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Microstructural conditioning for fatigue crack initiation in pressure vessel and piping materials

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ABSTRACT:The selected area (electron) diffraction method, SAD, was used to quantify dislocation cell to cell orientation differences developed during fatigue process in SA508, which was found to increase gradually as the cumulative fatigue damage increased. Microstructural change of Type316 stainless steel during fatigue process was studied by the positron annihilation, PA,line shape analysis.The changes in the PA parameters and dislocation density were well correlated.

1. Objective

It is intended to explore the role of microstructural conditioning ingredients with cumulative damage. Specific attentions is paid towards identifying the nature and mechanisms to crack initiation, The program combines quantitative experimental methods to study the microstructural origins and mechanisms of fatigue process in two representative alloys of interests to nuclear power industries; pressure vessel (low alloy) and austenitic stainless steel. Surface versus bulk damage development is also examined in order to identify the applicability of nondestructive or nondisruptive (requires a surface technique which probes to some minimum depth) techniques.

2. PRESSURE VESSEL MATERIAL

An effective method of measuring fatigue damage accumulation state in a pressure vessel material was identified by microstructural examination. The selected area diffraction method(SAD) enables one to quantitatively evaluate the damage level based on statistical data on micro-orientation change of fatigue induced dislocation cell wall structure observed by electron beam diffraction. The validation of this potential inspection method involved feasibility testing, variation testing for mixed spectrum cyclic loading, investigation of the impact of heat to heat variations and finally bench marking on a series of fatigue damaged samples from a plant in service.

2.1 SAD Method

In the feasibility study, for example, fatigue test bars fabricated an SA508 class 3 low carbon steel plate were cyclically deformed (constant strain low cycle fatigue) to crack initiation (100% cumulative damage, CD) and to the factors 75, 50, and 25%CD. The test bars were cut perpendicular to the stress axis at the center of the gage length. Thin foils (about 0.1 micron meter thick) were prepared from each cross section and used for transmission electron microscope (TEM) and SAD study. By the TEM, the undamaged (0%CD) sample was characterized high angle grain boundaries, small carbide precipitates, and dislocation cell networks in grains. These characteristics did not show any appreciable changes in all of the specimens with fatigue damages. Micro-orientation changes of the dislocation cells studied by the SAD of the foils and a statistical data analysis clearly demonstrated that the mean orientation difference in the cell increased gradually as the CD increased as illustrated in Figure 1 (Nakagawa, Yoshizawa, Lapides,1990).

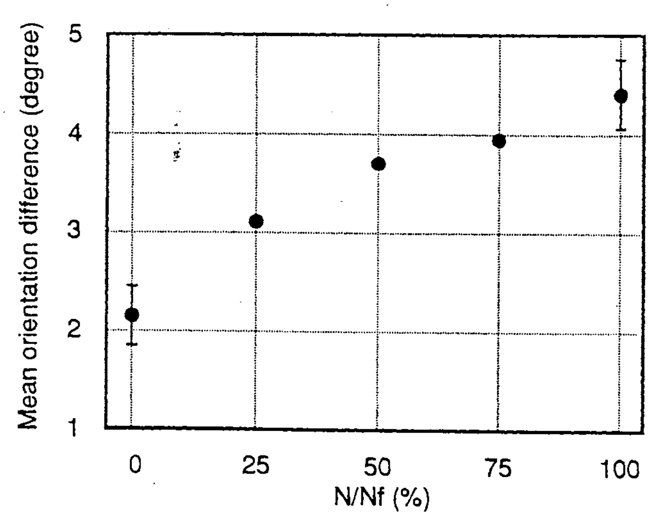

Figure 1 Mean orientation difference of cells measured by SAD as CD of SA508 LCF increases

2.2 SAD Application

A small sample removed from PWR feed water nozzle welds made of a low alloy steel believed to have failed by mixed high and low cycle fatigue was examined by the SAD method. The sample contained a major crack extending to about two third of the wall thickness and many small cracks located on near ID surface, They were all initiated from corrosion pits at geometrical stress raisers such as weld bead toes and counter bores. The crack surfaces were covered with corrosion products, but when the corrosion products were removed, the beach marks characteristics of moderate to high cycle fatigue were clearly observed, These marks and the crack morphology confirmed that fatigue was the major process for cracking, and that corrosion pitting and crevices contributed to the initiation process. As seen in Figure 2 the mean orientation difference of the dislocation cells examined by the SAD at two bulk volumes was 4.1(near OD surface) and 4.7(at the crack tip near ID surface) degrees which is about the critical value at which the fatigue crack failure is possible in the push-pull fatigue test bars(Figure 1). Two additional sector samples from different nozzles of the same plant were obtained that did not show obvious indications of cracking. After metallographic examinations it was found that each sector had one small crack initiating from the ID surface and extending to about 3% through wall(0.5mm deep). The nature of the crack path and the corrosion product suggested that these cracks were arrested or had not advanced for a long period of time. There were a number of corrosion pitts on the ID surface, but non were sites for the fatigue cracks. It was concluded that the nozzles that the second samples were taken were at a low damage state. SAD measurements made at close to the outer surface of the samples yielded the mean orientation difference of 3.1 and 3.2 degrees as illustrated in Figure 3, corresponding to 25-0%CD in the laboratory fatigue test results.

