An Investigation on the Cumulative Law of Damage

Ouyang Ping
Department of Mechanics, Huazhong University of Science and Technology, Wuhan, Hubie, The People's Republic of China

Abstract--The damage of material is essentially manifested as microcracks and microcavities. The irreversible process of damage cumulation is the process of nucleation and propagation of microcracks and microcavities, which are plastic deformation. The optical correlativity/1/,/2/ of the material surface steadily decreases with the development of the microplastic deformation. This is the basis on which the method of laser speckle spectrum correlation is built. The method is applied to an analysis of the process of damage growth and we have come to the conclusion that the cumulation law of damage for steel and aluminum alloys cannot be expressed linearly. In fact, there are different damage rates in the whole process, which consists of three stages.

The evaluation of damage is a process of assessing the initiation and development of microcracks and microcavities. As the process results in a change in micro-topography of the surface, the diffraction characteristics of the surface are varied, decreasing the optical correlation intensity. This is the basis on which the method of laser speckle spectrum correlation is built. Under the condition of cyclic loading, almost all damages occur at first on the surface of the structure, and one can predict the damage as well as the macrocracks by using the optical correlation method.

The damage measuring scheme is shown in Fig. 1. The specimen used is a cold roll steel plate, which is stimulated to vibration with electric-magnetic force. In Fig. 2, the uniformised curves representing the relationship between the cross correlation intensity signal S and the cyclic number N are given. The vertical axis represents signal S, the horizontal axis represents cyclic number N or time in minutes. The microstrain $\Delta\epsilon$ = 1500 in curve 1 and in curve 2 $\Delta\epsilon$ =2000. Since the stimulating force is not symmetric, the amplitudes of stretching strain and compression strain are not equal to each other. The given strain amplitude in Fig. 2 is compressive strain. At first, there is a small slope of curve 1 which changes linearly in the case of small strain amplitude. The damage is accumulated slowly at this stage. At 1.8×10^6 cyclic number, the velocity of losing of the optical correlation of the specimen surface increases. But the cracks cannot be observed with a microscope (900x). When the $N = 1.9 \times 10^6$, that is the beginning of the last stage, the value of S decreases steeply. The cracks in the size of less than 0.1 mm can be recognized with a microscope (Fig. 3). Then the cracks spread very rapidly and the value of S decreases fast to 0.1. Macrocracks appear and can be recognized by unaided eye (Fig. 4). Between the first and last stages, there is a transition section which includes only 1.3×10^5 cyclic numbers. A lot of S--N curves have the same tendency as those in Fig. 2. From the description we know that the process of damage cumulation consists of three stages. At the first stage, the damage increases linearly, slowly and steadily with respect to the run time. During the second stage, which is called the transition stage, the damage rate increases step by step and the initiation and growth of microcracks can be observed with a microscope. The final stage sees the damage steeply increasing with an approximate constant rate. The slope variation of the transition section of curve can be used to measure the damage evolution and to predict the appearance of cracks. Because of the fluctuation of laser intensity the values of S fluctuates. For large strain, there is no stage in which the slope of curve varies slowly and steadily. From the beginning of the S--N curve the values of S decrease steeply, which means that the damage evolves very rapidly, and the specimen has only a short life of about 35 minutes.

In Fig. 5, there is a waveform photograph of signal S taken from the cathodogram. The pulse amplitude which piles on the sinusoidal wave represents the value of signal S. During $N=0$, the value of S is maximum, i.e., $S=1$. The pulse amplitude decreases with the increase of cyclic number N and disappears at last. The sinusoidal wave caused by the specimen vibration expresses the variation of the incident and reflect angle of laser beam light on the specimen surface.

The Method of Speckle Spectrum Correlation

The scheme on speckle spectrum correlation is shown in Fig. 1, in which L--the incident laser beam, O--the specimen, L_1--Fourier transform lens, P--record plate, L_2--lens for the light convergence, P.D.--photoelectric detector. The specimen O is illuminated by parallel laser beam. On the back focus plane of Fourier transform lens L_1 a speckle spectrum pattern is obtained.

$$F\{O(x_o,y_o)\} = C\iint O_o(x_o,y_o)\exp\left[-i2\pi(f_x x_o+f_y y_o)\right] dx_o dy_o \qquad (1)$$

where C is a constant factor and can be neglected in the following calculation. The configuration of the speckle spectrum intensity recorded on the plate is

$$I_o(x,y) = F\{O_o(x_o,y_o)\}\cdot F^*\{O_o(x_o,y_o)\} . \qquad (2)$$

When the specimen is being loaded, the changed pattern is

$$I_t(x,y) = F\left|O_t(x_o,y_o)\right|^2 \qquad (3)$$

If the speckle spectrum pattern I_o is used as a space filter, the space filtration can be finished through the transform lens.

