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Ejection-Seat-Quick-Release-Fitting
Quantitative fractography and estimation of the local toughness using the topography of the fracture surface

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ABSTRACT: A Quick-Release-Fitting of an Ejection Seat broke and investigations were made to estimate the fracture mechanism on the basis of fracture surface characteristics.

Fractographic based investigations normally use qualitative characteristics to purify the cause of the failure. Generally the determination of the fracture location and its origin, the kind of fracture and special features on the fracture surface are enough to describe the cause of the fracture.

The aim of this investigation is to use quantitative fractography as a tool to get more information about crack propagation mechanism and also to get an estimation concerning striations, fracture topography and stretched zone. This results in a correlation to fracture mechanic concepts.

During crack propagation striations were created on the fracture surface caused by the service induced load changes. The distance of the striations were measured to estimate crack propagation and remaining life time.

In addition a plastic stretched zone could be found on the tip of the cracks. The width of these zones gave information about local fracture toughness. The 3-dimesional zone symmetry was measured on cross sections by using stereographical methods to get more information about the crack tip and the crack propagation.

To complete the failure analysis nondestructive evaluation, metallographic examination and chemical investigations were carried out. No additional cracks could be found. Most of the failed parts showed that the microstructure, the hardness and the chemical composition of the Al-alloy were within the specification, but some of the cracked parts were manufactured with an other material as specified.

Keywords: Al-alloy, crack propagation, fatigue fracture, fracture toughness, quantitative fractography, stretch zone,

INTRODUCTION

During the use of a Quick-Release-Fitting from a parachute emergency system, a miss function came up and it was not possible for the pilot to release his seat belt. The reason for that was a broken part (bell) within the central lock (Figures 1 and 2). The bell was constructed and manufactured as thin wall, cylindric part with a centred thick part in the middle of the bell which was surrounded by a slot half the circumference. In elongation of this slot the bell broke. Many other bells were checked and eight more bells with cracks were found.

Figures 3 and 4 show the broken bell „S“, the cracked bells „V1“ to „V8“, the new bell „N“ and the entire Quick-Release-Fitting. The fracture of the bell „S“ resulted in cracks along the solid central part which is surrounded by a semicircular oblong hole. The eight bells „V1“ to „V8“ with preinduced cracks are damaged in the same area. The bells „V1“, „V7“ and „V8“ showed preinduced cracks on both ends of the oblong hole.

The material specified for these bells was Al-alloy AlMgSiPb; heat treatment of the bells was to follow DIN 1747, part 1; this includes an approximate minimum hardness of Brinell HB 80; The following literature was used: some information about the function of the central lock, some engineering drawings, ESIS P2-92, DVM 002-Merkblatt and some information to the material. The bells were manufactured from aluminium alloy. The constituents of the bells „S“, „V1“, „V3“ to „V8“ were within the specification requirements for Al-alloy AlMgSiPb, but the bells „V2“ and „N“ were fabricated from Al-alloy AlCuMgPb (Table 1).

Table 1: Chemical composition and hardness of the bells

Samples or Reference Material	Element mass ratios [%]							Hardness
	Si	Mn	Cu	Mg	Fe	Zn	Pb+[2)]	HB
bell „S“	0,80	0,85	0,02	0,87	0,31	0,03	1,39	58
bell „V1“	0,75	0,40	0,06	0,64	0,29	0,02	1,57	60
bell „V2“	**0,36**	0,54	**3,70**	0,76	**0,72**	0,42	1,27	105
bell „N“	**0,44**	0,60	**3,84**	0,72	0,55	0,36	1,27	108
AlMgSiPb [3)] WL 3.0615	0,6 bis 1,4	0,4 bis 1,0	≤ 0,10	0,6 bis 1,2	≤ 0,5	≤ 0,5	1,0 bis 3,0	[6)]
A1CuMgPb [4)] WL 3.1645	≤ 0,8	0,5 bis 1,0	3,3 bis 4,6	0,40 bis 1,8	≤ 0,8	≤ 0,8	0,8 bis 1,5	[6)]

[1)] remainder: Al
[2)] Pb+Sn+Bi+Cd+Sb: 1,0 bis 3,0; Cd not specified
[3)] according to the drawing requirements the clocks were fabricated from AlMgSiPbF28; the values of AlMgSiPb were taken from DIN 1725, part 1 vom Feb.1983
[4)] the material destinated in according to the chemical analysis
[5)] other elements analysed: Cr 0,10; Ni 0,20; Bi 0,20; Sn 0,20.

Remarks: The chemical analysis of the bells "V3" to "V8" are not listed in table 1 because they had the same composition like the broken bell "S" and the cracked bell "V 1 " - these bells compare favorable to the requirements as shown in the table; the elements which not met the requirements are **bolted** in the table.

