APPLICATION OF FRACTOGRAPHY IN FULL-SCALE TESTS OF AIRCRAFT STRUCTURE PARTS

J. Kunz, I. Nedbal and J. Siegl*

A full-scale fatigue test of aircraft landing gear beams was carried out with the aim of durability proof and optimization of the beam design. Service conditions were simulated by the simple program loading. Direct optical measurements of fatigue crack length were extended by the quantitative fractography of fracture surfaces. Special care was given to the cracks propagating in the hidden locations of the beams, inaccessible to visual observation during the test. The fractographic reconstitution of fatigue crack kinetics was based on the striation spacing measurement. The results were presented in the two-dimensional form, i.e. in the form of dependence of the total area of fatigue-fractured cross section on the number of program-loading cycles.

INTRODUCTION

Fatigue tests of aircraft structures are time- and money-consuming experiments. The efficiency of the full-scale tests has been considerably increasing by the application of fractography. Quantitative data obtained by the fractography can be interpreted in the sense of fatigue process history reconstitution. By this way, it is possible to obtain information on

- the time necessary for initiation of cracks,
- the rates and directions of fatigue crack propagation in various locations of fractured parts,
- the time-dependent, two-dimensional description of fatigue crack propagation,
- the sequence of individual cracks and failures,
- the consequences of design changes or repairs on the fatigue-proof properties of structure components etc.

The above items are very valuable, especially in the case of hidden cracks inaccessible to direct visual monitoring during the test. Very often the fractographic information on fatigue failure of real aircraft parts is unobtainable in other ways.

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* Department of Materials, Faculty of Nuclear Science and Physical Engineering, Technical University of Prague, Czechoslovakia.

Methods of fractographic reconstitution of fatigue crack kinetics were described in detail in some of our previous papers (e.g. Nedbal et al (1) - (3)). The fractographic reconstitution is conditioned by the existence of striations, i.e. fractographic features whose measurable trait (striation spacing **s**) depends upon the macroscopic crack growth rate **v**. The relation between **s** and **v** is the key problem. On the basis of laboratory investigations on simple Al-alloy specimens, the above relation is influenced mainly by (4) :
a/ the existence of the so called "idle cycles",
b/ the deflection of local crack rate vectors from macroscopic crack growth direction, and
c/ the coeffect of various crack growth micromechanisms.
In the case of laboratory experiments on AlCu4Mg1 alloy (type 2024), the value of ratio **v/s** ranges from 0.2 (for the lowest ΔK) to 6.0 (for the highest ΔK) aproximately.

The results obtained were used in the fractographic analysis of various aircraft components. The paper presents the results of the fractographic analysis of landing gear beams fractured during fatigue test.

FATIGUE TEST OF LANDING GEAR BEAMS

The full-scale test of landing gear beams was a part of the durability proof of L 610 aircraft (Vrhel and Fiala (5),(6)). The beams were bolted down the bulkhead mock-up (see Fig. 1). Service conditions were simulated by the simple program loading. The program cycle (PC) parameters are presented in Fig. 1. The material of the beams was AlCu2MgSi alloy.

Both sides (left and right) of two tested beams were loaded separately, so four independent experiments were carried out in all. The description and designation of the four specimens are given in Table 1. The individual sides of the beams had different structural design. Design B and C differ from the original design A by a bigger transition radius of ribs and more continuous changes of thickness. In the case of design C the fastener hole in the lower flange plate was omitted as well (compare Fig. 2a and Fig. 2b).

TABLE 1 - Specimen Identification

Specimen No.	Beam No.	Side	Design
1	I	left	A
2	I	right	A
3	II	left	B
4	II	right	C

The experiments were carried out with the aim of beam design optimization from the fatigue resistance point of view. During experiments the fatigue crack lengths were measured optically in the visible and accessible areas. The macroscopic information was completed and extended by fractographic analysis of the primary fractured parts of beams, i.e. lower flange plates and web plates.

FRACTOGRAPHIC ANALYSIS AND RECONSTITUTION OF FATIGUE CRACK KINETICS

After fatigue experiments the broken parts of beams were cut and the fractographic analysis of fracture surfaces was carried out. The primary aim of the fractography was to obtain the information on initiation and propagation of fatigue cracks in the critical regions of the beam. Special care was given to hidden parts, inaccessible to direct visual observation during fatigue test.

