DAMAGE ANALYSIS OF Al(Mg)/SiC COMPOSITES UNDER FATIGUE CONDITIONS

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Abstract

Fatigue tests and microstructural observations were carried out to perform damage analysis of Al/SiC and AlMg/SiC metal matrix composites (MMCs). The materials were manufactured using the KoBo method. Ratcheting was a dominant damage mechanism for Al/SiC and damage parameter was calculated on the basis of mean inelastic strain. For AlMg/SiC, in most cases, cyclic softening followed by hardening during subsequent cycles were noticed. Microstructural observations identified existence of SiC concentrations which influenced the volumetric fraction of defects after fatigue tests.

1 Introduction

Recently, many efforts are focused on elaboration of the appropriate fatigue damage parameter [1-5]. The most promising method for the fatigue damage evaluation has been proposed by Socha [2, 3]. It is based on the application of inelastic strain amplitude as the fatigue damage indicator. The method was successfully used for monolithic materials like steels for example. For such kind of materials a dominant damage mechanism can be expressed by a change of hysteresis loops width and characterized by cyclic plasticity. In the case of composite materials a damage mechanism is more often described by ratcheting expressed by a movement of the hysteresis loops of constant width along the strain axis. Such behaviour can be described by a mean level of the inelastic strain which might be used as the fatigue damage indicator. On the other hand, for many materials damage parameter cannot be defined by a single mechanism, and therefore, a combination of mechanisms gives better results.

Fatigue tests and microstructural observations of materials performed before and after fatigue tests bring information connected with the efficiency of materials' production method as well as with the influence of fatigue loading on microstructure.

2 Materials and testing methods

2.1 Materials

The KoBo method was used [6, 7] for production of the Al and AlMg based metal matrix composites with silicon carbide reinforcement (0; 2,5; 5; 7,5; 10%).

The Al/SiC composite was manufactured from a commercial Al powder of 99,7% purity (an average particle size of 6,74 µm) and SiC powder of 99,8 purity (an average particle size of 0,42 µm). In the first stage of the process the powders were mixed, homogenized and subjected to isostatic consolidation.

The following components were used during AlMg/SiC production: Al7,9Mg powder of 99,7% purity and an average particle size 14,6 µm plus the same reinforcement as that for the Al/SiC production applied. Powders were blended and pressed to achieve consolidation of Al matrix.

Finally, both composite materials were extruded in the form of long rods with diameter equal to 8mm. KoBo 100T horizontal hydraulic press, equipped with a reversibly rotating die, was used during extrusion.

2.2 Testing methods

High cycle fatigue tests (tension-compression, $R = -1$) were performed under constant stress amplitude equal to 65 and 70 MPa for Al/SiC and 220 and 240 MPa for AlMg/SiC. Tests were carried out at the frequency of 20 Hz on the servo-hydraulic testing machine MTS 858. Sine shape symmetric cycles were applied and cylindrical specimens were subjected to cyclic loading until fracture at ambient temperature.

Microstructural observations were performed using a light microscope (Olympus PMG3 - metallographic analysis in macro- and micro- ranges) as well as a scanning electron microscope (SEM - JEOL 6360 LA).

3 Discussion of test results

3.1 Fatigue tests results and damage parameter

The results of fatigue investigations for both types of composites exhibited the ability of the AlMg/SiC to carry much higher stress amplitudes than those for the Al/SiC applied. The effect corresponds to higher stress response of the AlMg/SiC during tensile tests. In the next step of the analysis the magnitudes of the mean inelastic strain were compared for the material of matrices and reinforced composites. In the case of matrix material the largest magnitudes were observed for the Al. This means that the AlMg matrix exhibits better fatigue strain resistance (lower strain values were obtained). In general, the higher SiC content the lower mean inelastic strain magnitudes were achieved. Unfortunately, the shorter lifetimes, too, were observed. Variation of the mean inelastic strain for the AlMg/SiC as a function of cycles is presented in Fig. 1. A decrease of this parameter can be noticed in most cases under the increasing content of SiC.

