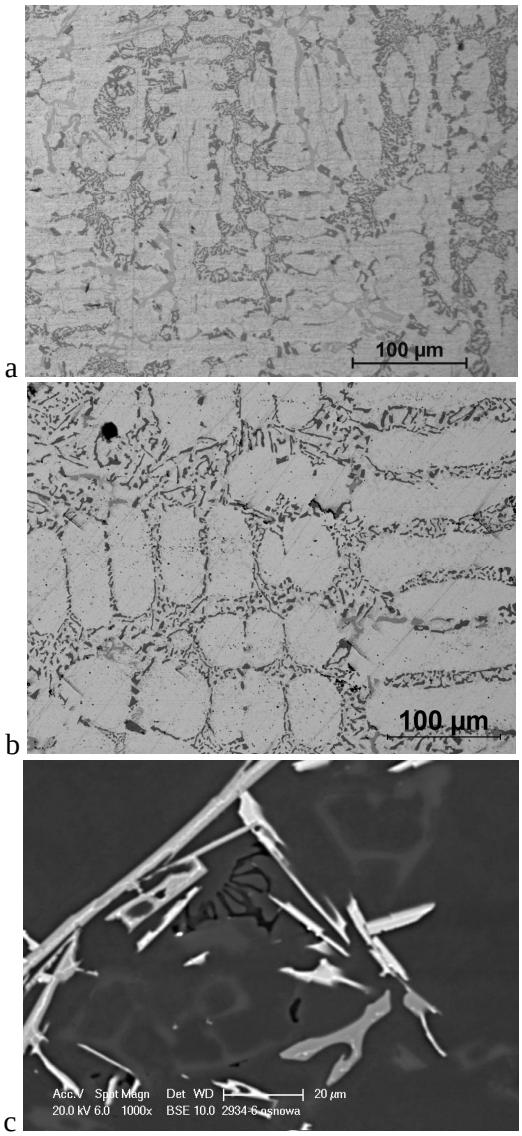


Fig. 1. Microstructure of aluminium matrix alloy: a) AlSi9Cu(Fe) alloy modified by 1%Mg + 0.03%Sr additions, OM; b) AlSi9Mn non-modified alloy, OM; c) AlSi9Mn non-modified alloy, SEM.

As the reinforcement used 2D and 3D carbon preforms which was prepared at the Institute for Lightweight Structures and Polymer Technology (ILK TU Dresden). For the preparation of carbon preforms applied A23 HTS40 12K fibres with nickel coating produced by TENAX Company. Roving bundle structure shown in Figure 2 [11].

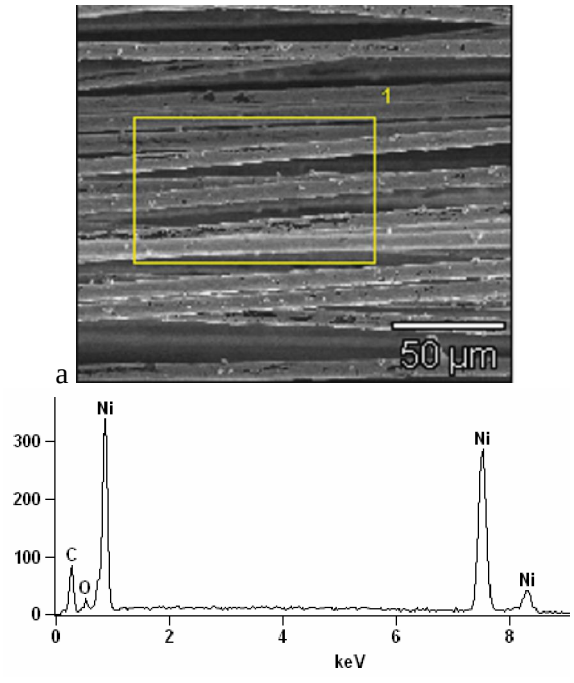


Fig. 2. Nickel coated carbon fibres: a) SEM image in bundle, (b) X-ray spectrum, EDS, area (1).

For infiltration of carbon textile preform with nickel coating by liquid aluminium alloy were applied a pressure-vacuum infiltration on the Degussa press (T=720^{0}C, p=15 MPa, t=15ô) and gas-pressure infiltration (GPI) in an autoclave (T=700^{0}C, p=4 MPa, t=5ô) designed and built at the Department of Materials Technology, Silesian University of Technology (PL) [10,12-17]. The structure of alloys, carbon fibres and cast composites was characterized by means of light and scanning microscopy methods. The phase and chemical compositions of the reinforcement were identified by diffraction and X-ray spectroscopy methods.

