DAMAGE OF AA2124/SiC METAL MATRIX COMPOSITE UNDER FATIGUE CONDITIONS

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Abstract

Fatigue tests of AA2124 based metal matrix composites (MMCs) with SiC particles reinforcement were carried out. The MMCs were manufactured using powder metallurgy. Hysteresis loops were observed during subsequent cycles. Cyclic plasticity and ratcheting were identified as main fatigue damage mechanisms. Inelastic strain amplitude and mean inelastic strain were calculated to be used as fatigue damage indicators. Ultrasonic measurements during fatigue tests were performed but they did not allow to detect damage during fatigue tests.

1. Introduction

Nowadays many attempts are made to design automotive and aerospace devices from materials that should be lighter and simultaneously more durable than traditional ones. Metal matrix composites seem to be able to fulfil such requirements [1, 2]. During exploitation the materials are often subjected to fatigue loadings. Thus, many researchers are focused on discovering the method of monitoring the evolution of fatigue damage during exploitation conditions [3-8]. One of the promising tools to achieve this goal seemed to be ultrasonic detection of fatigue damage. The first step to such an achievement is observation of ultrasonic wave parameters during laboratory fatigue tests. That could enable to receive knowledge about fatigue damage process evolution in a specimen.

Fatigue damage parameter calculated on the basis of inelastic strain amplitude and mean inelastic strain proposed by Dietrich and Socha [3-5, 7-8] seems to be useful during damage analysis of metal matrix composites. Changes of inelastic strain amplitudes during subsequent cycles are governed by cyclic plasticity, while ratcheting is expressed by a movement of hysteresis loops of constant width along the strain axis. Since the mean inelastic strain remains negative during tests it cannot be used as a simple fatigue damage indicator to calculate fatigue damage parameter. That is the reason why efforts are made to elaborate corrected fatigue damage parameter on the basis of absolute values of mean inelastic strain and inelastic strain amplitude increments. This method is still under development.

2. Materials and tests conditions

AA2124 aluminum alloy based metal matrix composites reinforced with 17 and 25% of SiC were subjected to fatigue test. The MMCs were manufactured using powder metallurgy.

Powders after high-energy mixing were subjected to hot isostatic compaction to form fully dense billets and were subsequently forged and subjected to T6 heat treatment.
Flat specimens with square gauge cross section and hourglass shape grip section were manufactured from the MMCs. Fatigue tests were carried out under stress control using MTS servo-hydraulic testing machine. Symmetric tension-compression loading was applied with stress ratio R = -1 and frequency of 10 Hz. Stress amplitudes were equal to 300 MPa for AA2124+17%SiC and 330 MPa for higher i.e. 25% SiC content.
Ultrasonic wave measurements were performed during fatigue tests. Two pairs of 4 MHz longitudinal wave probes and two pairs of 4 MHz Rayleigh wave probes were attached to fatigue specimens before tests (Fig. 1). Pulse amplitudes and time of flights were measured in 4 ms intervals during whole fatigue tests.