Metallographic samples were taken through the cross-section of the fracture origin on „S“, „N“ and „V8“. The cleanliness of the material was relatively good for the required alloy, despite of only few inclusions, but „N“ showed many precipitates and bands (Figures 5 and 6). Microhardness measurements were performed on cross-sections of these parts. The required hardness as specified on the governing engineering drawing for the component was 80 HB minimum. The hardness values obtained for „S“ (58 HB) and „V8“ (62 HB) were similar and did not confirm the specification. The hardness of „V1“, „V3“, „V6“ and „V7“ were within this range (60 HB to 65 HB) and also low, but „V4“ (81 HB), „V5“ (103 HB) and „V2“ (105 HB) showed relatively high values.

The stress distribution around the crack initiation area of the bell was calculated with the help of Finite-Element-Method and was found in good agreement with the different stages and locations of the broken bells (Figure 7 and 8).

To find out the damage cause usually qualitative fractographic investigations are sufficient in addition to other investigations. Normally the fracture origin, the kind of fracture and special features on the fracture surface are described. The goal of this investigation was to get information about remaining life span depending on crack length and to answer questions about possible influences of the different materials. Therefore it was necessary to determine the crack propagation and local fracture toughness by means of quantitative fractography. The approach included examination of the fracture and cracks concerning crack propagation, development of local fracture toughness and fracture mechanics evaluation of the stresses required to initiate the cracks.

Results

Fracture Examination

The bells „V1“ to „V8“ showed precrack extensions from 0.4 mm to 1.5 mm whereby the plate thickness was 1.5 mm. The circumference precrack extension runs from 4.5 mm up to 26 mm. Only „V4“ and „V8“ showed precracks on both sides (up to 0.3 mm). The longest precrack was found at „V7“ (26 mm). The results of the SEM-investigation showed that „S“ and „V1“ to „V8“ cracked due to fatigue fracture (Figure 9). The fatigue crack on „S“ was initiated by etch-pits and pittings underneath the 10 µm eloxal layer (Figure 10). The crack propagation took place from the outside of „S“. The crack propagation showed in addition to the operational load marks signs which points to the load of the bell during „put on-lock-take off“. Because of this operation the mass of the solid central part moves away from the mid part of the bell. Due to this loading the mid part is overcome by bending. The pits and pittings promoted the precracks in this area.

The fatigue fracture surface of the broken bell and the cracked bells were examined with respect to the striations at the origin area, the middle area and the crack tip area to quantify the crack propagation. Figure 11 shows the measured values (striations per mm) as a function of the crack length. These values were calculated by regression to get an average curve [1;2;3]. The integration of this curve lead to the crack propagation curve (Figure 12). The comparison of the derivated crack propagation (dl/dN) of the striation width with literature values shows that the crack propagation was uncritical at most investigated bells (Figure 13). This lead to the conclusion that for cracked bells even with relatively long cracks no critical stage can be expected during the time fixed life span,

Fracture Mechanics Evaluation

The area between the primarily crack (fatigue crack) and the final fracture (stable crack growth) is called „Stretched Zone“. Ductile materials show blunting at the crack tip due to mechanical stress, that means the beginning of the stable crack growth due to slip or shear processes. The development of the streched zone depends on the stress, the load, the velocity, the crystal structure and the texture. Quantitative statements to the local fracture toughness can be made by measuring the stretched zone width (SZW), the stretch zone height (SZH) and/or the crack tip opening displacement (CTOD).

The stretched zone measurements were done on stereo image paires by scanning electron microscopy on both corresponding fracture surfaces of the specimens „V1" and „V2" (Figure 14). Measurements along several base lines through the stretched zone achieved the streched zone width (SZW) calculated by digital image processing [4;5;6;7]. Based on the ESIS P2-92 and DVM 002-Merkblatt the mechanical properties for the local crack initiation were calculated. The crack initiation toughness defined by the J-Integral is connected with the stretched zone and can be set as

$$J_i = \frac{E \cdot SZW}{0{,}4 \cdot d^*}$$

J_i = Fracture resistance at crack initiation
E = Young's modulus
d^* = proportionality constant

By taking in the average SZW-values into this equation the bell V1 shows a J_i-value of 28 N mm/mm^2 and the bell V2 shows a J_i-value of 23 N mm/mm^2 On the other hand there exist a relation between J_i and K_{Ic}:

$$K_{Ic} = \sqrt{\frac{J_i \cdot E}{1 - \nu^2}}$$

ν = Poisson's ratio
K_{Ic} = Fracture toughness

After calculation the value for bell V1 results in 47 MN/ $\sqrt{m^3}$ and the value for bell V2 results in 42 MN/ $\sqrt{m^3}$. Because of the little difference in local fracture toughness the results show that different materials by itself did not cause additional problems.

