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Study of fatigue fractures of Al-Mn alloy

J Škoda¹, M Losertová¹, V Kubeš¹, K Konečná¹, P Hlinka¹ and P Czyz²

¹VŠB - Technical university of Ostrava, Faculty of Metallurgy and Materials Engineering, Ostrava - Poruba, Czech Republic

²Hanon Systems Autopal s.r.o., Lužická 984/14, 741 01 Nový Jičín, Czech Republic

E-mail: jan.skoda@vsb.cz

Abstract. Aluminum alloys have become a standard application in automotive industry due to their strength to weight ratio and corrosion properties. Aluminum alloys based on Al-Mn (class 3XXX) that are applied as components in air conditioning modules in automotive as well as in construction and consumer industries are often submitted to vibrations which can eventually lead to fatigue cracks and in the end to complete failure of the components. The study of fatigue failures of cyclic loaded Al-Mn alloy was performed using fractographic analysis on scanning electron microscope JEOL JSM-649OLV. The loading was realized from 100,000 to 1,369,000 cycles at room temperature. The features of fatigue fracture surfaces were discussed comparing different tempers of the A3003 alloy, specifically in the temper 1/4 hard (H12) and full soft (O). The results for corresponding loading cycles were compared. Areas close to the crack initiation were characterized by radial marks corresponding to fatigue propagation. Fracture was propagated through the growing lines in form of fine striations with secondary cracks and microcracks between them. The striations were arranged to bands and corresponded to crack propagation at each loading cycle. For final fracture the typical quasi-cleavage morphology was observed.

1 Introduction

Aluminum alloys become a standard application in automotive industry due to their strength to weight ratio and corrosion properties. Beside their strength and corrosion characteristics, fatigue properties of the aluminum alloys are also important features for automotive use. Unlike steel, the fatigue behavior of aluminum alloys isn't still sufficiently explored and in some cases data on fatigue strength are missing completely.

Aluminum alloys based on Al-Mn (class 3XXX) that are applied as components in air conditioning modules in automotive as well as in construction and consumer industries, are often submitted to vibrations which can eventually lead to fatigue cracks and in the end to complete failure of the components. Because of this there is need for further investigation to complete the data about fatigue behavior of aluminum alloys, especially for Al-Mn based alloys as their applications include not only automotive, but also construction and consumer products.

Components in air conditioning and cooling modules are loaded with vibrations which can eventually cause fatigue cracks and in the end complete failure of the components. Failures of the component due to the vibrations can be then distinguished as high cycle fatigued that resulted from engine run vibrations and low cycle fatigued as consequence of the suspension vibrations due to vehicle ride.



The aim of the fractographic study was to evaluate the fracture surfaces after cyclic loading of the Al-Mn alloy (AA3003) in two tempers, namely H12 and O.

2 Experimental

Two sets of experimental specimens (table 1) in the tube shaped form of 19 mm in outer diameter and of 2 mm in wall thickness were submitted to fatigue tests. The first set was in H12 temper (work hardened to quarter-hard, not annealed after rolling) and the second one in O temper (fully annealed, soft) [1]. Microstructure and phase analysis was performed on selected specimens using Olympus GX51 optical microscope with DP1 digital camera and EDX microanalysis by the JEOL JSM-649OLV scanning electron microscope (SEM) equipped with the OXFORD INSTRUMENTS INCA x-act tool, respectively. Fatigue tests were realized on a vibrational electromagnetic device at frequencies of approximately 80 Hz and loading mode was controlled by acceleration adjustment. Fractographic study of failure surfaces after cyclic loading was carried out using SEM JEOL JSM-649OLV.

The specimens for the metallographic observation were cold embedded in non-conductive acrylic resin Specifix, manually grinded on abrasive SiC papers and polished on DP Nap cloth with Struers DiaDuo 3 μm diamond paste using Compact 1031 device. The phases were observed in etched condition after immersion in Keller's reagent for 3 seconds. The grain shape and size, grain boundaries and other microstructural characteristics were showed after electrolytic color etching in a solution composed of 5 ml 48% HBF_4 and 200 ml H_2O using Struers Lectropol – 5.