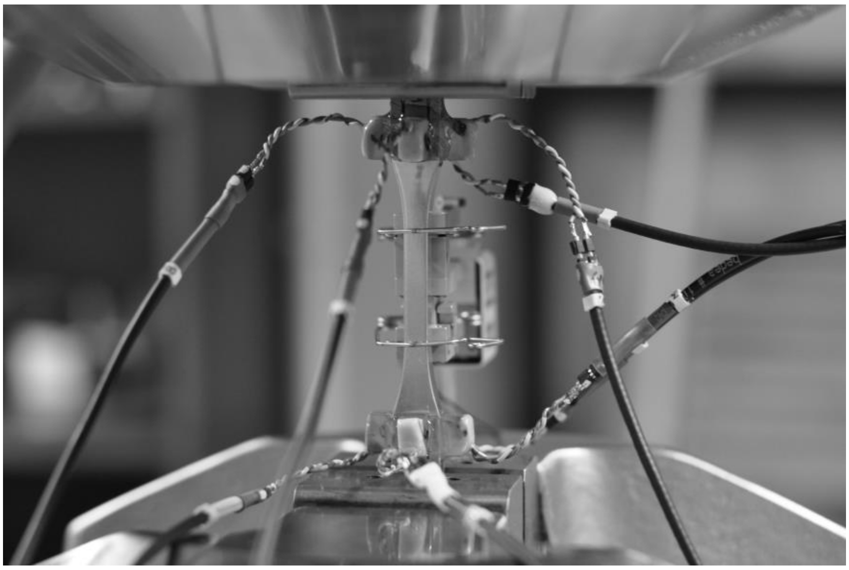

Figure 1. Test facilities for fatigue with ultrasonic probes

3. Tests results discussion

Cyclic plasticity followed by ratcheting was observed during fatigue tests. Hysteresis loop width enlarged during first cycle towards negative strains (Fig. 2 and 3). Subsequently hysteresis loops widths became narrower during next cycles (Fig. 4) and ratcheting towards negative strains was observed (Fig. 5). Inelastic strain amplitude and mean inelastic strain during subsequent cycles were calculated. In the case of AA2124 + 17% SiC (specimen 17_xe_zm_7), inelastic strain amplitude reached the value of 0,0005 mm/mm at the beginning of test (Fig. 6a), decreased during next 10 000 cycles and then stabilized at strain value equal to about 0,00005 mm/mm (Fig. 7). Mean inelastic strain remained negative during test (Fig. 6b, 8). At the beginning it decreased to the value of -0,0004 mm/mm, than increased slightly and after about 150 cycles decreased up to -0,0015 mm/mm. Thus, mean inelastic strain cannot be used as a simple fatigue damage indicator.
Shakedown effect was observed during first cycles. Initial voids and cracks were closing until 10 000 cycles. Afterwards inelastic strain amplitude stabilized, while mean inelastic strain increased slightly until fracture. It can be explain by creating of new fatigue defects. Thus, the fatigue damage process was dominated by ratcheting effect.
These two parameters, i.e. inelastic strain amplitude and mean inelastic strain can be used in the future as fatigue damage indicators to calculate corrected fatigue damage parameter.