CONCLUSION

A bell from a Quick-Release-Fitting broke due to fatigue fracture. Other cracked bells were found and showed fatigue fracture too, but differences in crack depth. Chemical analysis results pointed out that the bells were manufactured from different aluminium alloys. Metallographic examinations also resulted in different microstructure and hardness. The crack initiation site for all failed bells was located on the oblong hole in the middle of the bells, there were etch pits and pittings underneath the oxide layer which promoted the precracks. Striations were examined on some cracked bells and the derivated crack propagation was within an uncritical stage compared with literature values. The local fracture toughness of both materials showed little difference.
To improve the whole fitting area in termes of reducing the load in critical areas and to elongate lifw span the focus should be set on the optimisation of the construction which has been proposed. Additionally clear requirements should be given for the heat treatment of these parts.
The cause of the fracture and the cracks can be lead back to load and construction. Only an optimal harmonizing of material, load, manufactoring and construction leads to an optimal part. A proposal for modifiing has be done.

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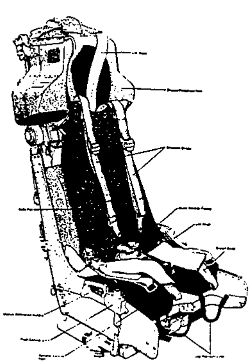

Figure 1
Ejection-Seat with the Quick-Release-Fitting

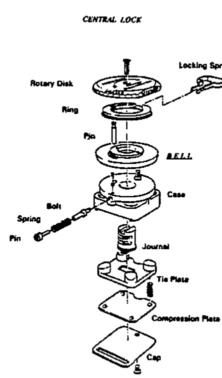

Figure 2
Schematic representation of the Quick-Release-Fitting with the bell

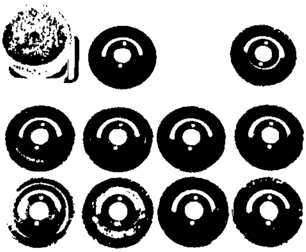

Figure 3 1:4,5
Overall view of the central lock, the unused new bell N, the damaged bell S and the cracked bells V1 through V8

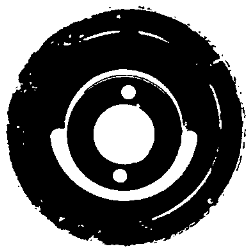

Figure 4 1:1,5
Bell S with the broken central part - view direction from the outside

Figure 5 200:1
Micrograph of a cross-sectional microstructure with only few precipitations - bell S

Figure 6 200:1
Micrograph of a cross section of the new bell N with numerous precipitations and distinct grains

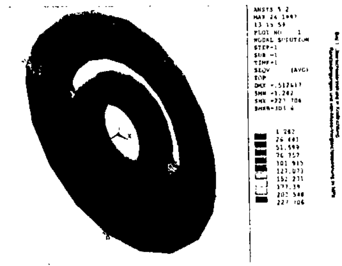

Figure 7
Overview of the von-Mises-Equivalent Stress in MPa

Figure 8
Detail of the von-Mises-Equivalent Stress in MPa

Figure 9
SEM-micrograph of the crack area with striations – bell S

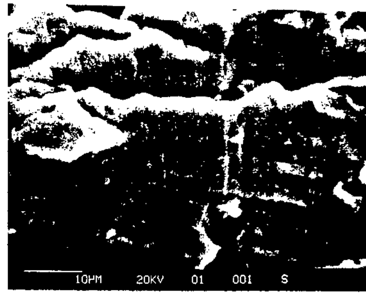

Figure 10
SEM-micrograph showing preinduced crack area with a crack origin underneath the eloxal layer – bell S

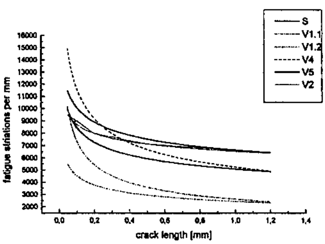

Figure 11
Results of the fracture surface measurements - „striations per millimeter as a function of the crack length"; the doted curve was determined by recession calculating.

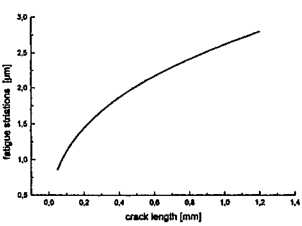

Figure 12
Crack extension curve, calculated from the average curve shown in Figure 9

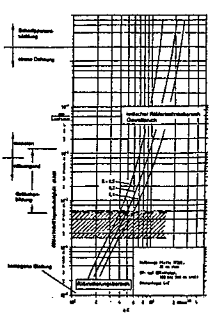

Figure 13
Comparison between the crack growth rate from the fracture surface (hatched) and the literature results for this material

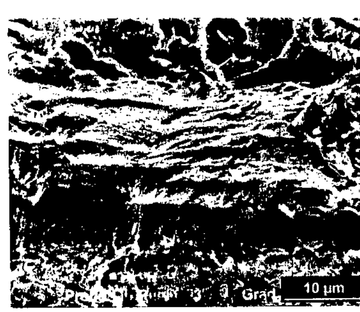

Figure 14
SEM-micrograph from the crack tip (SZW) - bell S1