Moreover, fatigue damage parameter for the Al/SiC composite was calculated and results for stress amplitude equal to 65 MPa were published [5]. The ratcheting phenomenon was assigned as a dominant damage mechanism (Fig. 2a), and therefore, the mean inelastic strain was taken into account as the fatigue damage indicator. Since the mean inelastic strain was increasing during subsequent cycles, a damage parameter was calculated in the stable growth period [2, 3, 5]. Variation of the damage parameter for the AlSiC (stress amplitude equal to 70 MPa) is presented in Fig. 2b. It is worth emphasizing that the rate of damage is relatively high at the beginning of stable period, however, subsequently it becomes lower.

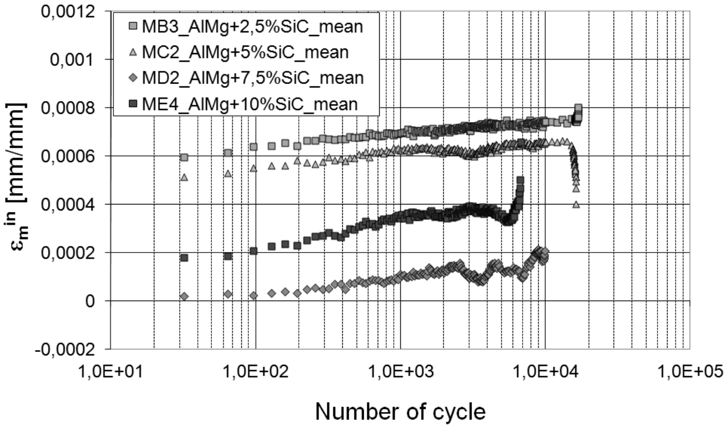

Figure 1. Mean inelastic strain as a function of cycle number for the AlMg/SiC (stress amplitude 240 MPa)

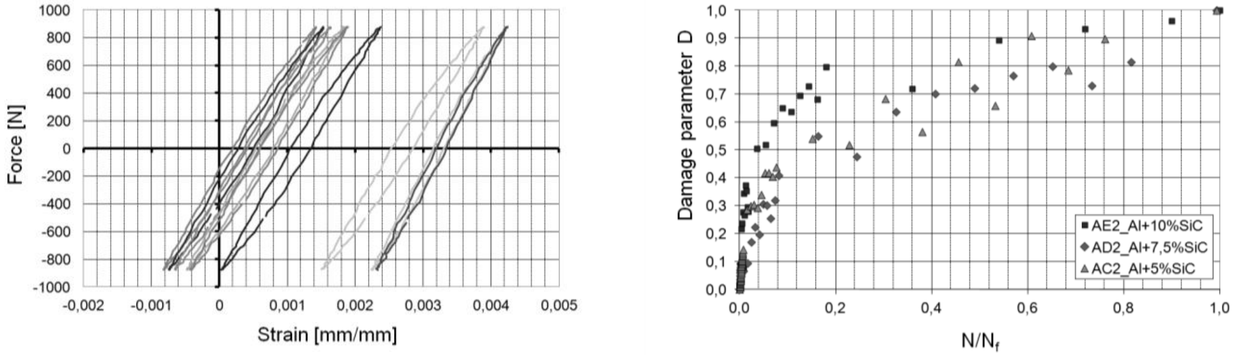
a) b)

Figure 2. Fatigue tests results for Al/SiC (stress amplitude 70 MPa): (a) hysteresis loops for Al+5%SiC; (b) comparison of damage parameter D as a function of normalized cycles N/N_f (where N_f is a number of cycle to the end of the stable damage development) for different SiC content