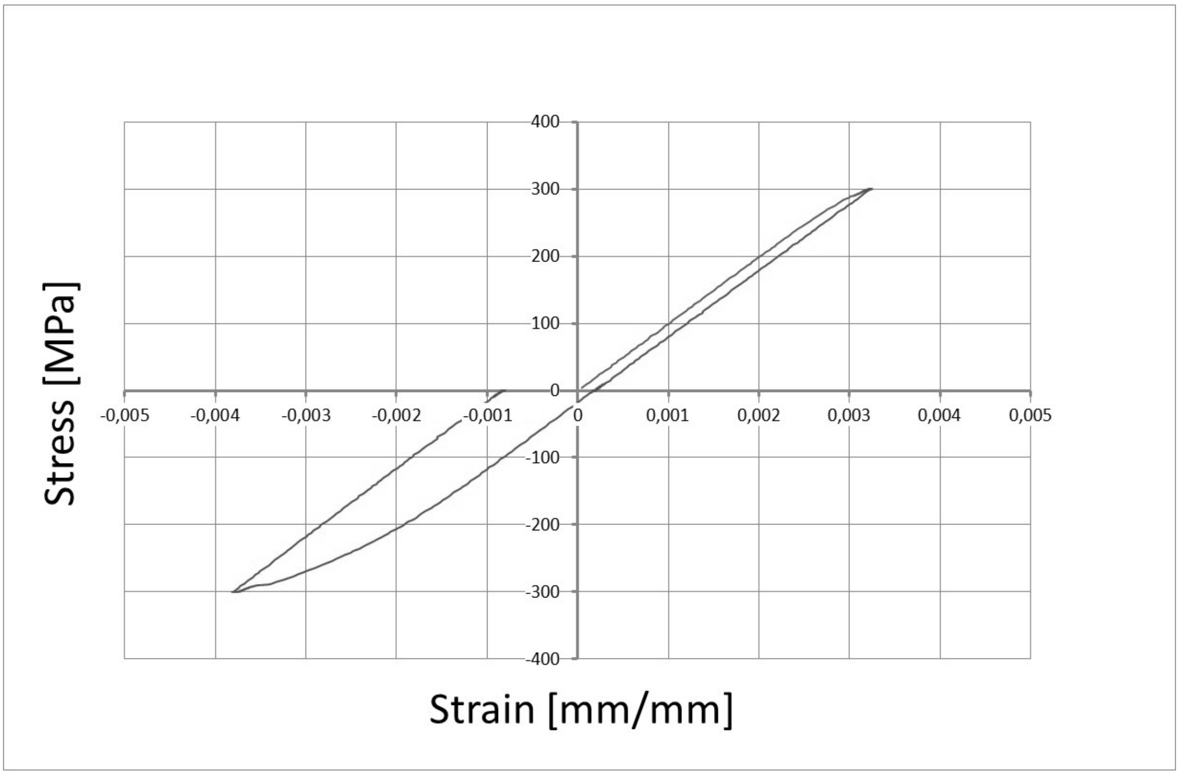

Figure 2. Hysteresis loop for AA2124+17%SiC (specimen 17_xe_zm_7) – first cycle

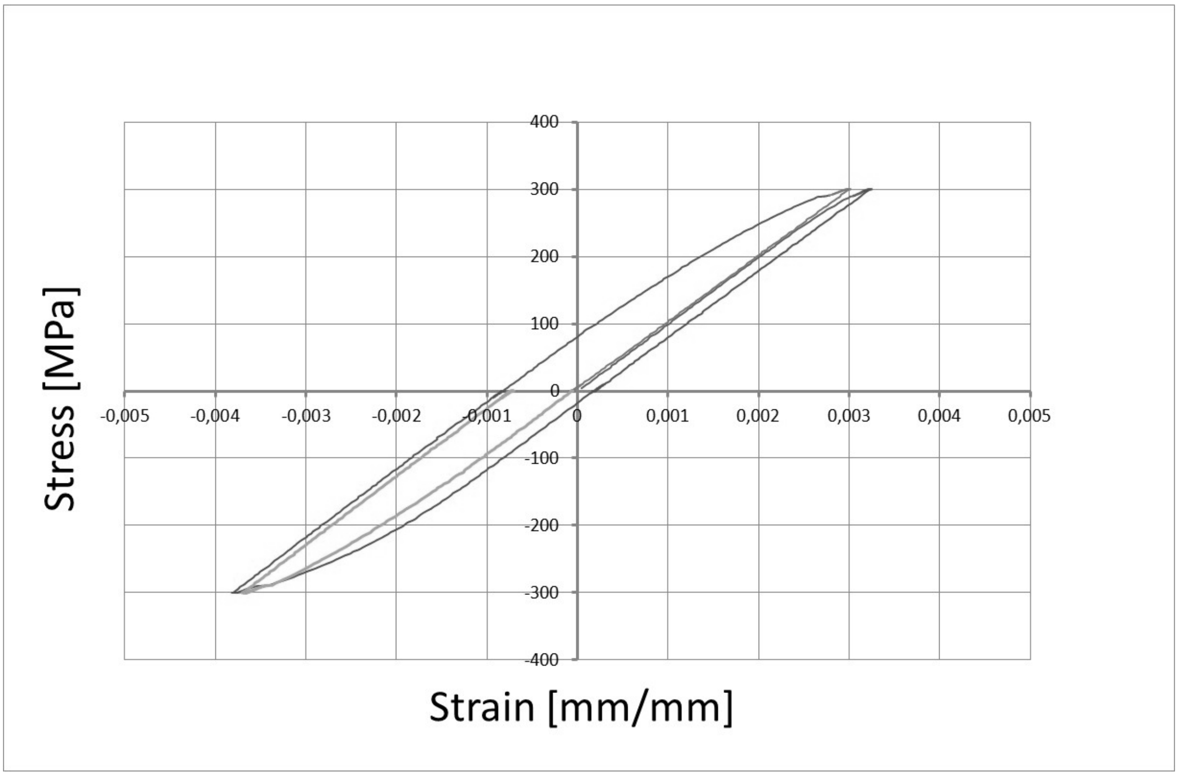

Figure 3. Hysteresis loops for AA2124+17%SiC (specimen 17_xe_zm_7) – first and second cycles