3 Results

The obtained composite plates were a regular shape, without casting defects on its surface. The typical microstructure of the investigated composites using by infiltration methods are presented in Figs. 3-9. On images of metallographic specimens, obtained at small magnification (Figs. 3;6a;7a,b), an alternate fibre packing was found ï characteristic for the applied roving weave. Among the individual roving bundles, there was an unporous matrix, which infiltrated the spaces between fibres. This testifies to good wetting at the macroscopic scale. The observations of microsections with the use of a scanning microscope showed good adhesion of the matrix to fibres (Fig.4;5;6c;7c). In AlSi9Cu(Fe)/Cf(Ni) composite, fabricated by pressure-vacuum process on Degussa press, an increase the concentration of silicon and magnesium in the carbon fibres regions was observed (Fig.4).

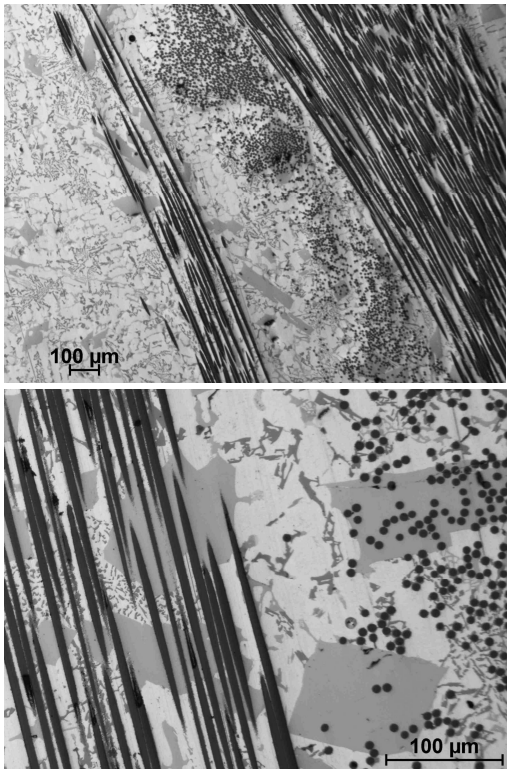


Fig. 3. Cross section of AlSi9Cu(Fe)/C_f(Ni) composites made by pressure-vacuum infiltration process on Degussa press, OM: a) 2D carbon performs; b) 3D carbon preforms.

The advantageous bonding between the components, obtained as a results of the applied process parameters, was confirmed by the composite fractures analyses. On fracture images presented in Figure 5 there is no visible isolation of the fibres from the matrix or their pulling.

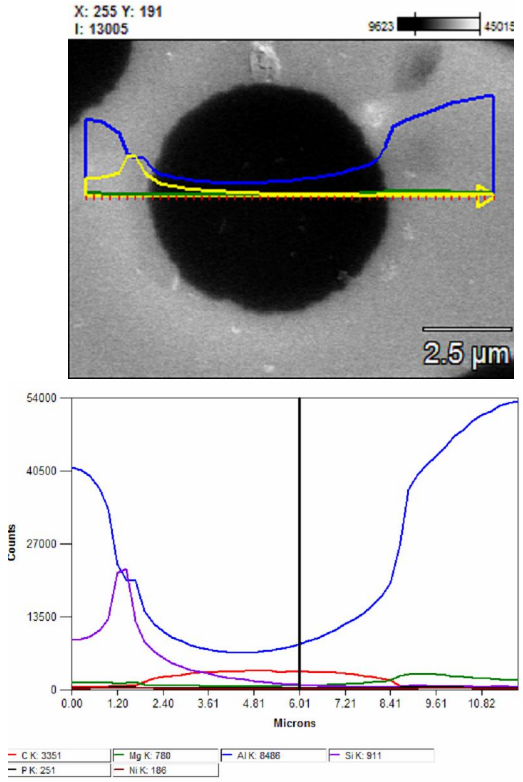


Fig. 4. Profiles of the C, Mg, Al, Ni, Si, Ni and P distribution in AlSi9Cu(Fe)/C_f(Ni) composite fabricated by pressure-vacuum process on Degussa press.

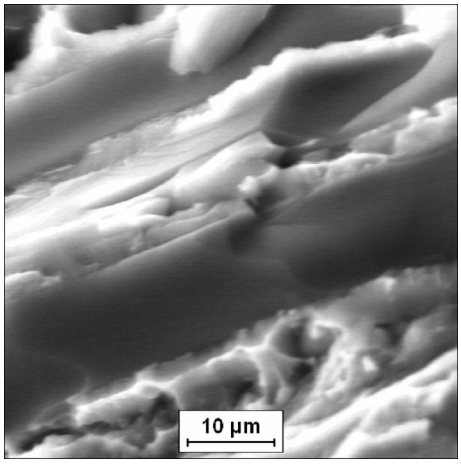


Fig. 5. Microstructure of AlSi9Cu(Fe)/C_f(Ni) composite fracture, SEM.

