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CAN ACOUSTIC EMISSION DETECT THE INITIATION OF FATIGUE CRACKS?- APPLICATION TO HIGH-STRENGTH LIGHT ALLOYS USED IN AERONAUTICS

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16. Abstract

Acoustic emission has been used for the detection of fatigue cracking in a number of high-strength light alloys including A-U4G1 and A-U2GNT6, used in aeronautical structures. Among the features studied in the test samples were: the influence of emission frequency, the effect of surface oxidation, and the influence of grains. It is concluded that acoustic emission is an effective nondestructive technique for evaluating the initiation of fatigue cracking in such materials.

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CAN ACOUSTIC EMISSION DETECT THE INITIATION OF FATIGUE CRACKS? APPLICATION TO HIGH-STRENGTH LIGHT ALLOYS USED IN AERONAUTICS

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Introduction

The purpose of this study is the detection of the appearance /41* of flaws in aerodyne structures, especially cracking under cyclic stress, with the goal of ensuring safe flights. With this goal in mind, we have endeavored to perfect a simple overall method on test-bars, but which could be applied mutatis mutandis to actual structures.

We have worked to link acoustical emission to the state of damage of the test bars. In particular, we followed the initiation and formation of the first fatigue microfissures on the surface of the test bar by metallographic observation and related them to acoustical emission, taking into consideration that cracking occurs in three generally recognized stages: surface damage which leads to initiation - slow propagation (stage 1)- rapid propagation (stage 11) for which all plastic deformations are localized at the base of the crack.

Since acoustical emission is linked to the plastically deformed volume, one can expect increased acoustical activity when damage is localized on the surface, but when deformation is localized at the base of a macroscopic crack, acoustical activity should, in principle, be less. Between these two extreme stages, initiation and macroscopic propagation, a transitional period characterized by the presence of one or several microfissures can appear in various forms, thus leading to emissions which cannot be reproduced from one test to another.

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* Numbers in the margin indicate pagination in the foreign text.

Thus, we see a priori that acoustical emission is an adequate means of following the various phases of fatigue cracking. We attempted to detect the initiation phase in light alloys having different surface treatments and under stresses leading to different lifespans. We also examined the effects of frequency and the case of initiation at the root of a notch.

Mode of Operation /42

We used a detection circuit operating within a frequency range of 100 to 500 Hz and recorded, in terms of time, the rate of acoustical emission (number of impulses per base unit of time whose amplitude is greater than a fixed threshold of one volt). The fatigue tests were carried out, at a frequency of 10 Hz without exception, on a hydraulic machine controlled by a servovalve subjected to bending stress at three points of support, under loads leading to rupture between 20,000 and 1,000,000 cycles.

The chosen test-piece is a bend-test bar (150 x 50 x 20 mm) on which the initiation of the crack occurs on the face subjected to stress in tension, to the right of the central point of support. This facilitates observation during the tests.

Results

We studied two light alloys: one noted for its ductility, A-U4G1 T3, the other more fragile, A-U2GN T6.

The surface on which initiation occurs was first polished electrolytically, then underwent chromic anodic oxidation for deposits of 4 to 5 μm or sulfuric anodic oxidation for deposits greater than 10 μm.

Lastly, some test bars were shot-blasted with glass balls in 6 to 12 passes. The special case of initiation at the root of a notch was examined in order to locate the plastic deformation which then no longer appeared on the surface.

Materials Studied

Initiation on Electrolytically Polished Test Bars

In the test bars whose surface subjected to stress in tension is electrolytically polished, an acoustical emission curve characterized by an increased rate at the time of surface deformation, is observed at the stress frequency of 10 Hz and for a life of less than 100,000 cycles. Following this extensive activity, the formation of microfissures begins which leads to initiation (fig. 1). It seems that the initiation detected by acoustical emission generally corresponds to the transition between stage 1, when it exists, and stage 11 of fatigue cracking. The rate of emission during stage 11 is always quite less than the rates of emission during the phase preceding initiation.

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Effect of Frequency

During the tests carried out at 0.1 - 10 and 30 Hz, we revealed that the shape of the acoustical emission curves was not modified, but that on the other hand, all else being equal, the rate increased at the same time as the frequency, it being understood in this case that the rate is related to the number of cycles and not to time.