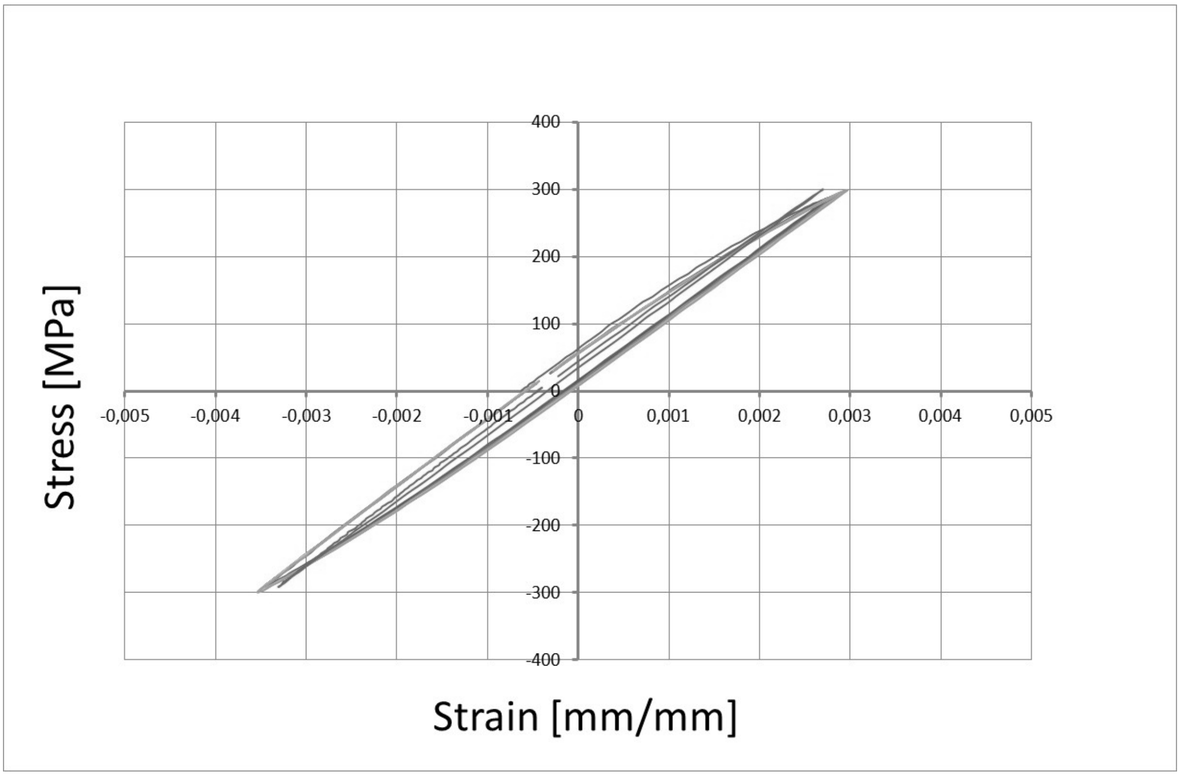

Figure 4. Hysteresis loops for AA2124+17%SiC (specimen 17_xe_zm_7) 3 – 502 cycles