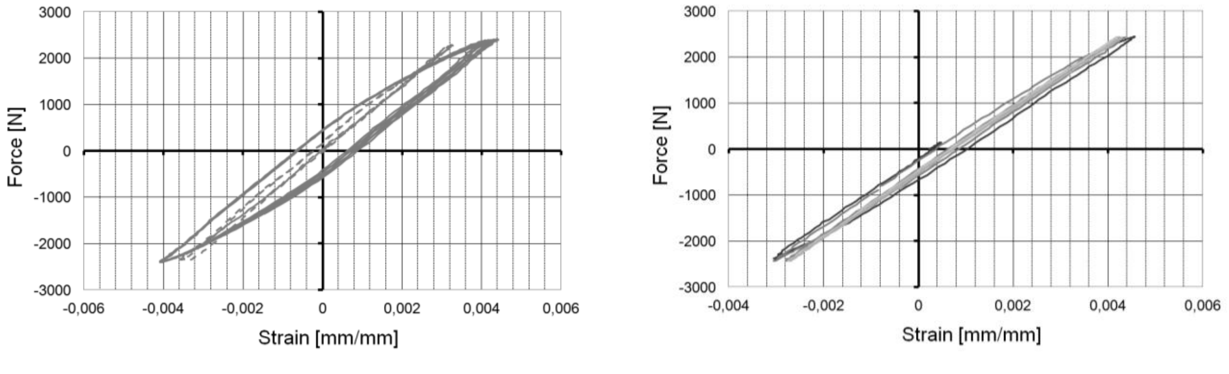
a) b)

Figure 3. Hysteresis loops for AlMg+2,5%SiC (stress amplitude 240 MPa): (a) selected cycles below 100; (b) selected cycles from 100 to failure

In the case of AlMg/SiC, cyclic softening (an increase of inelastic strain amplitude) below 100 cycles was observed. Contrary to that fact, cyclic hardening was observed for a higher number of cycles. Inelastic strain amplitude in many cases (especially for lower SiC content) exhibited higher values below 100 cycles and was decreasing during subsequent cycles (Fig. 3). Since the mean inelastic strain and inelastic strain amplitude values were not uniform (increased or decreased) during subsequent cycles, a method proposed by Dietrich was used to calculate the corrected inelastic strain as a sum of absolute values of inelastic strain amplitude and inelastic mean strain variations. The method assumes that each change of the inelastic strain is attributed to the material damage. Unfortunately, it is sensitive to the number of cycles taken into account and therefore the method still requires certain modifications.

3.2 Microstructural observations of the AlMg/SiC before and after fatigue tests

Microstructural observations of the material before and after fatigue tests were carried out. In the case of fatigue prestrained specimens the longitudinal cross sections along measurement part of specimens were observed. The microscopic structure for specimens after fatigue tests was similar for both places of analysis i.e. in the direct neighborhood of fracture surface and far away from it. As it is shown in Fig. 4, no defects were observed in the AlMg after fatigue test. Contrary to that fact, for the AlMg reinforced by SiC an essential microstructural degradation was observed (Fig. 5). It is especially visible in places of the SiC concentrations being the main reason of defect generation in the form of voids and cracks initiation and their subsequent propagation.