The presence of nickel and irregular bright phases containing Al and Ni was found in the matrix, which indicates dissolution of the nickel coating and precipitation in the form of intermetallic phase from the Al-Ni system (Fig.3). The forming of brittle nickel phase of large size, locally up to 100εm (Fig.3b), can lead to a reduction the mechanical properties of the composite.

Good connection between components were also obtained in the AlSi9Mn/Cf(Ni) composites (Fig.6).

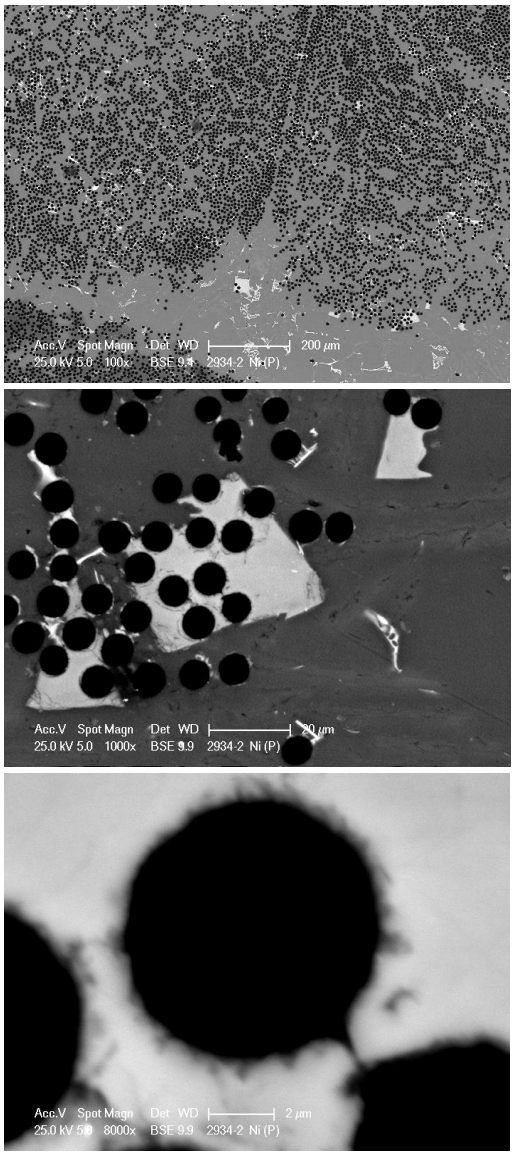


Fig. 6. Microstructure of AlSi9Mn/C_f(Ni), infiltration in Degussa press, SEM.

It is observed that Ni reacts with liquid aluminium to form Al_3Ni which may precipitate either at the Al-carbon interface or in the matrix material (Fig.6a). Moreover near the fibers the manganese concentration was observed, which together with nickel created the lamellar phase from Ni-Mn system visible in Figure 6b. The detailed microstructure observations with the use of high magnification (Fig.6c) showed areas in which observed the overgrowth of new phase on carbon fibers. The point analysis in these areas showed the presence of C, O, Al, and Si elements (Al:C= 15.45: 77.52). To clearly phase identifying TEM studies are required.

The best connection of components was observed in AlSi9Mn/Cf(Ni) composite, obtained by gas-pressure infiltration method (GPI), (Figs.7-10).

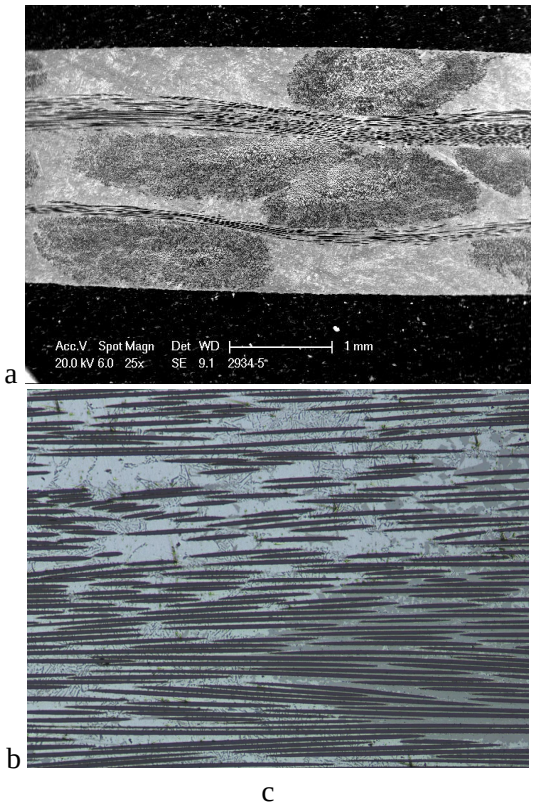
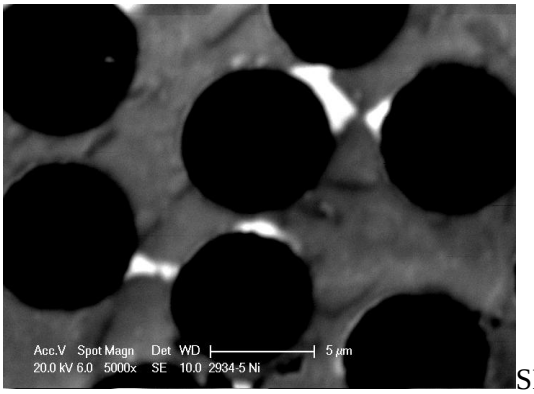


