AN INFLUENCE OF SiC CONTENT AT Al (AlMg) MATRIX COMPOSITES ON CREEP CHARACTERISTICS

Z.L. Kowalewski[1,2], A. Rutecka[1], K. Pietrzak[2], K. Makowska[2], J. Woźniak[3], M. Kostecki[3], W. Bochniak[4], A. Olszyna[3]

[1]*Institute of Fundamental Technological Research, Polish Academy of Sciences (IPPT PAN), Department for Strength of Materials, 5b Pawińskiego St.,02-106 Warsaw, Poland*
[2]*Motor Transport Institute, Centre of Material Testing and Mechatronics, 80 Jagiellońska St., 03-301 Warsaw, Poland*
[3]*Warsaw University of Technology, Faculty of Materials Science and Technology, 141 Wołoska St., 02-507 Warsaw, Poland*
[4]*AGH University of Science and Technology, Faculty of Non-Ferrous Metals, Al. Mickiewicza 30, 30-059 Cracow, Poland*
**zkowalew@ippt.gov.pl*

Keywords: metal-ceramic composites, KOBO method, creep, silicon carbide (SiC).

Abstract
Creep tests under a range of step-increasing tensile stresses were carried out on the AlMg/SiC composites produced by means of the KOBO method. The content of reinforced phase was equal to 2.5, 5, 7.5 and 10%. The AlMg/SiC creep characteristics were compared to those of the Al/SiC composites. Structural assessments of materials in the as-received state and after creep were carried out.

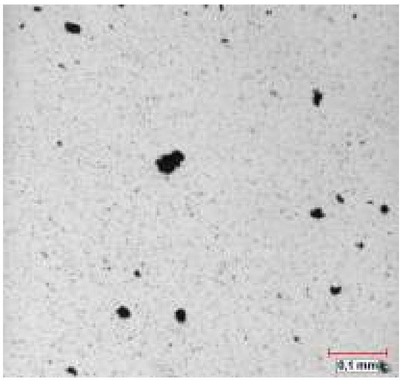
1 Introduction
New methods for production of novel materials enforce necessity of their characterisation reflecting exploitation conditions associated with creep or fatigue phenomena. In this paper a range of tests were carried out to recognize mechanical parameters of the selected metal matrix composites subjected to creep conditions.
Currently, many composites are produced using cast methods [1-3], especially based on squeeze casting procedure [1] or powder metallurgy methods [4, 5]. In this research the KOBO method was applied [6] as a representative modern production technology for manufacturing of composites with a reinforcement distributed homogeneously. This method relies on superimposing of cyclic torsion on the axial deformation of metals or their alloys during extrusion, forging or drawing [7] for example. The significant advantages of this technique are connected with both control of the metal substructure (properties) and low costs of manufacturing [8]. In this research authors focused on analysis of an influence of the SiC reinforcement content on creep properties of two metal-ceramic composites produced by means of the KOBO method.

2 Materials and testing methods
The Al/SiC and AlMg/SiC composites as well AlMg alloy manufactured by means of the KOBO method were investigated. The content of reinforced phase was equal to 5, 7.5 and 10% SiC particles. Additionally, the AlMg alloy was reinforced by 2.5% of SiC. An average size of the single SiC particle was about 0.42μm. The reinforced phase of 99.8% chemical purity was supplied by Alfa Aesar Co. The commercial Al powder of an average particle size

