An Effect of Prior Austenite Grains on the Fatigue Strength of Martensitic Structure

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INTRODUCTION Too many complicated parameters in the microstructure of the high hardened or high strength steel have made the interpretation of its fatigue behavior more difficult.(1) Most of the works in this field have discussed mainly on the reduction of fatigue strength from the viewpoint of notch effect due to the non-metallic inclusion.(2) It is most essential that the fatigue behavior of the matrix of martensitic structure should be investigated. In this paper, the relationship between the fatigue strength and low carbon martensitic structure was studied with special interests of the Prior Austenite Grain (PAG) size as well as Austenite grain boundary. In particular, the role of PAG on the fatigue strength was studied in comparison with the ordinary grains of the annealed metals.

EXPERIMENTALS AND DISCUSSIONS The annealed specimens of 0.17% carbon steel (Fig.1) were induction-hardened. By changing the time required to reach the maximum temperatures as tabulated in Table 1, five kinds of specimens having PAG size of 25 to 250μ were obtained as seen in Fig.2, and they were used in experiments without any further heat-treatment after being bored out to release macroscopic residual stresses due to heat-treatment. It was found from random micro Vickers indentations (100g) of more than 100 points to each specimen that all of them have equal hardness of H_v=450 as the mean value. Thus, it is considered that the effects of PAG alone upon the fatigue behavior could be studied. In Table 1, the condition of induction-hardening, mean hardness and fatigue limit of each specimen are tabulated. Fatigue experiments were performed by means of rotating bending and reversed torsion types under the stress cycles of 3000 cpm. Fig.3 shows the relationship between the fatigue limit for rotating bending and PAG size. As recognized from this figure, the fatigue limit would not show the simple tendency of so-called Hall-Petch relation,(3) but has the maximum value at the optimum grain size. It might be inferred that the invalidity of Hall-Petch relation comes from the fact that PAG boundary does not behave as barriers to slip and crack propagation, as the grain boundary in the annealed metal does.(4) Several reports(5),(6) have been published in which the role of PAG on the fatigue behavior is discussed, but the PAG size dependence upon fatigue process has not been made clear.

In the followings, the microstructural observations during fatigue process will be stated with respect of Austenite grains. Fig.4 gives a scanning electron micrograph of micro-fatigue crack recognized in martensitic plates within the microstructure having PAG size d=250μ under N=1x10^4 and σ=80 kg/mm^2 for rotating bending. Such a microcrack appeared in the structure in which the grain is more coarse than the optimum grain size, while it would not appear in the structure having finer grain size. On the other hand, the crack along the grain boundary were found irrespective of PAG size in the structure. Fig. 5 is an electron micrograph showing the microcrack along PAG boundary in the structure having d=25μ under N =1x10^4, σ=54 kg/mm^2 for the rotating bending. Thus, it turned out that only the boundary crack appears in fine structure, while the mixed mode does in coarse structure. Further observations revealed that both cracking are of shear mode as illustrated in Fig.6 for the reversed torsion, and also that the transcrystalline crack is significant along martensitic plates in the

maximum shear stress direction. Details of the grain boundary cracking have been already reported by authors'.(7) The final fracture should occur by coalescences of two kinds of cracks for coarse grain structure and of only grain boundary cracks for fine structure as seen in Fig.7.

COCLUSION It was concluded from the above discussions that PAG boundary does not behave as the grain boundary in Hall-Petch's type strengthening mechanism as recognized for the annealed metals. PAG has very complicated roles on the fatigue behavior from the viewpoints of the followings, that is; PAG size will give the restrictions to the dimension and configuration of martensitic plates at their nucleation, and PAG boundary itself will be a favorable site for the formation of fatigue cracks.

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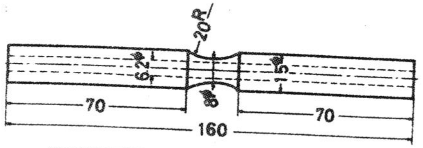

Fig. 1 Geometry of specimen

Specimen series symbol	Chemical composition (%)	Rapidly heat treatment condition		Grain size No. (ASTM)	Average grain diameter (mm)	Hv (mean) (100g)	Fatigue limit σ_{wo} (Kg/mm^2)	Stress concentration factor
A	C : 0.17 Mn: 0.56 Si : 0.20 S : 0.021 P : 0.016	1300°C 60sec		1	0.25	470	42	1.07
B		1150°C	60sec	3.5	0.10	470	60	
C			30sec	5	0.065	433	60	
D			10 sec	6	0.040	440	48	
E		900°C 10sec repeated:3		7.5	0.025	410	38	

Table 1 Chemical composition, mechanical properties and conditions of induction-hardening