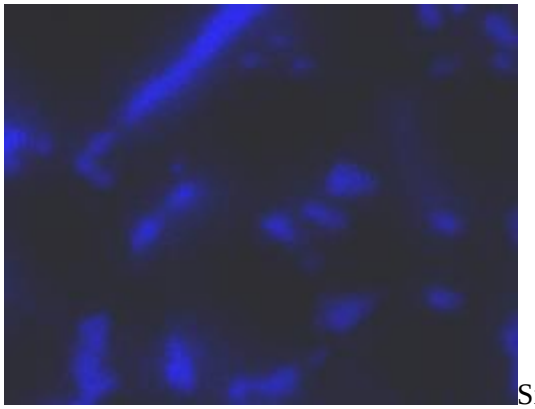
Fig. 7. Microstructure of AlSi9Mn/C_f(Ni) composite, infiltration in GPI process: a) SEM; b) OM.

On metallographic specimens, good interface between fibres and the aluminium matrix were observed. In the boundary area of the fiber-matrix identified nickel connected in the Al-Ni phases and silicon precipitation (Fig.7b). The studies did not reveal the presence of the structure of aluminum carbide at the fiber-matrix boundary (Fig.8), as well as in the matrix (Fig.9). This experimental

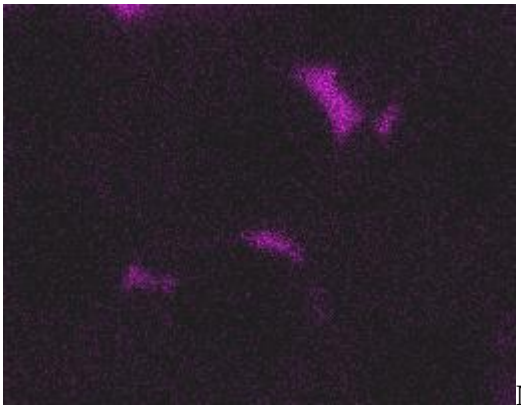
verification requires which is planned in the successive stage of the research.



a SEI



b SiK



c NiK

Fig. 8. Structure of AlSi9Mn/C_f(Ni), infiltration GPI: a) OM; b) SEM, mag. 4000x

Acknowledgments

The studies were supported by Polish Ministry of Science and Higher Education and by DFG in Germany as the Polish-German Bilateral Project ***ñ****3D-textile reinforced Al-matrix composites (3D-CF/Al-MMC) for complex stressed components in automobile applications and mechanical engineering****ò***

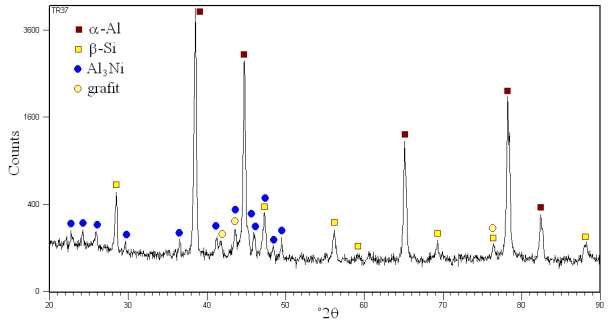


Fig. 9. XRD phase analysis

3 Conclusions

Obtained research results have confirmed the validity of the assumptions made concerning the need for appropriate technology selection and the chemical composition of aluminum alloy for use as a matrix composites reinforced with carbon fibers. Reducing reactivity in the Al-C system was made possible by the use of 9% Si in the matrix alloys. Whereas, reduces the surface tension and reducing the wetting angle obtained by the Mg, Ti and Mn additives. Is also indicated proper selection of manufacturing parameters of the composite in the direction of lower temperature and shorten time of infiltration process. As shown a shorter contact time the carbon preform with the molten aluminium matrix in GPI process limited the formation of large and brittle phases at the fiber-matrix boundary. Further work will focus on the selection of the aluminium matrix modification in order to ensure appropriate conditions for wetting in the system Al/CF and subsequent reduce the reactivity between the components in the processes of infiltration pressure (Degussa press, GPI). Planned studies will also involve the selection of the conditions of heat treatment of alloys and composites, enabling the development of the proposed properties of the composite material.

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