Table 1. Number of loading cycles for selected specimens.

Temper	Specimen	Number of fatigue cycles
H12	1	106,890
	2	487,080
	3	1,369,000
O	1	100,000
	2	302,000
	3	950,000

3 Results and discussion

The microstructure of the polished specimens of both sets was formed of an aluminum solid solution and primary phase particles that were defined as a ternary phase of Al-(Fe,Mn)-Si type [2] using EDX microanalysis. The intermetallic Al-(Fe,Mn)-Si particles can influence the recrystallization and precipitation behavior as well as the fracture toughness of the studied alloys and they are difficult to eliminate by homogenization at temperatures below 650 °C because of the risk of melting [3 – 6].

The color etched microstructures in the transverse cross section of H12 and O specimens are presented in figure 1. The work hardened temper (H12) showed equiaxed fine grained structure with recrystallized grains with average size of 20 μm (figure 1 a). The annealed microstructure (O temper) is characterized by coarse grains with average size of 200 μm (figure 1 b).

The comparison of fatigue behavior was performed with respect to both different tempers of the material (H12 and O, respectively) and the number of fatigue cycles. Fatigue crack initiation of both specimens set started at the locality with highest stress concentration, therefore at outer surface of the tubes. From here the crack propagated across the tube wall until the final fracture was accomplished. Macroscopically, the crack propagation is proved by radial steps with quasi-cleavage facets (figure 2a, 3a, 4a, 5a, 6a and 7a). Microscopically, the fatigue failure propagated through the growing lines in the form of fine striations between of which the secondary cracks and microcracks were observed (figure 2b, 3b, 4b, 5b, 6b and 7b). The morphology of final crack was

characterized by mixed quasi-cleavage fracture, with ductile dimples inside that primary phase particles were observed. The occurrence of dimples is typical for ductile matrix.

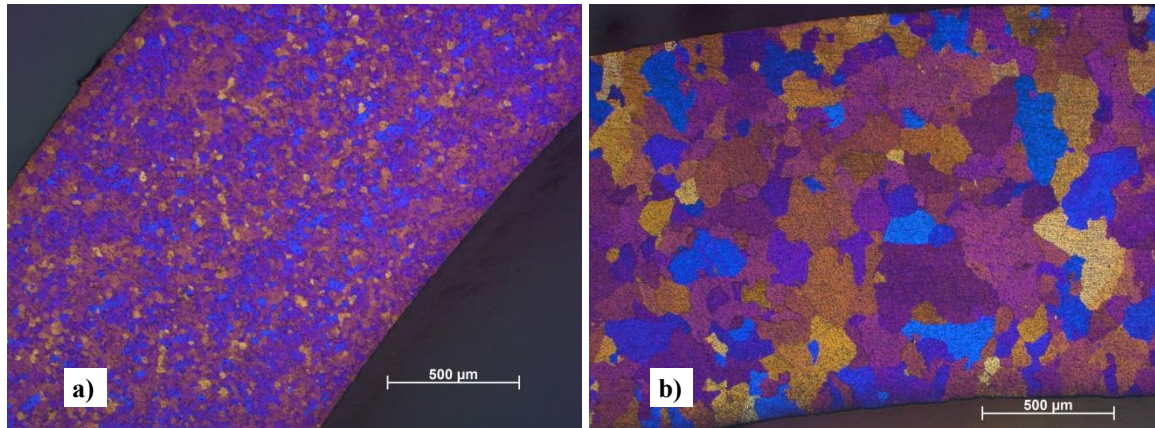


Figure 1. Microstructure of the cross sections of Al-Mn tubes: a) fine grain size structure for H12 temper; b) coarse grain size structure for O temper.