In all four cases (see Table 1), the primary fatigue cracks initiated and propagated in the lower flange plate and web plate (see Fig. 2). In the case of specimens No. 1, 2 (design A) and No. 3 (design B), the fatigue cracks initiated on the fastener hole in the lower flange plate (see Fig. 2a). High nominal stress level in the lower flange plate and also stress concentration effect of the fastener hole turn this area into the critical point of the beam. Therefore the beam design was changed and the fastener hole was omitted (specimen No. 4 - see Fig. 2b). In this case (design C), the fatigue crack initiation was changed both from the quantitative and qualitative point of view : the crack initiated on fastener hole in the web plate (see Fig. 2b) and the initiation stage was substantially longer than on the former three specimens.

The fatigue cracks were propagating predominantly by the micromechanism of striation formation. In the primary period of fatigue crack propagation, each striation coresponds to one program cycle PC (see Fig. 3a). This striation was formed by the major cycle only, i.e. by transition from the minimum to the maximum load level (see Fig. 1). In these cases, six minor cycles in PC (with low load range) did not take part in the crack tip propagation. In the last period of the fatigue process, also the minor cycles participated in crack propagation; an example in detail is perceptible in Fig. 3b. A correlation between the program loading (Fig. 1) and the fracture micromorphology (Fig. 3b) is evident.

Fractographic reconstitution of the fatigue crack kinetics was based on the striation spacing measurements. An example of the results obtained is in Fig. 4. In the graph, the relation between striation spacing **s** and crack length **a** is presented for specimen No. 1. The measurements were carried out along lines A-B-C, A-D, E-F, G-H-J, and K-L (see the schematic drawing of beam cross-section in Fig. 4). Similar results were obtained by the quantitative fractographic analysis of fracture surfaces of specimens No. 2, 3 and 4.

The striation spacing data **s** were converted to macroscopic crack growth rates **v** by the procedure developed on the basis of experimental investigations carried out previously on simple specimens. This problem was disscused in detail by Nedbal et al (4). For the presented example of specimen No. 1, the result of the fractographic reconstitution (i.e., the crack growth rate **v**) is given in the same graph as the striation spacings - see Fig. 4. The same procedure was used for specimens No. 2, 3, and 4.

Further steps of the fractographic reconstitution of fatigue crack kinetics were described in detail elsewhere (1) - (3). Numerical integration of the **v** = **v(a)** dependence obtained by the above fractographic procedure enables to assess the crack propagation curve **a** = **a(N)**. For example, the results for specimen No. 1 are given in Fig. 5. It is clear that the most valuable contribution of the fractography is that it can determine fatigue crack kinetics in the hidden parts of the beam where no other quantitative information on crack growth is available. In accessible parts of beams, the visual monitoring of crack propagation was done directly during the fatigue test. In these parts it is possible to appreciate the reliability and accuracy of the results obtained fractographically. An example of confrontation of crack propagation curves obtained by quantitative fractography and by direct optical measurements is given in Fig. 5. In the graph, the last stage of individual fatigue crack propagation in the lower flange plate of specimen No. 1 is presented. Both data sets are in good agreement.

A detailed fractographic study of crack growth directions in various locations of fracture surface, added to the above reconstitution of fatigue crack kinetics, gives an objective basis for estimating the dependence of both the shape and the position changes of the crack front on the number of program cycles **N**. An example of the results is given in Fig. 6. Quantitative information of this type enables the transformation of the "classical" crack growth curve **a** = = **a(N)** into the two-dimensional description of fatigue crack kinetics in the form of **A** = **A(N)**, where **A** is the total area of the fractured beam cross section. The obtained dependence **A** = **A(N)** for all the four cases are presented in Fig. 7. The specimens (and consequently the designs) differ both by the crack initiation period length and by the crack kinetics. In the case of specimen No. 4 (i.e. design C), the longest period of crack initiation is a consequence of the fastener hole omitting in the critical region of the lower flange plate and the higher slope of dependence **A** = **A(N)** corresponds to the load range increase in the finals. The lower propagation rates of the cracks in specimen No. 2 were due to the repair : riveting the splice plate on to the beam.