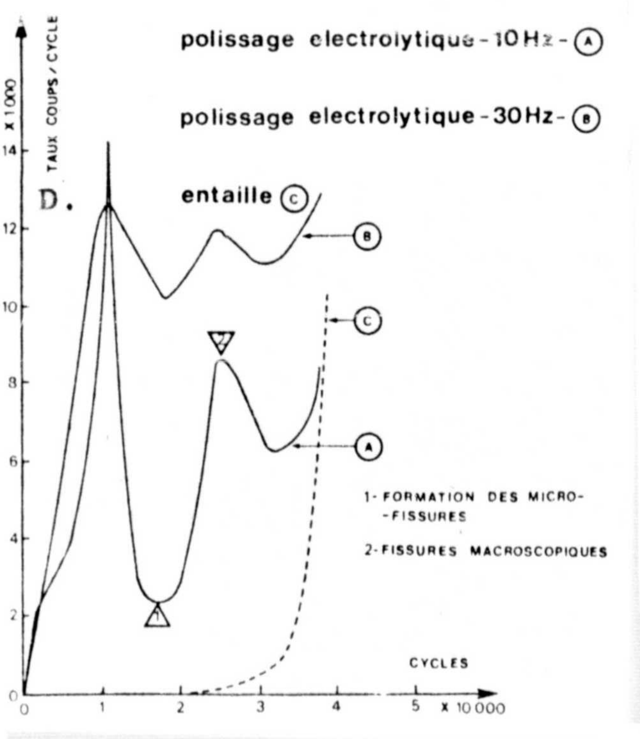

Fig. 1
Key: 1. Formation of microfissures, 2. Macroscopic fissures, A. Electrolytic polishing, B. See A, C. Notch, D. Blows/Cycle ratio

Effect of Lifespan

With the electrolytically polished test bars, the rate of acoustical emission decreases with the increases in lifespan. We observed the spread of this phenomenon, and for approximately 1,000,000 cycles before rupture, the detection threshold which we set is too high to be able to record under suitable conditions.

Initiation at the Root of the Notch

The special case of initiation at the root of the notch seemed of interest to us, on the one hand, because it occurs frequently in practice, and on the other hand, because plastic surface deformation does not occur.

TABLE 1 - A-U4G1 TEST BARS

N°	R	σ max $\sim$	Nb cycles rupture Nr	F Hz	$\frac{No}{Nr}$	$\frac{N'o}{Nr}$	Observations
G 12	0,1	540	59 000	10	0,360		
G 7	0,1	450	82 000	10	0,325		1. Eprouvettes polies
G 5	0,1	450	101 500	10	0,280		
G 1	0,1	270	326 820	10	0,170		
G 2E	0,1	200	9 120	10	$\simeq$ 0		
G 3E	0,1	100	1 453 000	10	$\simeq$ 0		
G 4E	0,1	150	37 370	10	$\simeq$ 0		2. Eprouvettes entaillées
G 5E	0,1	125	66 530	10	$\simeq$ 0		
G 6E	0,1	190	12 000	10	$\simeq$ 0		
G 7E	0,1	110	669 590	10	$\simeq$ 0		
G 8E	0,1	120	196 500	10	$\simeq$ 0		
G 10A	0,1	540	23 960	10	0,11		OAC 4 µm
G 20A	0,1	450	46 000	10	0,18		OAC 3,5 µm
G 30A	0,1	290	233 900	10	0,11		OAC 4,5 µm
G 50A	0,1	270	458 540	10	0,26		OAC 3,5 µm
G 70A	0,1	350	146 480	10	0,10		OAC 3 µm
G1 OAS	0,1	350	103 270	10	0,09		
G2 OAS	0,1	540	29 000	10	0,44		OAS 13 à 14 µm
G3 OAS	0,1	350	104 070	10	0,62		
1 AG6	0,1	540	31 640	10	0,17	0,17	
2 AG6	0,1	400	184 380	10	0,39	0,12	3. Eprouvettes grenaillées 6 passes
3 AG6	0,1	400	109 000	10	0,27	0,09	
4 AG6	0,1	540	41 400	10	0,19	0,19	
6 AG6	0,1	375	307 700	10	0,88	0,01	
1 AG12	0,1	540	40 800	10	0,09	0,09	
2 AG12	0,1	400	215 590	10	0,14	0,14	4. Eprouvettes grenaillées 12 passes
3 AG12	0,1	400	543 900	10	0,20	0,04	
4 AG12	0,1	540	42 000	10	0,11	0,11	
5 AG12	0,1	375	712 200	10	0,40	0,03	
6 AG12	0,1	375	1 098 450	10	0,75	0,02	

Key: 1. Polished test bars, 2. Notched test bars, 3. Shot-blasted test bars, 6 passes, 4. Shot blasted test bars, 12 passes

The fatigue tests were performed on notched bend-test bars, /44 the root radius of the notch being 0.02 mm. For a notch of this sharpness and for no matter what lifespan between 10,000 and 1,000,000 cycles before rupture, we no longer observe the acoustical emission which we attributed to surface deformation. In general, the rate of emission increases regularly until rupture of the test piece without considerable irregularities. Thus, we assume that initiation, as we understand it, is reduced in the very first cycles and that cracking begins at the start of the test.