For the H12 temper, as the number of the fatigue cycles increased the tendency to large steps development was remarked in initiation and propagation areas that could be related to fine grained microstructure and the strengthened temper. Unlike H12 fracture surfaces the fatigue areas of O specimens showed more rough relief that correspond to coarse grain size structure of soft temper. The occurrence of ductile striation confirmed the plastic deformation behaviour during fatigue loading. The secondary cracks or microcracks were generated after the magistral crack passing. Although the striation represent certain response to each loading cycle and some differences in striation distances were remarked, it was not possible to determinate this characteristic as a proof related with the cycle number during fatigue loading. More detailed analysis of dislocation structures by means of transmission electron microscopy [7] would give more information to generalize the effect of number of loading cycles on the fracture feature.

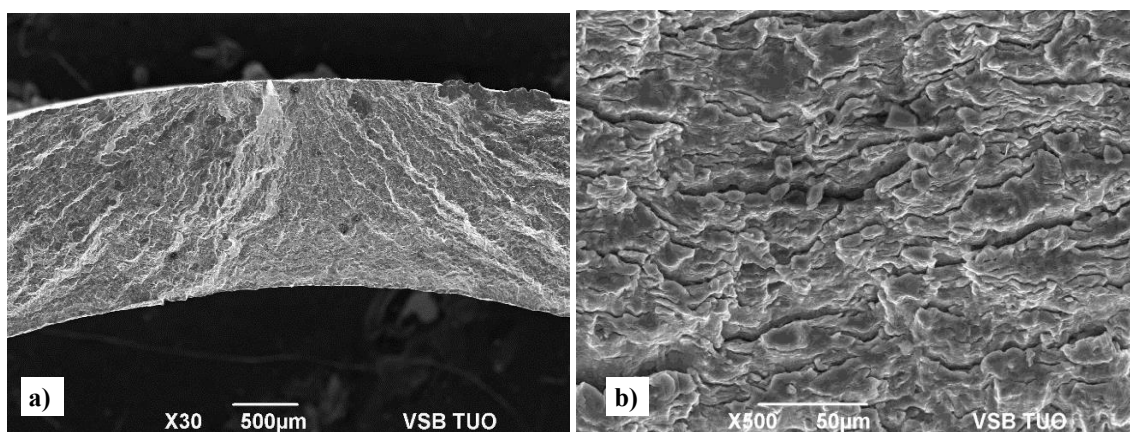


Figure 2. SEM fractography of specimen 1 fatigue tested in H12 temper, 106,890 cycles: a) view of crack initiation and b) detail of initiation area with steps, secondary microcracks and striations.

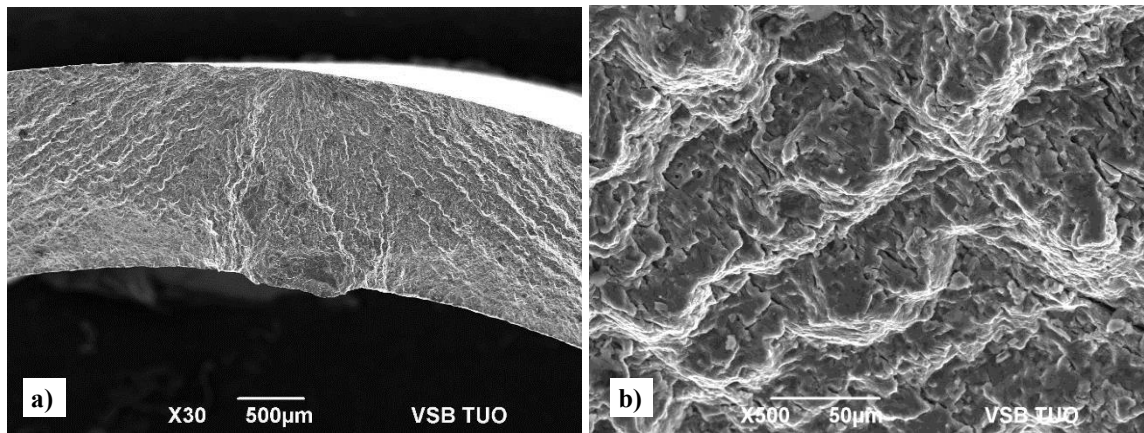


Figure 3. SEM fractography of specimen 2 fatigue tested in H12 temper, 487,080 cycles: a) view of crack initiation and b) detail of initiation area with steps, secondary microcracks and striations.