CONCLUSION

A full-scale fatigue test of aircraft landing gear beams was carried out in ARTI, Prague, by the program loading simulating service conditions. The partial information on the crack propagation obtained by the direct optical measurements was completed by the quantitative fractography.

The fractographic reconstitution of fatigue crack kinetics was based on the striation spacing measurement. The problem of the relation between striation spacing and macroscopic crack growth rate was investigated in the previous laboratory experiments. The results were used to determine the dependence of the fatigue crack length in the landing gear beams on the number of applied program-loading cycles. By this way, also the approximation of initiation stage length can be obtained. The results of the fractographic reconstitution of fatigue crack kinetics were also presented in the more realistic, two-dimensional form, i.e. in the form of dependence of the total area of fractured cross section on the number of program-loading cycles. The results obtained offer reliable information about the influence of design changes and repairs on the durability of the tested aircraft components. The example presented shows how quantitative microfractography can provide a valuable tool for the experimental study of the fatigue process in complex structures.

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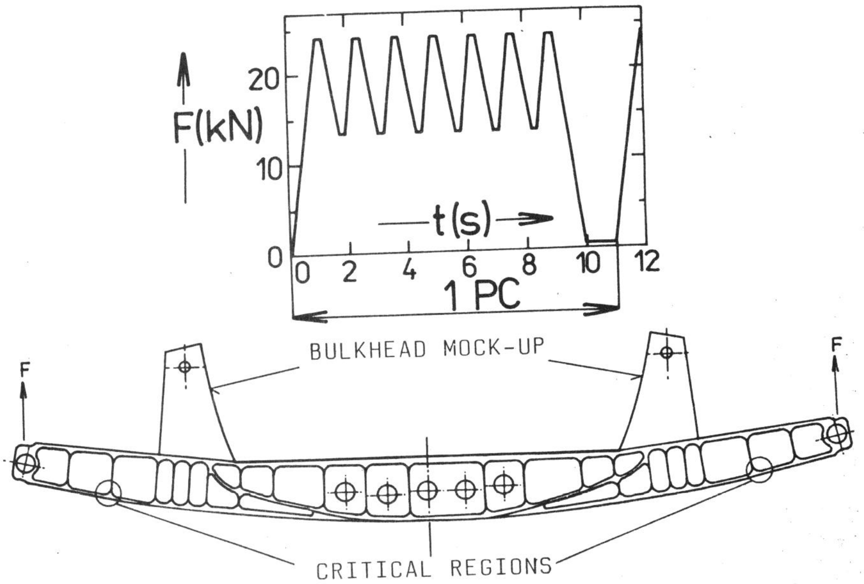


Figure 1 Parameters of loading program cycle (PC) and scheme of full-scale test of landing gear beam of transport aircraft

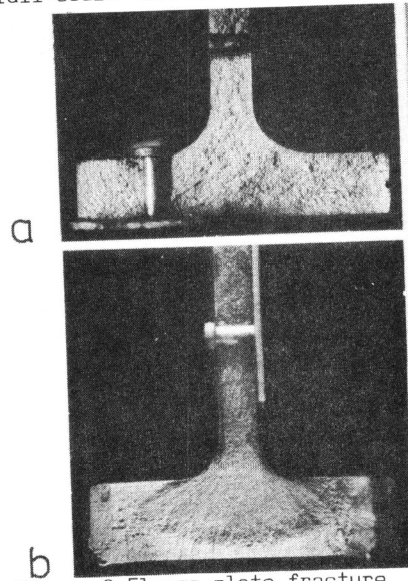


Figure 2 Flange plate fracture (a - design A,B; b - design C)