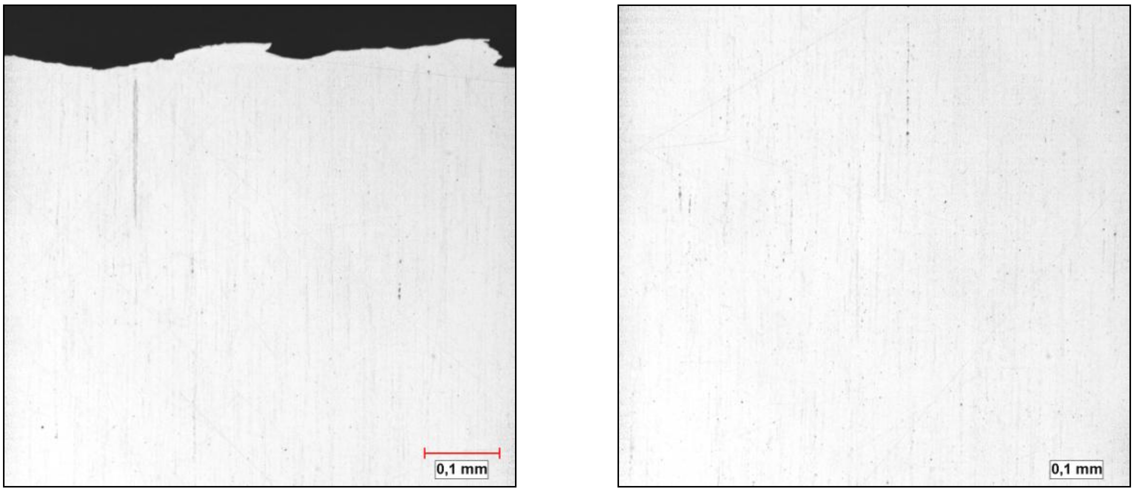

Figure 4. Images of microstructure (longitudinal cross section). AlMg after fatigue test (magn. 100x): (a) close to the fracture surface; (b) far away from the fracture surface

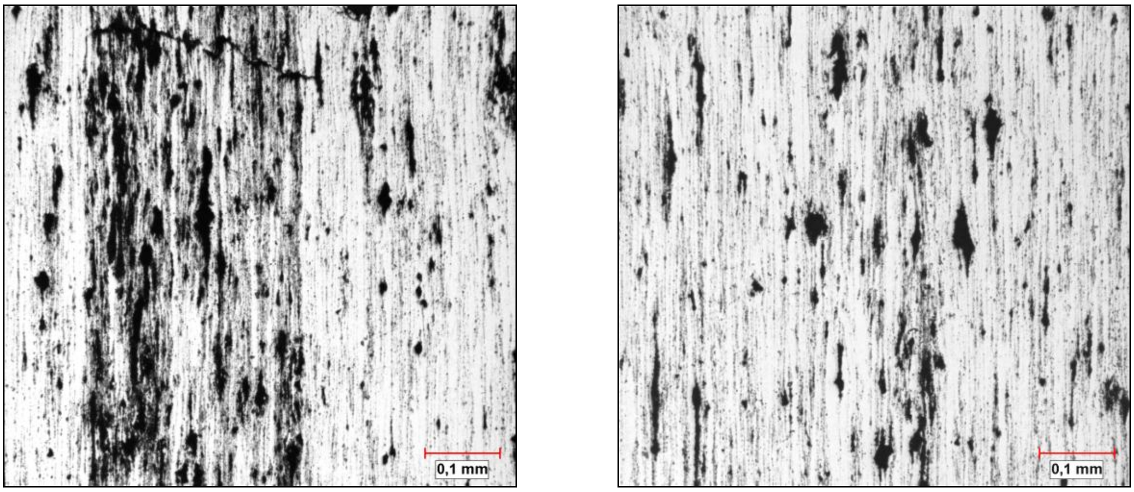

Figure 5. Microstructural degradation of AlMg+10% SiC after fatigue tests (longitudinal cross section), (magn. 100x): (a) close to the fracture surface; (b) far away from the fracture surface

In the next stage of microscopic analysis a volumetric fraction of the SiC particle concentrations and fraction of defects (treated as a sum of cracks, voids and material discontinuities) were calculated for the materials before and after fatigue tests (Fig. 6). These parameters increase with an increase of the SiC content. It is supposed that an increase of the volumetric fraction of the SiC concentrations with the SiC content increase may be a reason of microstructural degradation and fatigue lifetime decrease.

In general, the fatigue fracture type was observed for tests performed. Moreover, some voids and cracks were identified in the fracture areas (Fig. 7). Their amount increases with an increase of the SiC and its concentrations content.