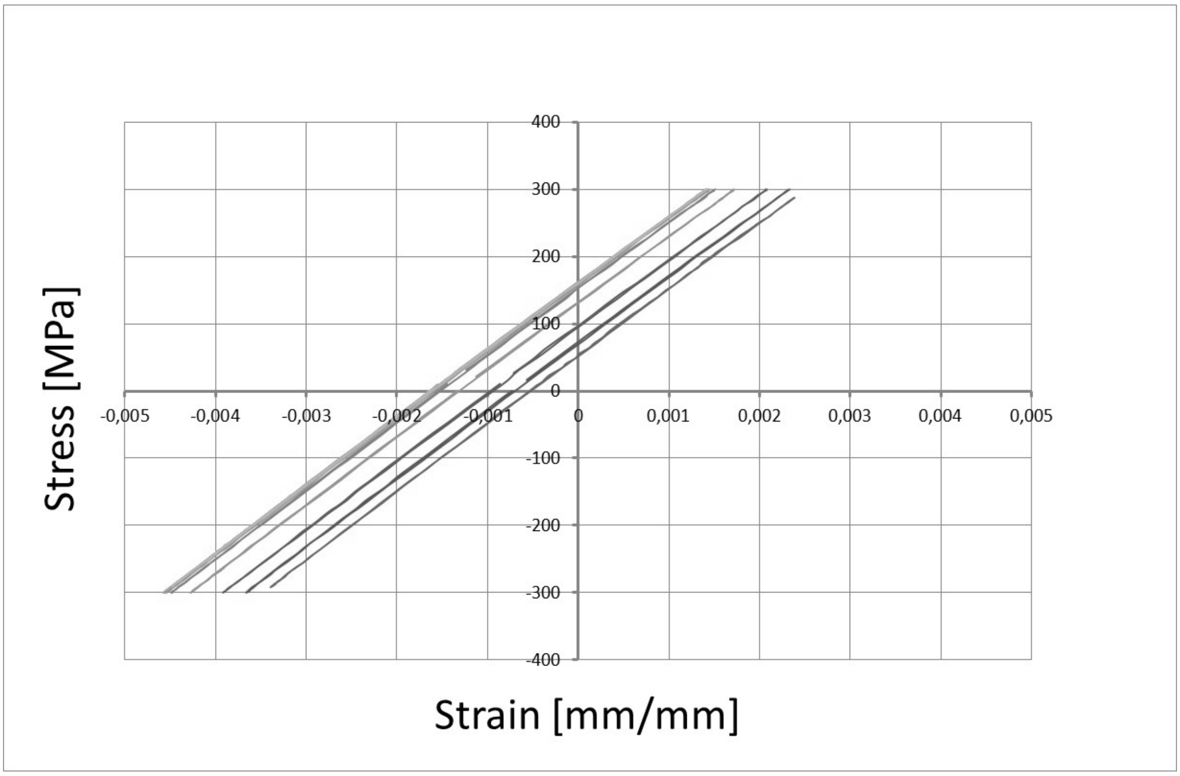

Figure 5. Hysteresis loops for AA2124+17%SiC (specimen 17_xe_zm_7) 503 – 5 000 cycles

a) b)

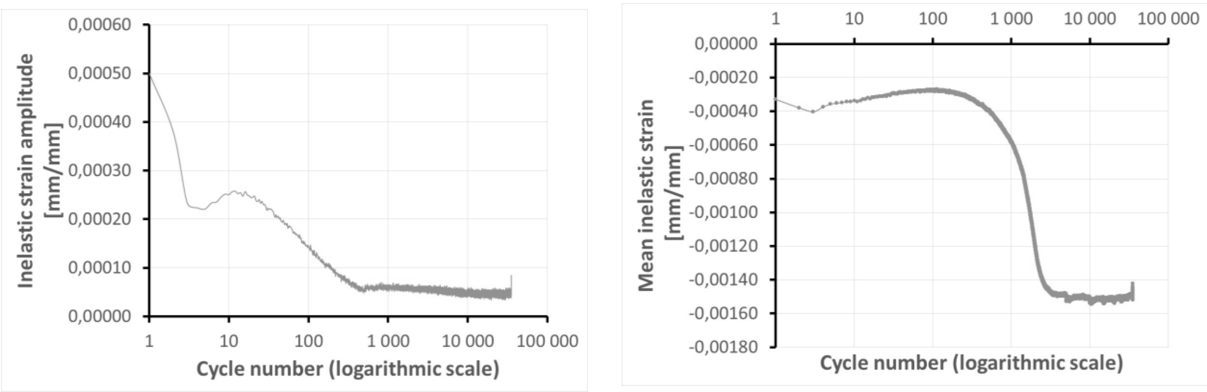

Figure 6. a) Inelastic strain amplitude (logarithmic scale) for AA2124+17%SiC (specimen 17_xe_zm_7); b) Mean inelastic strain (logarithmic scale) for AA2124+17%SiC (specimen 17_xe_zm_7)

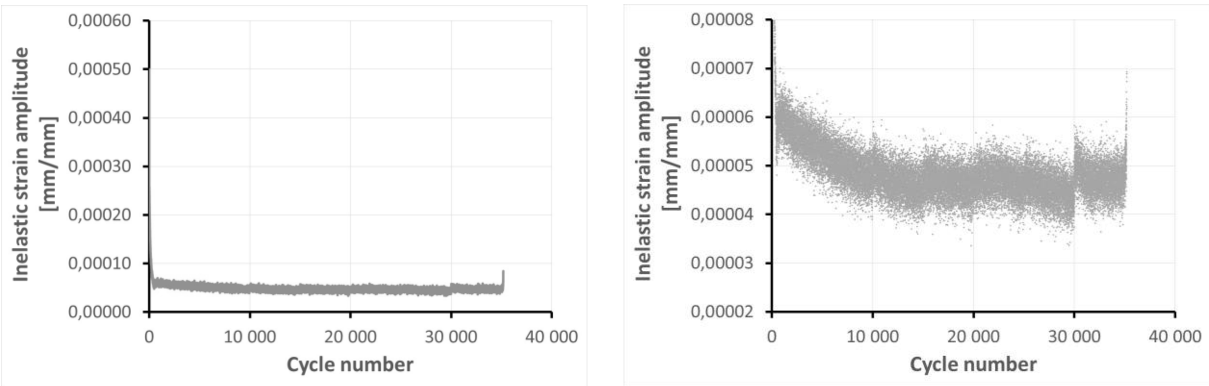

Figure 7. Inelastic strain amplitude for AA2124+17%SiC (specimen 17_xe_zm_7)