3 AUSTENITIC STAINLESS STEEL

3.1 Positron Annihilation

Positron annihilation(PA) line shape analysis has been used to detect material degradation caused by various plastic deformations (Hughes,1982). The PA line shape analysis is based on the measurement of the Doppler broadening of the 511KeV gamma-rays from annihilation of the electrons in a material and the positrons from a radioactive isotope such

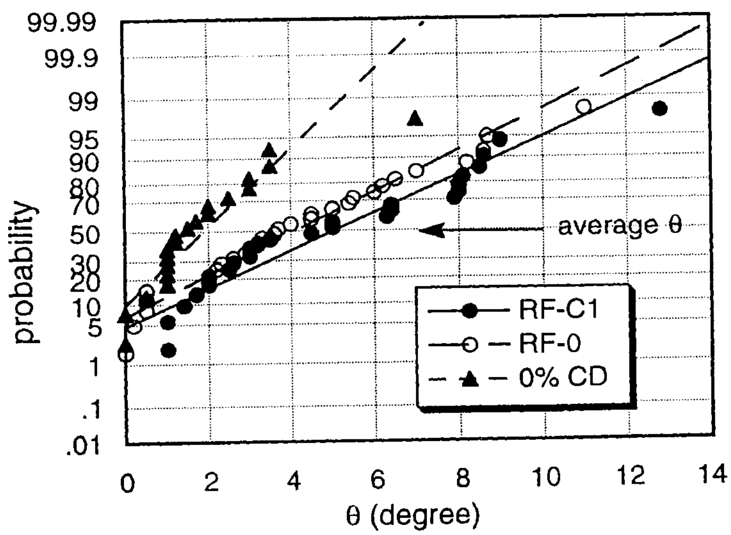

Figure 2 Normal distribution of the cell orientation difference for cracked PWR SG nozzles

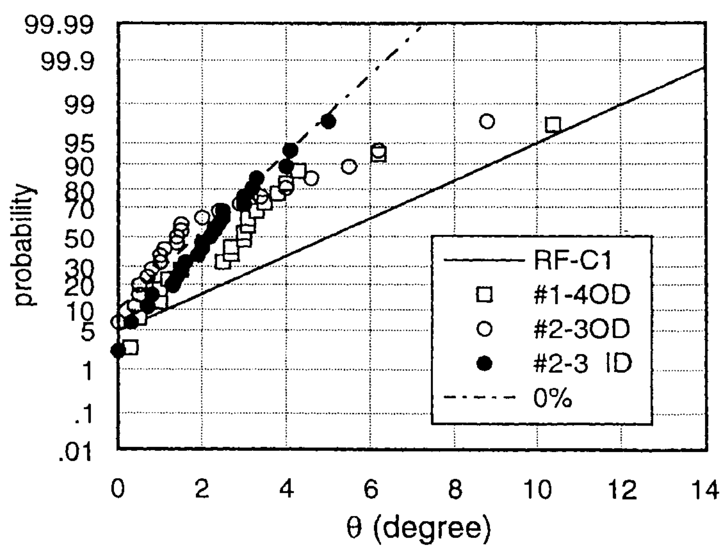

Figure 3 Normal distribution of cell orientation difference for PWR SG nozzles without cracking

22Na or 68Ge. With in a metal thermalised positrons can ihilate with either conduction electrons of the Fermi rgy, or with valence electrons of somewhat greater etic energies. The Doppler broadening is dominated by etic energy of electrons. Annihilation with valence ctrons give greater Doppler broadening than those with duction electrons. In undamaged materials both presence vacancy defects or of dislocations has two effects; only ocalized conduction electrons are available for ihilation in such defects; and the absence of metal ions es such vacancy defects negatively charged so that they ract positrons. Thus as the vacancy defects centration is increased, so also is the probability of ihilation with conduction electrons. The annihilation e shape therefore changes and narrows slightly. The rowing is evaluated using the line shape parameter, S, en by the central region gamma-ray counts divided by the al counts as schematically shown in Figure 4. If the ihilation line shape narrows, the S-parameter is eased.

PA Measurements for Fatigued Type 316 Stainless Steel

crostructural change of Type316 stainless steel during igue process was studied by the PA line shape analysis, TEM. The PA measurements were performed on sample aces and the bulk fatigued to various levels of the CD. PA line shape parameter markedly increased to 20%CD sured both on the surface and in the bulk. The isolated ocation line density increased up to 1%CD, beyond which dislocations started to tangle forming the cell cture. The changes in the PA parameters and dislocation ity were well correlated. Slip lines and development of surface microcracks were observed by replica during the gue process. The slip lines were found as early as 1%CD e, and the dislocation density and the surface roughness eased afterward. The microcracks were detected at 20% nd after. The micro- crack density (number/unit surface) gradually increased up to 85% CD, and they rapidly esced to a major crack which lead to the sample failure een in Figure 5. It is concluded for the fatigue damage austenitic stainless steels that the microstructural ge is dominant in the early stage of the life followed rack initiation and propagation in the later stages. The ostructural changes in the early stage of the life are detected by PA.