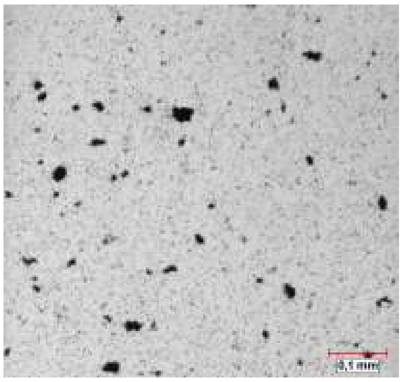
equal to 6.74μm and 99.7% purity was delivered by the Bend-Lutz Co. It was used as a matrix of the Al/SiC composite. The matrix of AlMg/SiC composites was produced using the Al7.9Mg powder of an average particle size 14.6μm and the chemical purity of 99.8%.
The composites and AlMg alloy were directly extruded using a reversible rotating die. Firstly, the powders of matrix and reinforced phase of sufficient contents were mixed together and homogenized. The dried mixtures were granulized and subjected to isostatic consolidation. The materials machined to the desired dimensions were extruded using the hydraulic press. Thanks to the reversible rotating die the machine enabled to obtain the required deformation path.
The manufactured materials were subjected to creep test. The load was changed after every 24 hour to reach stress levels equal to 40, 60 and 70 MPa. The temperature during creep of Al/SiC composites was 250ºC, whereas that for AlMg and AlMg/SiC composites 200ºC.
The last step of the experimental programme contained microstructural observations of the AlMg alloy and AlMg/SiC composites. The main goal was to identify a type of specimens fracture, distribution of the SiC particles and discontinuities. Investigations were performed for composites in the as-received state and after creep tests in order to evaluate the final microstructural degradation. The qualitative observations and quantitative metallographic assessments of AlMg and AlMg/SiC composites in the non-etched state were carried out by means of light microscope (Olympus PMG3) coupled on-line with the image analyser (CLEMEX). All quantitative metallographic measurements were conducted under the same measuring conditions based on procedures presented in [9, 10]. The observations by means of scanning electron microscopy (SEM - JEOL 6360 LA) were also carried out.

3 Results and discussion

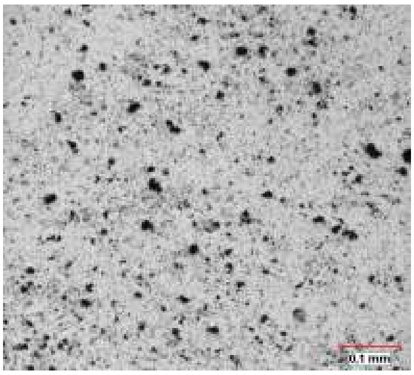
Microstructures of the AlMg/SiC composites in the as-received state were observed on the transverse (perpendicular to loading direction), Fig. 1a,b,c,d, and longitudinal (parallel to loading direction), Fig. 4a,c,e,g, cross-sections in order to determine an influence of the reinforced phase content on the creep. It was observed that the SiC particles have a tendency to generate clusters in the composite matrix. These clusters may affect creep properties significantly, whereas an influence of the singular, fine SiC particles distributed uniformly in the composite matrix and also fine clusters created of a diameter below 1μm seems to be less important. That is the reason why only the large clusters were quantitatively analysed using metallographic quantitative methods [9,10]. The three stereological parameters were determined on the cross-sections cut in the parallel and perpendicular directions to the specimen axis, i.e.: content of clusters (A_A [%]) related to the unit area of metallographic sample (1 mm^2); mean quantity of clusters - N_A [1/mm^2]) and mean Feret's diameter ($F_{śr}$ [μm]). The results of the microscopic quantitative analysis are given in the bottom of images presented in Fig. 1. It should be emphasised that the increase of SiC particles content causes the increase of both the content and mean quantity of the SiC clusters.
In the case of higher contents of reinforced phase (7.5%SiC and 10%SiC) the much smaller clusters occur in the composite matrix. This tendency is connected with a lower mean Feret's diameter ($F_{śr}$ [μm]) of the SiC particles than that observed in the case of AlMg + 2.5%SiC and AlMg + 5%SiC composites.



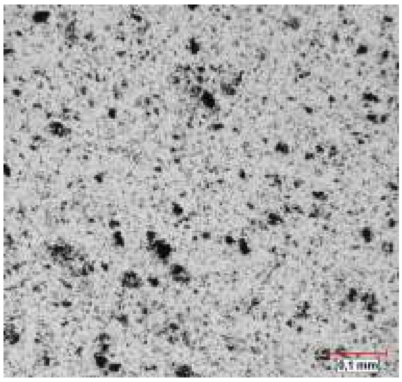
a) AlMg + 2.5% SiC, $\overline{A}_A$= 0.61 [%], $\overline{N}_A$= 56 [1/mm^2], $\overline{F}_{śr}$ = 10.9 [μm].