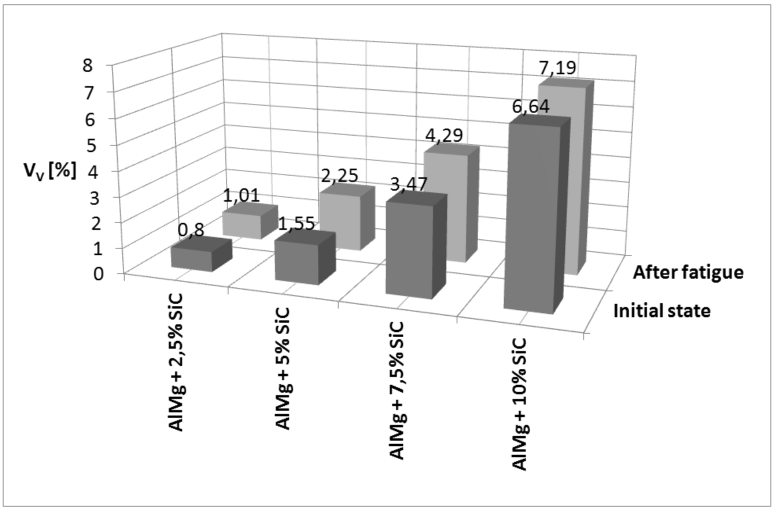

Figure 6. Volumetric fraction of the SiC particle concentrations at the initial state, and defects after fatigue tests

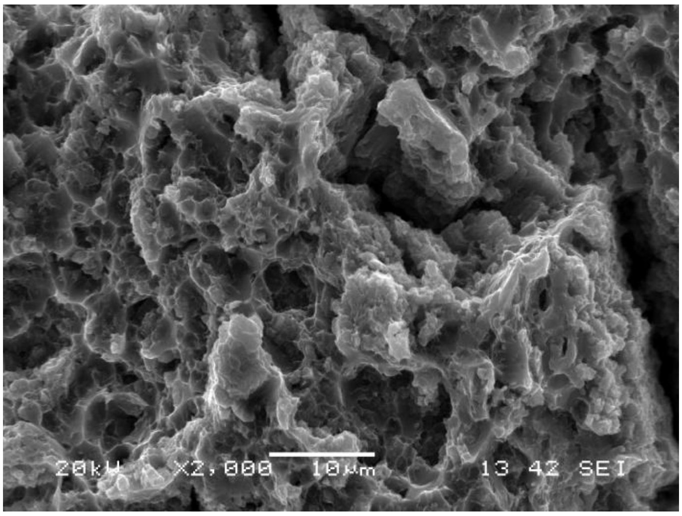

Figure 7. Fracture image after fatigue test for the AlMg + 7,5%SiC (SEM) (magn. 2000x)

4 Final remarks

It can be concluded that the specimens were better fatigue strain resistant (lower strains were achieved) with an increase of the SiC content. Despite the lower mean inelastic strain the AlMg/SiC specimens exhibited lower lifetimes with an increase of the SiC content.

The dominant damage mechanism during fatigue of the Al/SiC was the ratcheting. Therefore, the mean inelastic strain amplitude was applied as a fatigue damage indicator. The rate of damage parameter took higher values at the initial state of fatigue, and in most cases it increased with the increase of the SiC content. Such effect may lead to a premature fracture of constructions in the first period of fatigue process.

Cyclic softening followed by cyclic hardening were observed during fatigue tests of the AlMg/SiC. Since the mean inelastic strain and the inelastic strain amplitude not only increased but also decreased during subsequent cycles, they should not be used as the fatigue damage indicator in this case. Hence, the method based on the corrected inelastic strain is currently under development to allow assessment of fatigue damage indicator for the composite.

The KoBo method used during the MMCs production led to generation of the SiC concentrations that include incoherent particles. They were arranged in accordance with the rods axis i.e. extrusion direction. Discontinuities were identified during microstructural observation of materials in the as-received state as well as after fatigue tests. They appeared at areas of the SiC concentrations. The volumetric fraction of discontinuities increased with an increase of the SiC content. Further attempts are currently made to eliminate the SiC particle concentrations.

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