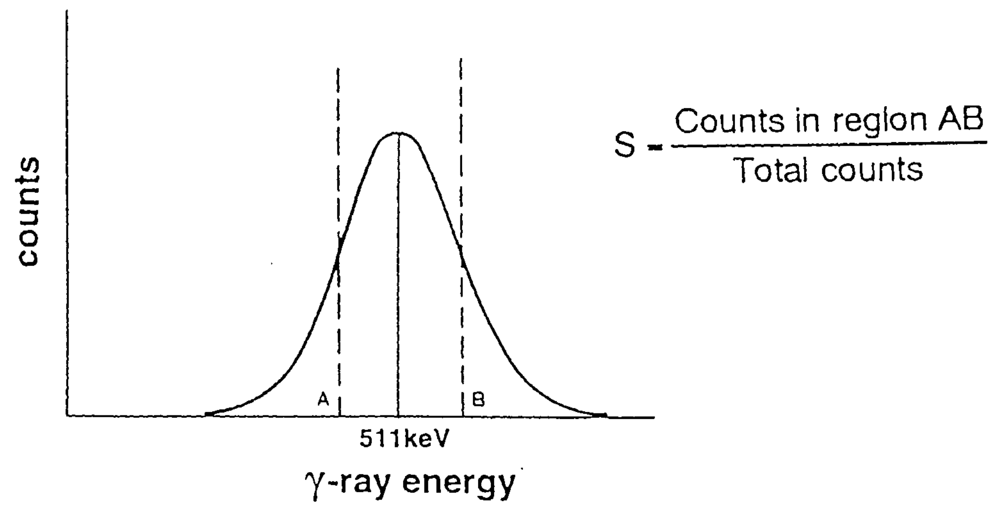

Figure 4 definition of the S-parameter for PA line shape analysis

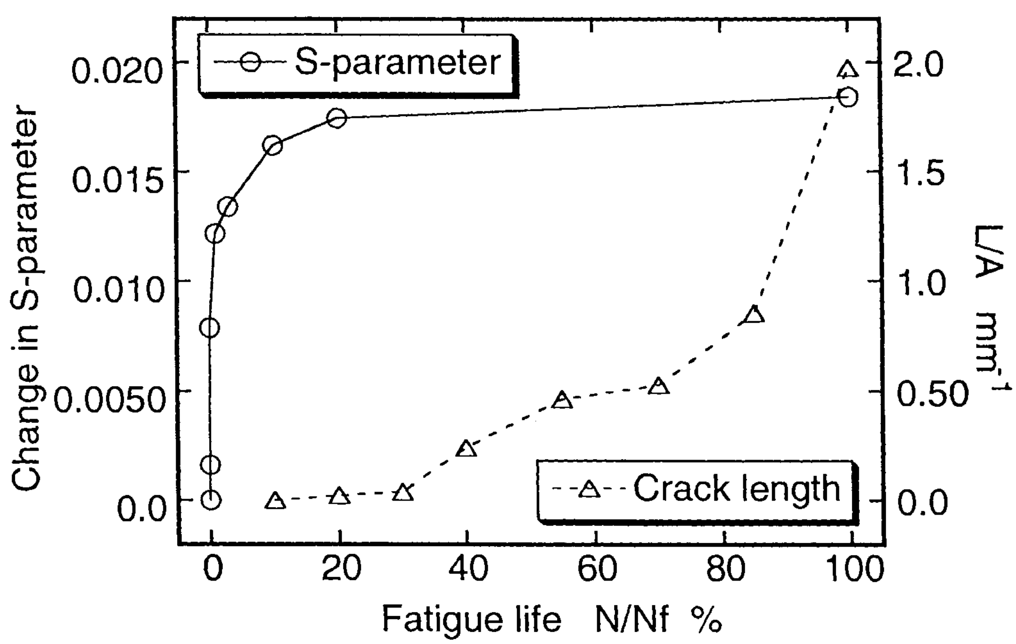

Figure 5 Change in S-parameter and crack length of fatigued type 316

4.CONCLUSIONS

Micro-orientation changes of the dislocation cells studied by the SAD for fatigued SA508 and a statistical data analysis clearly demonstrated that the mean orientation difference in the cells increased almost linearly as the CD increased. The SAD method was successfully applied to the analysis of fatigue failed PWR SG nozzles.
As for the fatigue damage of austenitic stainless steels the microstructural changes were found dominant in the early stage of the life followed by crack initiation and propagation in the later stages, The microstructural changes in the early stages of the life are well detected by PA.

5 ACKNOWLEDGEMENT

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6.REFERENCES

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