b) AlMg + 5% SiC, $\overline{A}_A$= 1.22 [%], $\overline{N}_A$= 133 [1/mm^2], $\overline{F}_{śr}$ = 9.9 [μm].



c) AlMg + 7.5% SiC, $\overline{A}_A$= 2.58 [%], $\overline{N}_A$= 697 [1/mm^2], $\overline{F}_{śr}$ = 6.48 [μm].



d) AlMg + 10% SiC, $\overline{A}_A$= 6.37 [%], $\overline{N}_A$= 1518 [1/mm^2], $\overline{F}_{śr}$ = 6.70 [μm].

Figure 1. Microstructures of the AlMg/SiC composites in the as-received state, non-etched state, transverse cross section, conventional light, magn. 100×.

The results of creep tests on the AlMg alloy and AlMg/SiC composites are shown in Fig. 2. They demonstrate that the AlMg/SiC composites are characterized by better creep properties than those for the AlMg alloy obtained. It has to be noticed that among all the studied materials only the AlMg + 5% SiC composite with clusters content of 1.22% represents the best creep properties expressed by the longest lifetime, and the lowest minimum creep rate as well. The similar time to fracture, but quite higher minimum creep rate was obtained for the AlMg + 2.5% SiC composite with 0.61% clusters of SiC. The content of reinforced phase is not sufficient to provide optimal creep properties. Further increase of the SiC content led to significant deterioration of either time to rupture or minimum creep rate. In comparison to the creep results for the Al/SiC composites [11] for the case of the Al + 10% SiC the lowest minimum creep rate and maximum time to rupture were achieved. As it is seen in Fig. 3 durability defined by the time to rupture enhances with the reinforcement volume fraction increase. Moreover, a decrease of minimum creep rates indicates better creep resistance of the higher SiC content composites (Fig. 3).

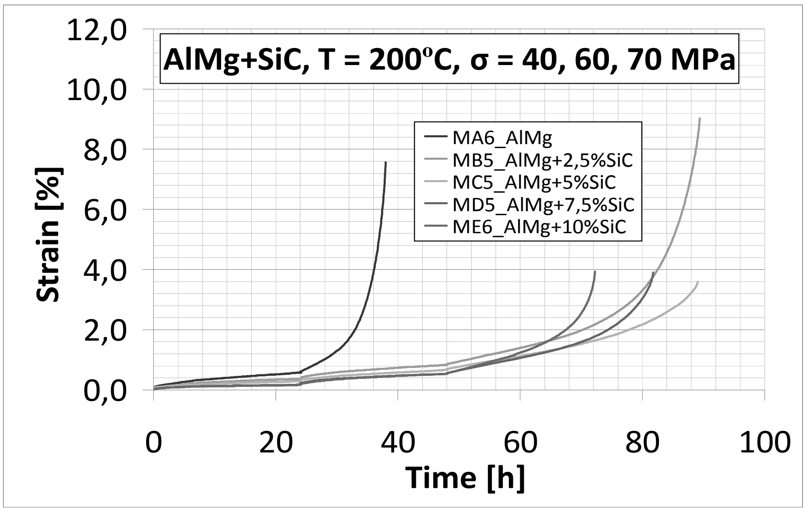


Figure 2. Creep curves for the AlMg alloy and AlMg/SiC composites.