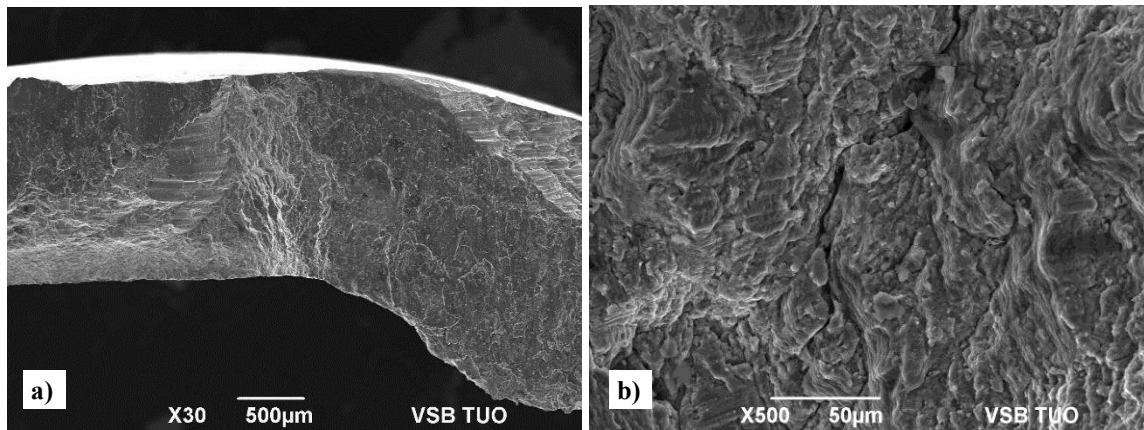


Figure 4. SEM fractography of specimen 3 fatigue tested in H12 temper, 1,369,000 cycles: a) view of crack initiation and b) detail of initiation area with steps, secondary microcracks and striations.

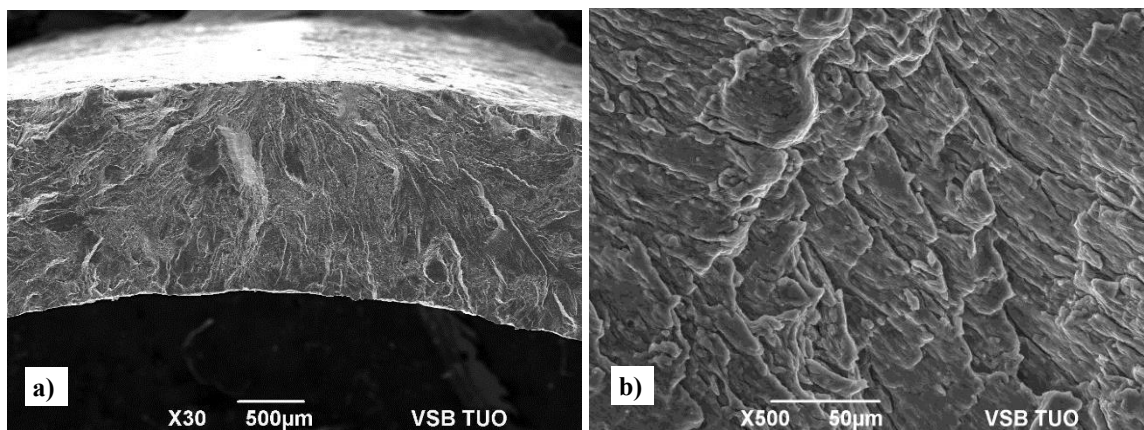


Figure 5. SEM fractography of specimen 1 fatigue tested in O temper, 100,000 cycles: a) view of crack initiation and b) detail of initiation area with steps, secondary microcracks and striations.