Effect of Anodic Oxidation

The effect of anodic oxidation was studied on completely oxidized test pieces. At the beginning of the test, we observed a typical appearance of the acoustical emission curve represented in figure 2 which allows a number of cycles before initiation to be revealed (See Table 1). During the entire period preceding initiation, the variations of emission rates are numerous but of small amplitude.

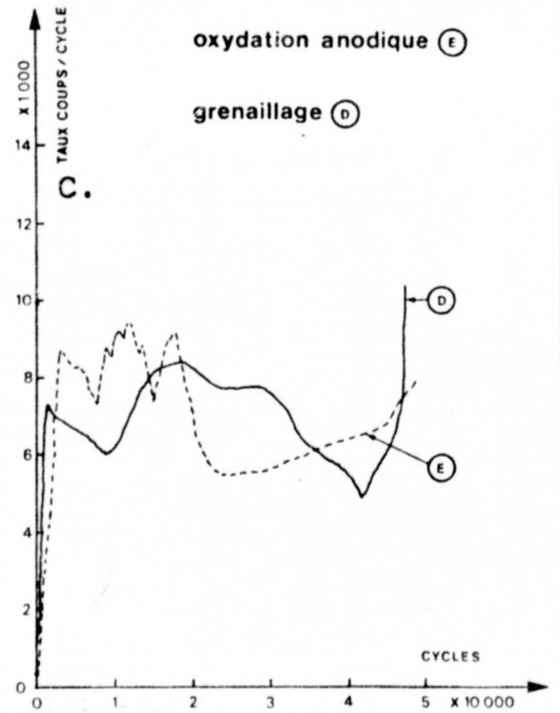

Fig. 2
Key: C. Blows/Cycle Ratio, D. Shot-Blasting, E. Anodic Oxidation

Effect of Shot-Blasting

The acoustical emission curve recorded from the shot-blasted test bars is very different from the one obtained previously, At the beginning of the test, we observe a quite sizeable acoustical emission peak, then a period of less intense activity which decreases and then increases once again, thus allowing a minimum to determined. We feel that this minimum characterizes initiation of the crack. The first peak observed seems related essentially to the cyclic peening of the shot-blasted surface layer. This number of cycles is indicated in the table by the letter N'o whereas the number of cycles before initiation is indicated by No. In the same table, we can see that the number of cycles before initiation can reach nearly 90% of the number of cycles before rupture.

Discussion

By means of micrographic examination methods on sections, we could verify that the acoustical emission gave information on the development of fatigue damage. In particular, we could reveal the appearance of microfissures within the grains which other nondestructive test methods are not able to reveal (1).

In order to obtain several types of fatigue damage, we modified the mechanical parameters of the test and the metallurgical state of the surface. In each case, we obtained a characteristic profile of the rate of acoustical emission which we related point by point to the damaging of the material, by stopping the tests during the process of fatigue. The metallographic observations allowed us to associate the development of damage to the rate of acoustical emission, and we feel that this nondestructive means of control, under the indicated conditions, allows the initiation of cracks in test pieces to be detected, despite the usual propagation in fatigue tests. Some previous results led to the same conclusions. (2) - (3).

The results show that the rate of acoustical emission is particularly high in the phase where there is generalized deformation of the surface and even more so when deformation is great, the speed of deformation is high, and the elasticity of the material is great.

Under cyclic stress, we find the effect of the same parameters as under monotone stress: mobility of dislocations, plastically deformed volume, speed of deformation. The studies which we have carried out on the shot-blasted and anodically oxidized test pieces confirm that the life span in fatigue is increased by shot-blasting and decreased by anodic oxidation. Thanks to acoustical emission, we will show that initiation, in other words the beginning of stage 11, occurs later when there is shot-blasting. We have seen above that the profile of acoustical emission is clearly different in these two cases.

Up until now, acoustical emission has only been implemented /45
to follow the development of fatigue cracks, to foresee rupture, and to locate flaws in test pieces and structures. This study, carried out at the Central Laboratory of Aérospatiale, shows that acoustical emission can also be used as a discriminating method for following fatigue damage up until the initiation of cracks. Other nondestructive test methods do not seem to be able to provide as much information.

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