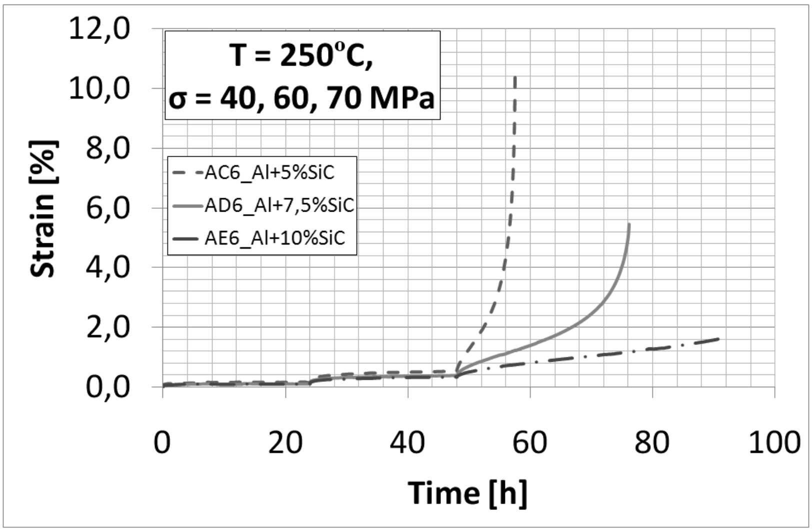
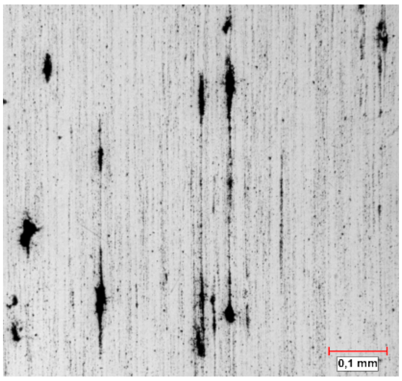


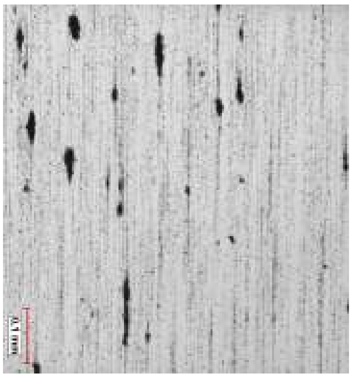
Figure 3. Creep curves for the Al/SiC composites [11].

Microstructural images of the composites before creep process and composite microstructure degradation assessed from area close to the fracture after creep were compared in Fig. 4. Based on the microscopic observations conducted in the conventional light it was ascertained that the composite microstructural degradation increases with the increase of clusters content (Fig. 4a-h). In the case of AlMg alloy a damage was not observed after creep in the conditions considered.