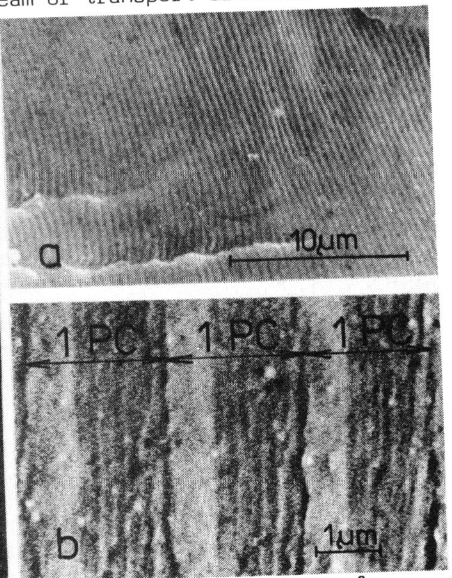


Figure 3 Micromorphology of fatigue fracture (a - low ΔK)

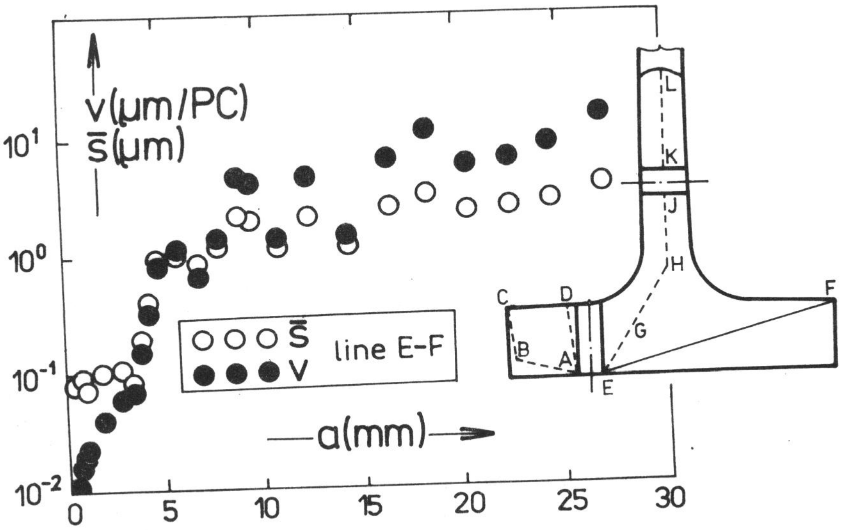


Figure 4 Striation spacing $\bar{s}$ and macroscopic crack growth rate **v** = D.$\bar{s}$ versus crack length **a** (specimen No. 1, along line E-F)

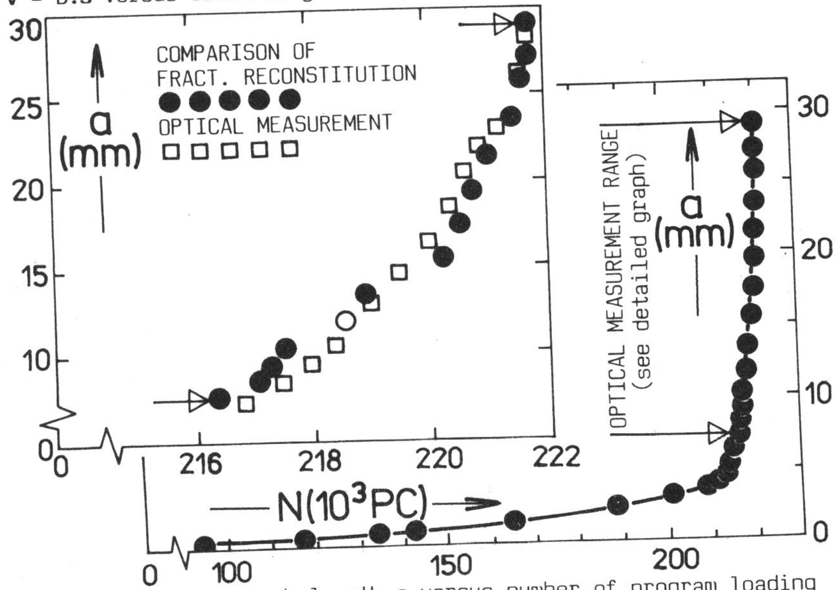
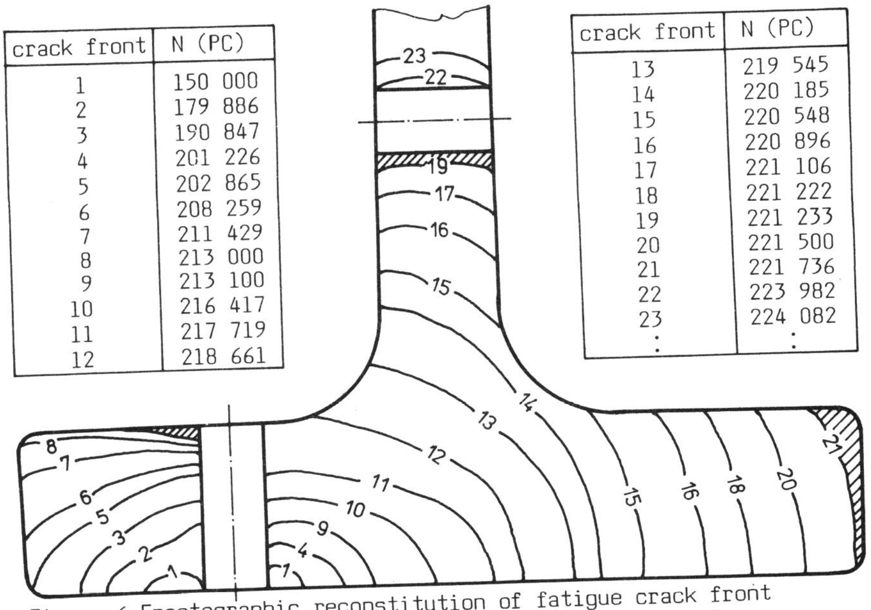


