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Effect of orientation of small defects on fatigue limit of steels

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Abstract. In order to clarify the effect of defect orientation on the fatigue limit of three types of steels; JIS-S15C, JIS-S45C and JIS-SNCM439, a small semi-circular slit was introduced into the surface of a round specimen. The slits were tilted at 0°, 30° or 60° with respect to the plane normal to the loading axis, but all of them had the same defect size, $\sqrt{area} = 188\,\mu$m, where the *area* denotes the area of the domain defined by projecting the defect on a plane normal to the loading axis. In all the combinations of the materials and tilting angles, a non-propagating crack was found at the fatigue limit, *i.e*. the fatigue limit was determined by the non-propagation condition of crack initiated from the defect. In JIS-S15C and JIS-S45C, the fatigue limit was nearly independent of the tilting angle, which was in good agreement with the predicted value by the $\sqrt{area}$ parameter model. On the other hand, in JIS-SNCM439, the fatigue limit was also in agreement with the prediction at the tilting angle of 0°, but it increased with an increase in the tilting angle. These results indicated that the $\sqrt{area}$ parameter model can predict a conservative fatigue limit for the tilted defects. In this paper, the mechanistic reason for the effect of the tilting angle on the fatigue limit will be discussed by paying special attention to the crack path and length of non-propagating crack.

1. Experimental

This study used three types of steels; JIS-S15C, JIS-S45C and JIS-SNCM439. The average Vickers hardness *HV* of each material measured with a load of 9.8 N was 117, 186 and 293, respectively. A semi-circular slit or hole was introduced into the round specimen with a diameter of 7 mm by electro-discharge machining or drilling. The slits were tilted at 0° 30° or 60° with respect to the plane normal to the loading axis, but all of them had the same defect size, $\sqrt{area} = 188\,\mu$m, where the *area* denotes the area of the domain defined by projecting the defect on a plane normal to the loading axis. Figure 1 details the shapes and dimensions of the small defects. Fully reversed tension-compression fatigue tests were carried out at a test frequency of 150 Hz. The tests were periodically halted to observe the crack by the plastic replica method. The fatigue limit σ_{FL} was determined as a stress amplitude at which the specimen does not fail until 1×10^7 cycles.

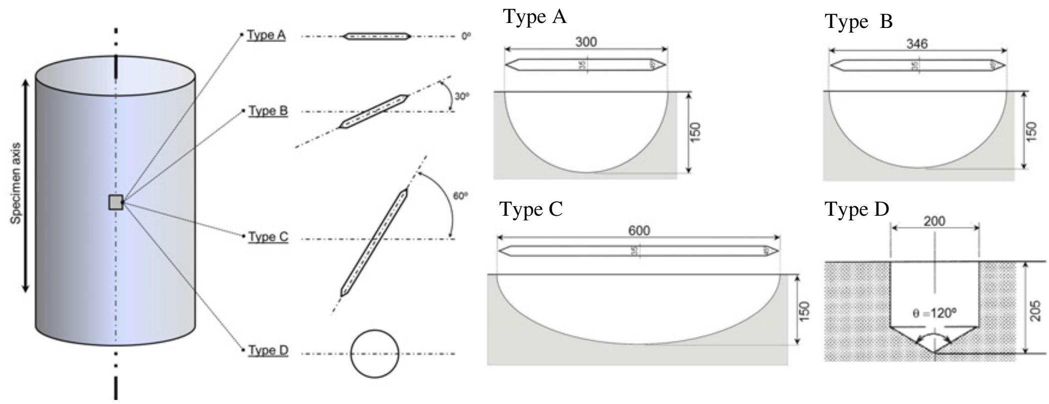

Figure 1. Geometries and orientations of artificial defects.

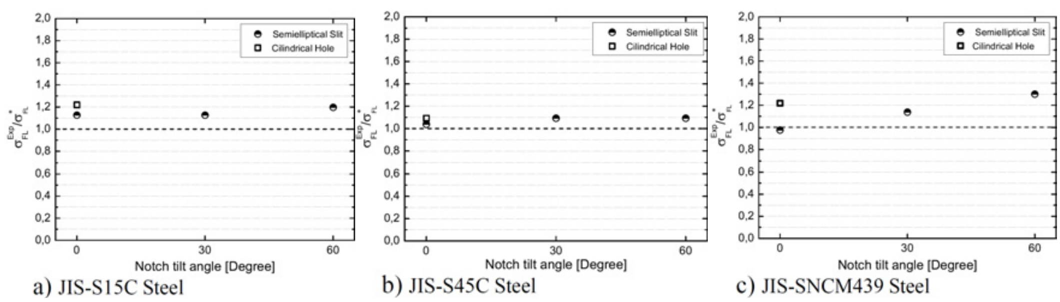

Figure 2. Fatigue limit as a function of the tilting angle of defect for three types of steel.

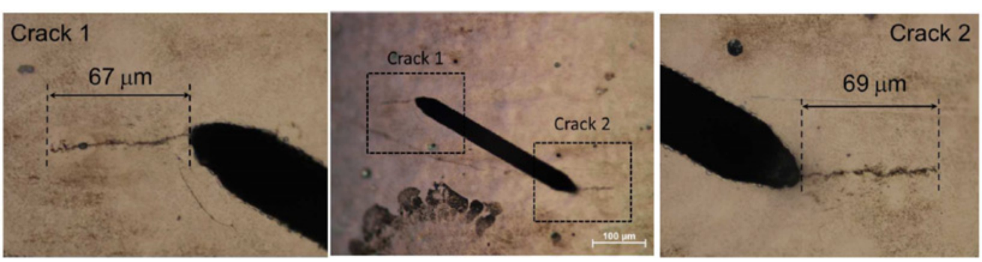

Figure 3. Non-propagating cracks found at the fatigue limit (JIS-SNCM439, Defect type B, $\sigma_{\mathrm{FL}}^{\mathrm{exp}} = 260$ MPa).

2. Results

2.1 Fatigue limit

Figure 2 shows the $\sigma_{\mathrm{FL}}^{\mathrm{exp}}/\sigma_{\mathrm{FL}}^{*}$ as a function of tilting angle, where $\sigma_{\mathrm{FL}}^{\mathrm{exp}}$ is the experimentally found fatigue limit and σ_{FL}^{*} is the predicted fatigue limit using the $\sqrt{area}$ parameter model. In JIS-S15C and JIS-S45C, the fatigue limits were nearly independent of the tilting angle, which were in good agreement with the predicted values by the $\sqrt{area}$ parameter model. On the other hand, in JIS-SNCM439, fatigue limit was also in agreement with the prediction at the tilting angle of 0°, but it increased with an increase in the tilting angle.

2.2 Non-propagating cracks

Non-propagating cracks were found at the fatigue limit for all the combination of steel types and defect orientations. Figure 3 shows an example of the non-propagating crack. These cracks started at a very early stage of the fatigue tests and gradually diminished the growth rate until the complete arrest.

The followings were clarified with respect to the non-propagating cracks:

(1) The length varied greatly according to the steel types, *i.e.* longer non-propagating crack was observed in softer steel.

(2) The length was independent of the tilting angle in the case of JIS-S15C and JIS-S45C, whereas in the case of JIS-SNCM439, the length increased with an increase in the tilting angle.

(3) The crack path was in good agreement with the direction normal to the maximum principle stress near the defect.