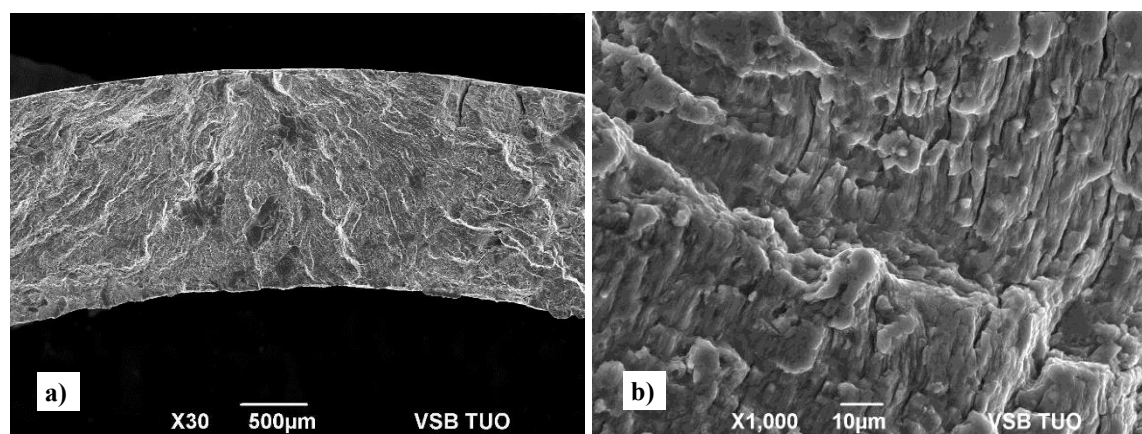


Figure 6. SEM fractography of specimen 2 fatigue tested in O temper, 302,000 cycles: a) view of crack initiation and b) detail of initiation area with steps, secondary microcracks and striations.

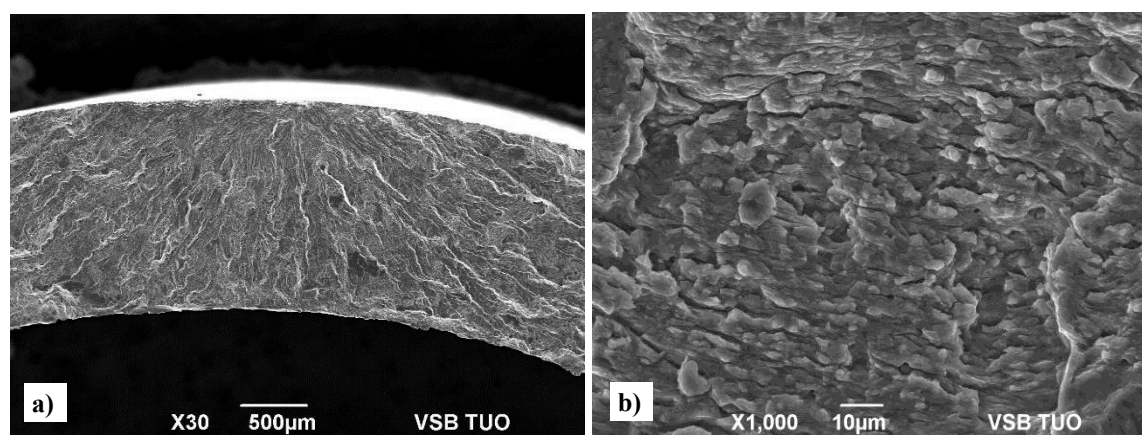


Figure 7. SEM fractography of specimen 3 fatigue tested in O temper, 950,000 cycles: a) view of crack initiation and b) detail of initiation area with steps, secondary microcracks and striations.

4 Conclusion

The fracture surfaces taken from the tubes of the Al-Mn based alloy were subjected to the fractographic analysis and investigated to find a correlation between the morphology of the fracture surface and the number of loading cycles completed. The macroscopic morphology of both temper states corresponded to grain size of microstructure.

The issue of studying the life and fatigue behavior of Al-Mn alloys is complex and cannot be generalized only on the base of literature data. To create more general theory and find some connections between the loading cycles and failure morphology of Al-Mn materials, it is necessary to receive and discuss various sets of results after low-cycle as well as high-cycle fatigue tests in different temper conditions. For better understanding of the fatigue propagation and striation during cyclic loading, it is necessary to complete the fracture analysis with the study of the dislocation structure using transmission electron microscopy.

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