材料内部欠陥形成機構の解明と非破壊検出法の開発

研究代表者　理工学研究部(工学)　塩澤　和章

In recent years, interest of the topics about the gigacycle fatigue behaviour of metals is increasing, because of a requirement for high efficiency and reliability for machines and structures, a long-term employment of facilities beyond their original design lifetimes in advance due to the difficulty of their replacements, such as ageing facilities that have exceeded 10^8 cycles, and also the need of lightweight components used the high strength materials for reduction of the environmental loads to the globe. Numerious studies were reported on the gigacycle fatigue properties of high strength steels. The most important result of these studies is that steels fail below the conventional fatigue limit in the long life regime above 10^7 loading cycles and crack initiation site changes from the specimen surface to the interior of the specimen, forming so-called internal fish-eye. Nonmetallic inclusion is usually observed in the center of the fish-eye acting as crack nucleation site. Due to the change in crack initiation site, 'duplex' or step-wise *S-N* curve was usually exhibited in the rotating bending tests. On the fracture surface resulting from subsurface crack initiation and propagation in a gigacycle cycle fatigue regime, a distinctive feature is observed in the vicinity of a nonmetallic inclusion at the fracture origin inside the fish-eye zone. This area was named as the granular-bright facet (GBF) by the authors [1,2], and it was pointed out that the formation of the GBF area during the long fatigue process controls the internal failure mode and is an important factor clarifying fatigue behavior in a very high cycle fatigue regime, and ensuring the long durability of machine components and structures. A mechanism for the formation of the GBF area occurred during the high-cycle fatigue process was clearly proposed by the authors as 'dispersive decohesion of spherical carbide' model, based on the experimental results and the computational simulation of the fracture process [3].

From the detailed observation of the fracture surface, three types of failure mode are usually observed, such as, surface-induced failure (S-mode), internal-induced failure without the GBF area (I-mode) and that with GBF area (IG-mode) depending on the stress amplitude level and lifetime [4]. It is an interesting practical problem how to and when a failure mode changes in the long fatigue life regime. In this paper, in order to discuss the transition of fatigue failure mode from surface to interior in high speed tool steel, a cantilever-type rotary bending fatigue test operated at a frequency of 52Hz was carried out in an open environment at room temperature using hourglass-shaped specimens. Based on experimental results, the shape of *S-N* curve and the transition of the failure mode were discussed from point of view

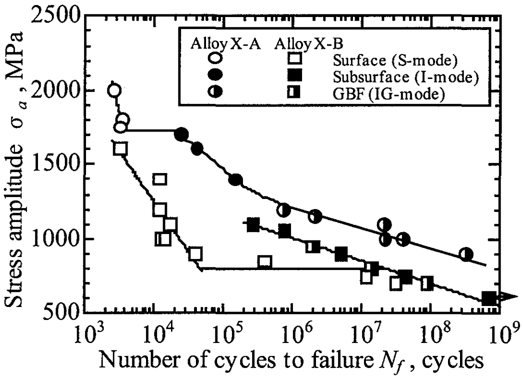

Fig. 1 *S-N* curves obtained by a cantilever-type rotary bending fatigue test.

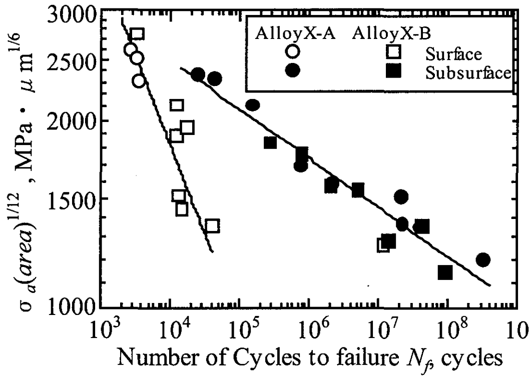

Fig. 2 Effect of inclusion size at crack origin on the *S-N* curve.

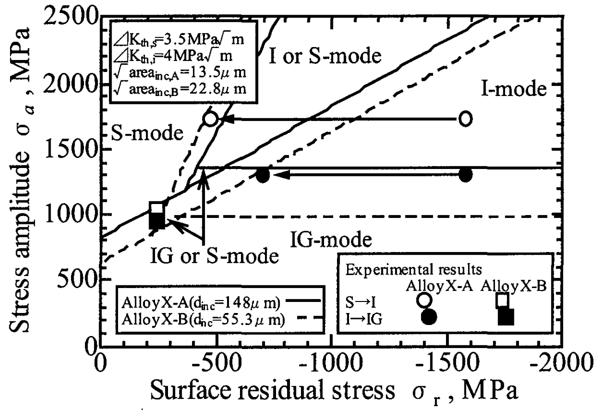

Fig. 3 Map of the change in failure mode affected by compressive residual stress on surface layer.

about an effect of nonmetallic inclusion size and residual stress on the specimen surface layer.

Fig. 1 shows the *S*-*N* curve obtained from two kinds of specimen, which was processed by different method. One specimen, named AlloyX-A, was processed with a cutting tool and compressive residual stress of about 1575MPa was measured on the specimen surface by X-ray diffraction method. The other named AlloyX-B was processed with a grinder having a mesh of #100 and the compressive residual stress was about 215MPa. Stress amplitude changing the failure mode from S-mode to I-mode and from I-mode to IG-mode is different between specimens because of the effect of residual stress on the specimen surface. Fatigue strength of the AlloyX-A specimen failed by the I-mode and IG-mode is higher than that of the AlloyX-B. This difference is caused by the variation of a nonmetallic inclusion size at internal crack origin. The effect of the inclusion size, $(area)^{1/2}$, was explained by the relationship between $\sigma_a(area)^{1/12}$ and fatigue life, N_f, as shown in Fig. 2.

Transition of the failure modes depending applied stress amplitude was discussed based on the fracture mechanics and consideration of compressive residual stress. A map relating the stress amplitude with the residual stress as shown in Fig. 3, was divided into five zones for three failure modes, due to competing between surface crack growth rate and subsurface one. Experimental results plotted in this figure were fairly good agreement with the calculated result, with considering the relaxation of residual stress on the specimen surface during fatigue process.

References

[1] K. Shiozawa, and L. Lu, Internal fatigue failure mechanism of high strength steels in gigacycle regime, Key Engineering Materials, **378-379**, pp.65-80, 2008.

[2] K. Shiozawa and L. Lu, Very high-cycle fatigue behavior of shot-peened high carbon-chromium bearing steel, *Fatigue Frac. Eng. Mater. Struct.*, **25**, 813-822, 2002.

[3] K. Shiozawa, Y. Morii, S. Nishino and L. Lu, Subsurface crack initiation and propagation mechanism in high-strength steel in a very high cycle fatigue regime, *Int. Jour. Fatigue*, **28**, 1520-1532, 2006.

[4] K. Shiozawa and L. Lu, Effect of mon-metallic inclusion size and residual stresses on gigacycle fatigue properties in high strength steel, Advanced Materials Research, **44-46**, pp.33-42, 2008.