Figure 5 Fatigue crack length **a** versus number of program loading cycles **N** (specimen No. 1)



crack front	N (PC)
1	150 000
2	179 886
3	190 847
4	201 226
5	202 865
6	208 259
7	211 429
8	213 000
9	213 100
10	216 417
11	217 719
12	218 661

crack front	N (PC)
13	219 545
14	220 185
15	220 548
16	220 896
17	221 106
18	221 222
19	221 233
20	221 500
21	221 736
22	223 982
23	224 082
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Figure 6 Fractographic reconstitution of fatigue crack front evolution (specimen No. 1) - information base for Fig. 7

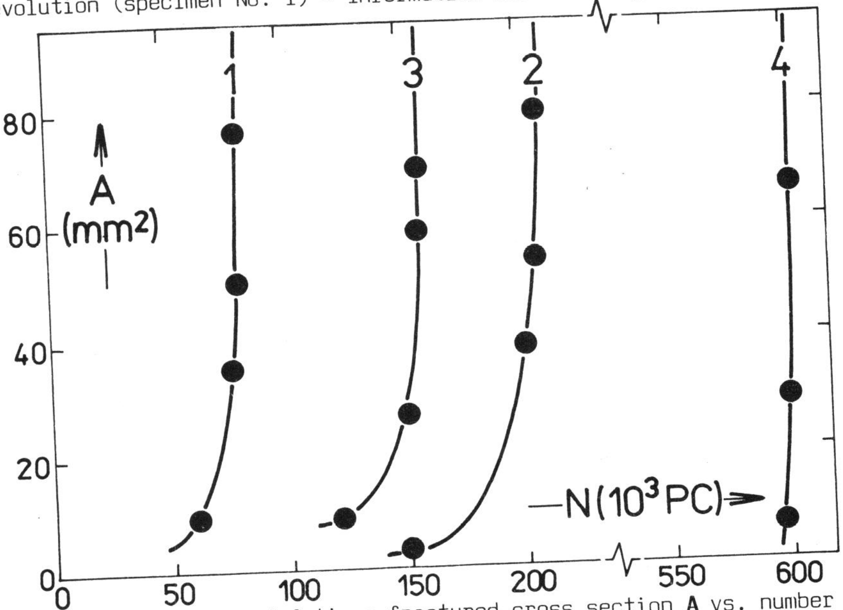

Figure 7 Total area of fatigue-fractured cross section **A** vs. number of program loading cycles **N** - comparison of 4 specimens under study