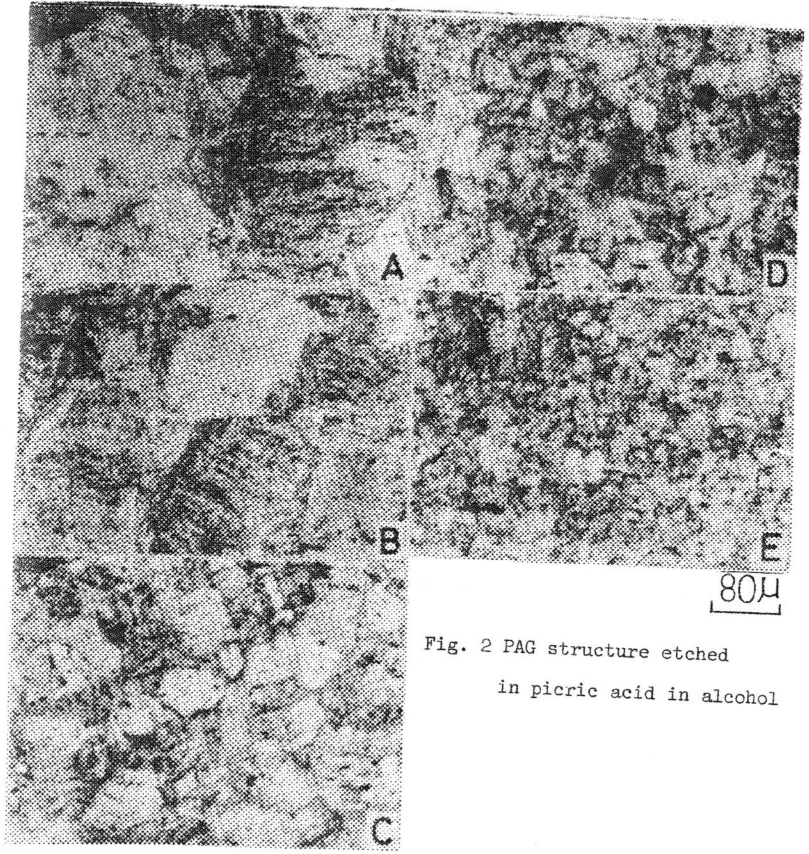

Fig. 2 PAG structure etched in picric acid in alcohol

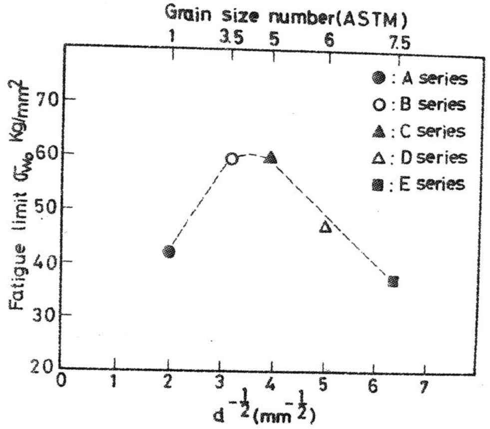

Fig. 3 Relationship of fatigue strength to PAG size

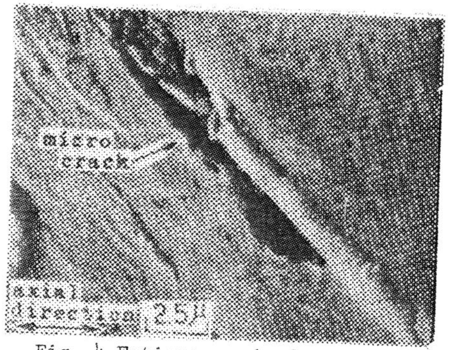

Fig. 4 Fatigue crack along martensitic plate (SEM)

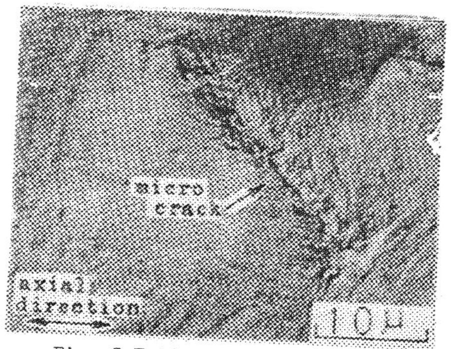

Fig. 5 Fatigue crack along PAG boundary (TEM)

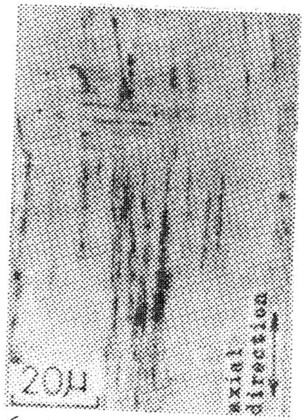

Fig. 6 Shear mode crack under reversed torsion, τ=35 kg/mm^2, N=1×10^4

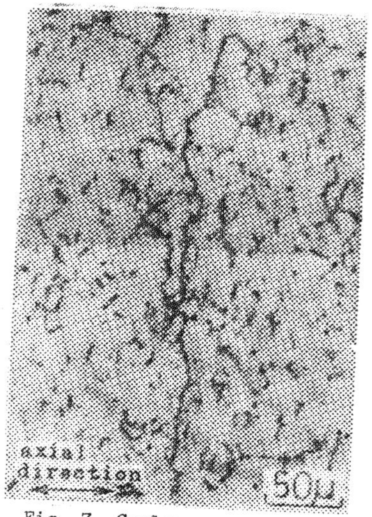

Fig. 7 Coalescence of PAG boundary cracks, d=25μ, σ=54 kg/mm^2, N=1.2×10^5