$$I_o\cdot I_t = \left|F\{O_o\}\cdot F^*\{O_t\}\right|^2 \qquad (4)$$

and

$$I_o\cdot I_t = \left|F\{O_o * O_t\}\right|^2 \qquad (5)$$

where the symbol $*$ represents the cross correlation calculation. Except for the signal of D.C., the variation signal is obtained in the photo-electric detector.

$$S = \iint\left|F\{O_o * O_t\}\right|^2 dx_o dy_o \qquad (6)$$

According to the Parceval Law, we have

$$S = \iint \left|O_o * O_t\right|^2 dx_o dy_o \qquad (7)$$

If O_t is equal to O_o, the value of S is maximum. The value of S will continue to decrease as O_t becomes more and more different from O_o until finally $S=0$.

Conclusion

In general, the process of damage cumulation consists of three stages in small strain amplitude. Specimens with different surface conditions such as rolled, sanded and polished surface obey this damage evolution law alike. The speckle spectrum correlation method is sensitive to the surface deformation caused by whatever factors. Since it is insensitive to specimen translation, it is not necessary to strictly isolate the specimen from environmental vibration and it can be used to monitor the damage evolution of engineering structures and predict the initiation and growth of cracks, thus making it possible to avoid disastrous failures.

References

/1/ Narom, E., "Fatigue Detection Using Holographic Technique", The Engineering Uses of Holography, pp. 237-247, 1970.
/2/ Groh, G., "Engineering Uses of Laser-Produced Speckle Patterns", the Engineering Uses of Holography, pp. 483-494, 1970.

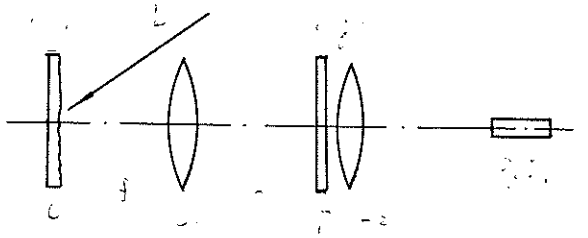

Fig. 1. The Scheme on damage measuring.

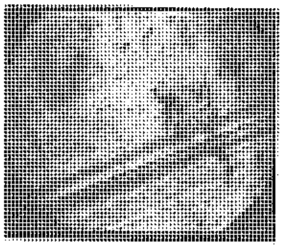

Fig. 3. The cracks in the size of less than 0.1 mm.

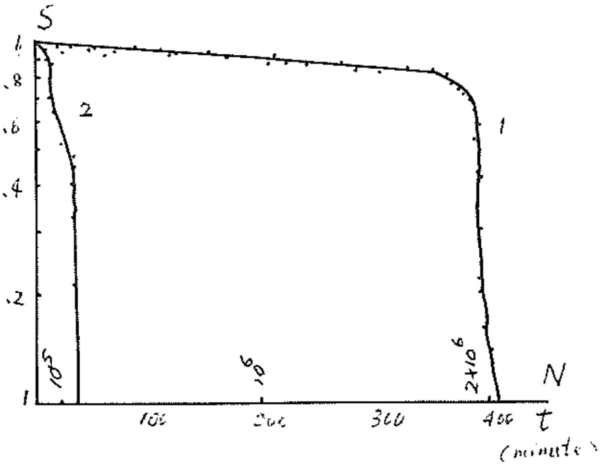

Fig. 2. S-N curves.

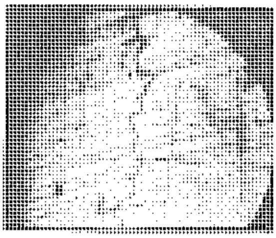

Fig. 4. Photograph

of macrocrack.

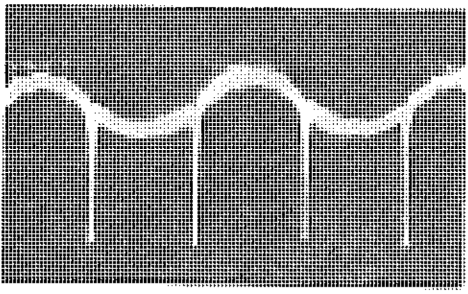

Fig. 5. Waveform photograph of signal S.