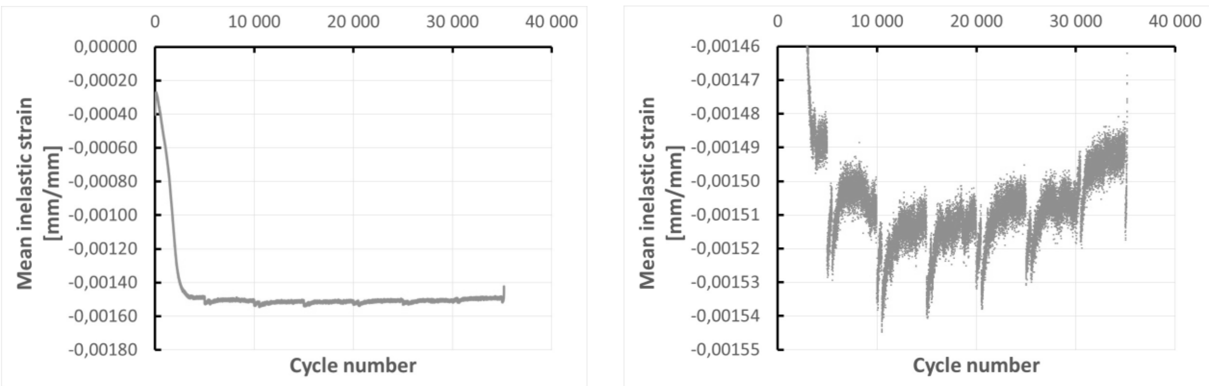

Figure 8. Mean inelastic strain for AA2124+17%SiC (specimen 17_xe_zm_7)

Ultrasonic measurements during fatigue tests were carried out. Amplitude and time of flight of longitudinal and Rayleigh wave pulses were observed. Preliminary investigations showed decrease of longitudinal wave amplitude during fatigue process, which can signal damage evolution in specimen under fatigue conditions. Further investigations were performed to verify the results obtained. Unfortunately, the longitudinal wave amplitude did not change during subsequent cycles. But the amplitude changes of longitudinal waves during last cycles were observed (Fig. 9). Increase of attenuation was noticed in the last seconds of specimen fatigue life.

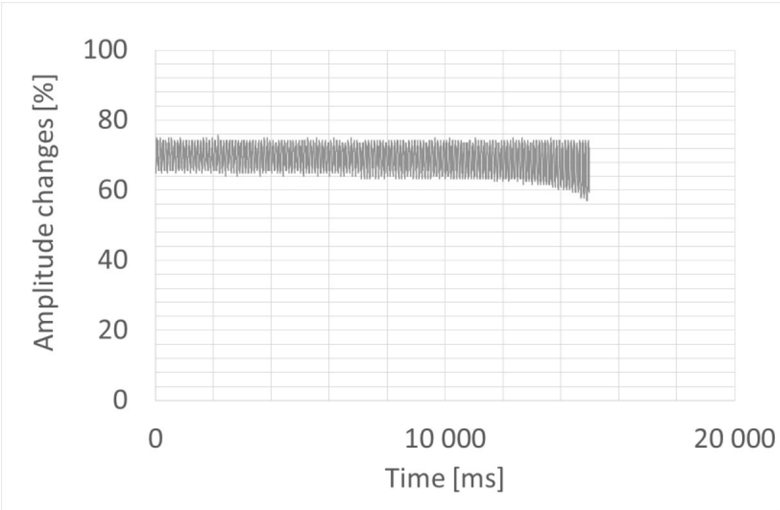

Figure 9. Amplitude changes of longitudinal ultrasonic pulse in AA2124+17%SiC (specimen 17_xe_zm_7) during last 15 s of specimen fatigue life

4. Final remarks

Fatigue tests of AA2124/SiC identified cyclic plasticity and ratcheting as the main mechanisms involved in fatigue damage process of the composites. Mean inelastic strain values were negative during tests. That is why it could not be used as a simple fatigue damage indicator to calculate fatigue damage parameter.
Shakedown effect during first cycles of fatigue tests was observed. It can be explain by initial voids and cracks closing up to 10 000 cycles. Afterwards the process of creating new fatigue defects is dominated by ratcheting. Both inelastic strain amplitude and mean inelastic strain or their combination are the promising tools for monitoring development of fatigue damage. Attempts are made to use them as fatigue damage indicators during calculation of corrected fatigue damage parameter based on absolute values of increments of the parameters aforementioned.
Ultrasonic measurements during fatigue tests did not allow to identify fatigue damage of the composites during subsequent cycles. Amplitude changes of longitudinal waves during last cycles were observed. Further investigations will be performed to analyze specimen microstructure during fatigue tests.

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