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Fatigue Crack Propgation of Induction-hardened Steel Specimen

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It has been known that the fatigue strength of steel specimens strikingly rises up by treating the induction-hardening on them which is broadly utilized as effective means for the improvement on fatigue strength of the axle of rolling stock and of many other machine parts.

Concerning the cause of such an improvement on the strength of steel due to induction-hardening, many subjects remain unresolved.

However, up to the present it has been pointed out that the remarkable uprise of the fatigue strength due to induction-hardening can be attributed to

(1) a change in the structure of steel associated with quenching after rapid heating.

(2) the existence of the macro compressive residual stress at the surface layer of the specimen.

The author appreciated the importance of studying the latter effect, that is, the effect of residual compressive stress upon fatigue strength.

For the purpose of studying the effect of residual stress on fatigue strength, firstly the experiment for the investigation on the characteristic of macro crack growth was performed which seems to be closly related to the residual stress.

Based on the experimental results obtained, it was discussed at what stage of fatigue processs the residual compressive stress plays a dominant role, and what interpretation can be given to the effect of residual compressive stress upon fatigue behavior.

Experimental results concerning the behavior of macro crack in the induction-hardened notched specimens of low carbon steel may be summarized as follows:

1) The macro crack appears at very early stage of the fatigue process and almost all part of the fatigue life is actually occupied by the growth process of the macro crack.

2) There exists a characteristic of the behavior of macro crack growth, peculiar to induction hardened specimen that the rate of macro crack growth decreases rapidly as the crack grows.

Next, in order to study the above quantitatively, the author discussed about the stress at the crack tip due to the loading where a sufficiently large residual com-

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pressive stress exists at the notch root and at the crack tip, and deduced that in such a case the stress at the crack tip is equal to the stress at the same point of the specimen before crack forms, in other words the residual compressive stress acts so as to prevent the crack from opening, thus the stress concentration does not occur at the crack tip.

Such an evaluated stress was named "effective stress at the crack tip," with which the characteristic of macro crack growth, previously mentioned, can be interpreted very clearly.

Also a new concept concerning consecutive crack development was proposed, which can predict the theoretical crack depth which agreed well with the experimental data.

Furthermore, the relation between the new law of crack propagation proposed by the author and that by other investigators, was discussed and it was confirmed that the former is not contradictory to the latter.

Then, for the purpose of examining the adequacy of several assumptions involved in the proposed concept, the auther conducted the following two series of experiments.

(1) How does the crack behave when the residual compressive stress is relieved?

(2) How does the crack behave when the axial compressive stress which can be regarded as the residual compressive stress is exerted on the notched specimen, previously relieved from the residual stress?

Judging from the results of those experiments, the author concluded that the residual compressive stress has the remarkable effect of preventing the crack from propagation.

In addition, the author studied the behavior of fatigue crack under the multiple repeated stress. As a result it became obvious that the change in stress amplitude gives a complicated effect to the behavior of crack, in other words the behavior of crack depends upon its pre-loaded condition.

Consequently, the basic assumptions of the Miner's cumulative damage law that the fatigue damage increases linearly with stress cycles and that it can be superposed with each other, may not be allowed at least during the crack propagation period, while they seem to be allowed at the stage of the initation of crack.

From these results, it was pointed out that the Miner's law is not applicable to the fatigue behavior of induction-hardened material.

Finally, the author's description turned on the subject of strength-design of machine parts, taking into consideration of the fatigue crack propagation.