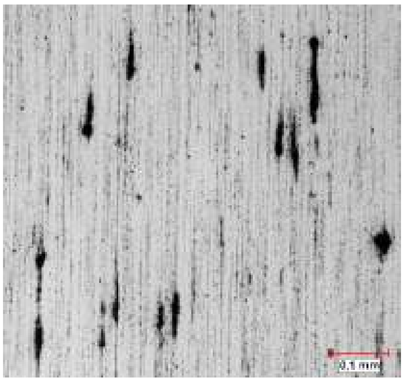
a) AlMg + 2.5% SiC, before creep



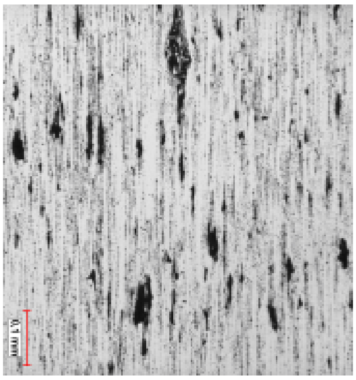
b) AlMg + 2.5% SiC, after creep



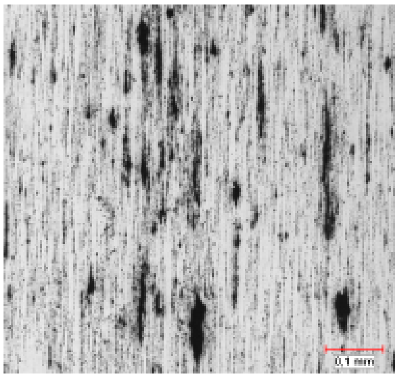
c) AlMg + 5% SiC, before creep



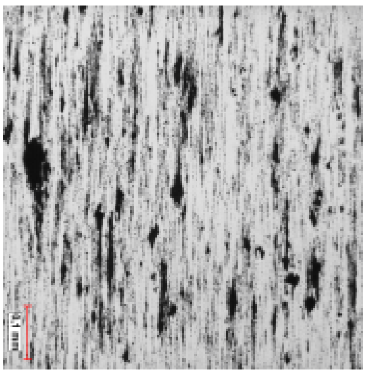
d) AlMg + 5% SiC, after creep



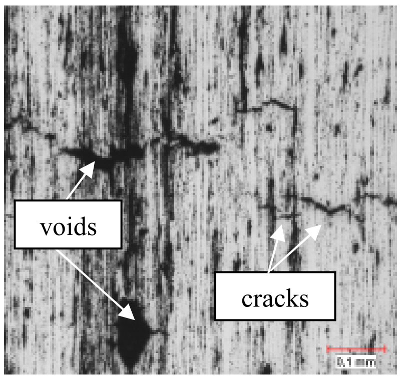
e) AlMg + 7.5% SiC, before creep



f) AlMg + 7.5% SiC, after creep



g) AlMg + 10% SiC, before creep



h) AlMg + 10% SiC, after creep

Figure 4. Microstructures of the AlMg/SiC composites before creep (a,c,e,g) and after creep near the fracture (b,d,f,h), non-etched state, longitudinal cross section, conventional light, magn. 100×.

An initiation of the cracks occurred at the interfacial boundary between clusters and composite matrix (Figs. 4h,5,6). The further cracks development followed in the perpendicular direction with respect to the bands of the reinforcement. Finally, the cracks took the form of voids resulting from complete loss of coherence between the reinforcement and composite matrix. As a consequence, it led to the deterioration of creep properties.

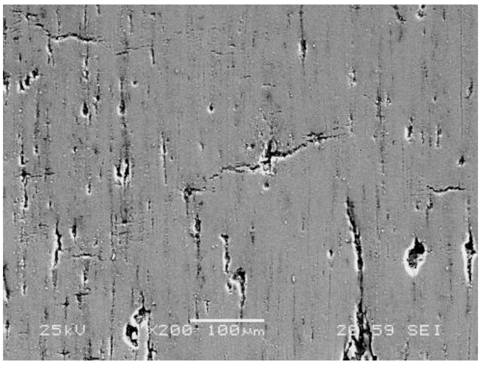


Figure 5. Degradation of the AlMg + 7.5% SiC composite after creep, magn. 200×.

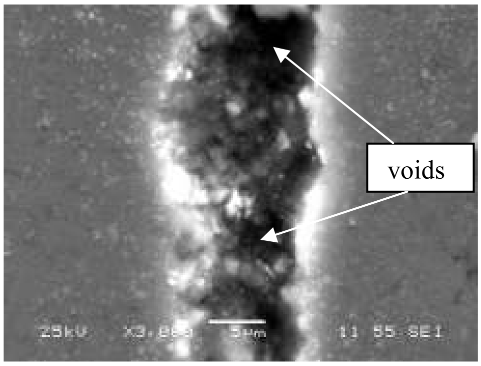


Figure 6. Voids visible in the reinforcement of the AlMg + 7.5% SiC composite after creep, magn. 3000×.

The changes in contents of clusters and defects for the AlMg/SiC composites in the as-received state and after creep are shown in Fig. 7. The clusters after creep process were determined from the area near specimens fractures. The results presented in diagram (Fig. 7) reveal that the clusters and content of defects increase as the result of creep tests leading to the weaker coherence between reinforcement phase and composite matrix. It is also evident that this effect is the largest for the AlMg + 10% SiC composite (Fig. 7).

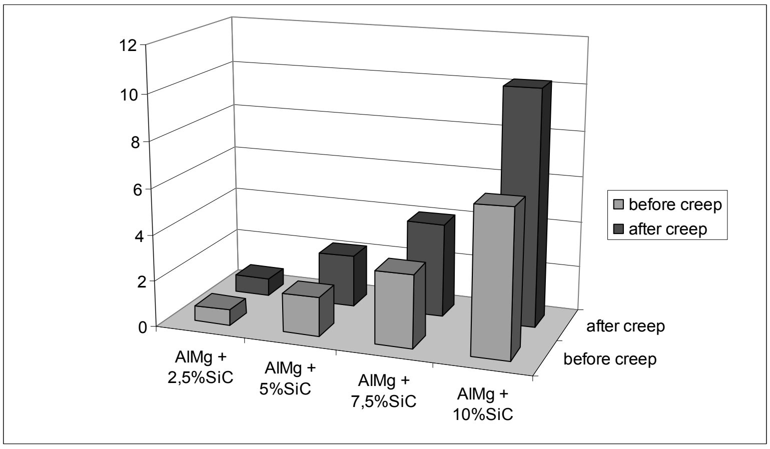


Figure 7. Contents of clusters and defects in the AlMg/SiC composites counted on the longitudinal cross sections before and after creep.

4 Conclusions

The SiC particles introduced into the pure Al and AlMg alloy improve creep properties of the final composite material. However, it has to be emphasized that it is dependent of the SiC content and type of composite as well. It was found that the AlMg + 5% SiC composite represents the best creep parameters among the considered AlMg/SiCs. The highest minimal creep rate and the lowest time to rupture was achieved for the AlMg alloy reinforced by 10% of SiC. This means that an improvement of creep parameters due to an increase of the SiC content at the AlMg/SiC composites can be obtained only if it is lower than 5%. The results achieved for the Al/SiC composites are in contradiction in some way to that remark, since the Al +10% SiC composite represents the best creep properties. Direct reasons of different creep behavior of the composites in question depending on the SiC content can be obtained on the basis of microstructural analysis. In the case of AlMg/SiC composites a lowering of typical creep parameters is connected with the SiC clusters generation. This is especially evident for higher than 5% of the SiC content at this composite.

Acknowledgements
The results presented in this paper have been obtained within the project "KomCerMet" (project no. POIG.01.03.01-00-013/08 with the Polish Ministry of Science and Higher Education) in the framework of the Operational Programme Innovative Economy 2007-2013.

References

[1] Sobczak J. *Kompozyty Metalowe*. Instytut Odlewnictwa i Instytut Transportu Samochodowego, Kraków-Warszawa (2001).
[2] Hashim J., Looney L., Hashmi M.S.J. Metal matrix composites: production by the stir casting method. *Journal of Materials Processing Technology*, **Volumes 92-93**, pp. 1-7 (1999).
[3] Hashim J., Looney L., Hashmi M.S.J. Particle distribution in cast metal matrix composites—part II. *Journal of Materials Processing Technology*, **Volume 123**, pp. 258–263 (2002).
[4] Liu Y.B., Lim S.C., Lu L., Lai M.O. Recent development in the fabrication of matrix-particulate composites using powder metallurgy techniques. *Journal of Materials Science*, **Volume 29,** pp. 1999-2007 (1994).
[5] Biało D. Wytwarzanie kompozytów w procesach metalurgii proszków. *Composites,* **Volume 1**, pp. 89-92 (2001)1.
[6] Bochniak W., Korbel A. KOBO – type forming: forging of metals under complex conditions of the process. *Journal of Materials Processing Technology,* **Volume 134**, 120-134 (2003).
[7] Bochniak W., Korbel A., Błaż L., Brzostowicz A. Wytwarzanie drobnoziarnistych wyrobów ze stopu aluminium 7075 w procesie wyciskania metodą KOBO. *Przegląd Mechaniczny*. **Volume 10**, pp. 33-37 (2009).
[8] Korbel A., Szyndler R. The new solutions in the domain of metal forming – contribution of the Polish engineering idea. *Obróbka Plastyczna Metali,* **Volume 3,** pp. 203-216 (2010).
[9] Underwood E. E. *Quantitative stereology*, Addison-Wesley Publishing Company, Ontario, (1970).
[10] Ryś J. *Stereologia Materiałów*, Fotobit Design, Kraków (1995).
[11] Rutecka A., Kowalewski Z.L, Pietrzak K., Dietrich L., Makowska K., Woźniak J., Kostecki M., Bochniak W., Olszyna A. Damage development of Al/SiC metal matrix composite under fatigue, creep and monotonic loading conditions. *Procedia Engieering,* **Volume 10**, pp. 1420-1425 (2011).