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METALLURGICAL ANALYSIS OF CRACKED PISTON SKIRTS FROM EMERGENCY DIESEL GENERATORS SHOREHAM NUCLEAR POWER STATION

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SUMMARY

Three piston skirts from the emergency diesel generators (EDG) at Shoreham Nuclear Power Station (SNPS) were found to have fatigue cracks in eleven of the twelve piston skirt bosses. None of the cracks had grown to failure. The chemistry and microstructures appeared consistent with typical ductile iron properties. Skirt Brinell hardness values were within the specifications attributed to the manufacturer.

INTRODUCTION

This is a preliminary report on the metallurgical analysis of the cracked piston skirts discovered in the emergency diesel generator engines at SNPS. A subsequent report, to be issued on or about December 16, 1983, will include photographs and documentation of the metallurgical and stress analysis of the skirts.

In view of reported failures of the piston crown-to-skirt attachments in Transamerica Delaval Inc. (TDI) Enterprise engines, nondestructive inspection and analysis of the SNPS pistons were initiated. Initially, dye penetrant inspection revealed linear indications near the stud attachment boss region in several piston skirts. Subsequently, all SNPS piston skirts were inspected, and linear indications were observed in all but one skirt, which proved to be a later design designated as AN by TDI. With this one exception, the piston skirts were of the type designated as AF, factory modified according to 10 CFR Part 21, issued on November 5, 1981. This modification, performed late in 1981 by TDI, consisted of spot facing each of four bosses through which studs extended to secure the separate piston crown to the skirt and replacing the originally supplied spherical washer set with two stacks of Belleville washers. The spot facing reduced the height of the stud attachment bosses from 2 inches to approximately $^{1}/_{4}$ inch. The type AN skirt embodies essentially the same geometry in the casting as in the factory-modified AF skirt.

All SNPS piston skirts were manufactured to ASTM Specification A536-65 for ductile cast iron. According to TDI, the AF skirts were normalized and tempered. They were austenitized at 1700°F - 1750°F for 3 hours then cooled in ambient air. They were subsequently tempered at 1050°F for 3 hours followed by cooling in ambient air.

Three of the skirts identified as having potential cracks were shipped to Failure Analysis Associates (FaAA) for confirmation and analysis of the cause of these cracks. These piston skirts have been designated 1, 2, and 3. The number 1 skirt was removed from the number 4 cylinder of EDG #101. The second piston skirt is from the number 6 cylinder of EDG #102. The number 3 piston skirt is from the number 7 cylinder of EDG #103.

VISUAL

The three AF-type pistons were examined by eddy current to confirm the presence of cracks, and it was found that eleven of the twelve bosses contained one or two cracks. The cracks appeared on the inside of the piston, in the vertical ridges remaining after spot facing of the bosses. Cracks were subsequently saw-cut and fractured out of all three piston skirts. Four linear indications, revealed by dye penetrant testing, were all opened by fracturing and proved to be pre-existing cracks. The cracks were similarly located at the base of the ridges and ranged from 0.3-inch deep by 0.9-inch long to 0.2-inch deep by 0.3-inch long.

These pre-existent cracks appeared to be fatigue cracks. Some of them had faint beach marks. In addition, evidence of ductile dimples or cleavage was not observed in the flat fatigue crack region. The origin was impossible to locate for three of the cracks. However, one crack appeared to have its origin at the tip of the ridge that remained after the bosses had been spot faced. Freshly overloaded portions of the fractures, produced in opening the cracks, were rougher than the smooth, pre-existing cracks. A notable feature, visible using a lower power stereomicroscope, was the many graphite nodules intersected by the fracture surface. These nodules were smoothly fractured in the fatigue cracked areas but were more disturbed in the fresh overloaded regions of the fractures.

On several of the fractures, black, included material was apparent near as-cast surfaces. This appears to have been organic binder that has been incorporated from the core. This included material does occur using typical foundry practices. However, these areas in the current piston skirts are deeper than those typically observed in similar castings. The included material did not appear to significantly affect the fatigue crack initiation or growth in the four cracks broken open.

ELECTRON MICROSCOPY

Cracks from each piston skirt were examined using a scanning electron microscope. The character of fractographic features varied with location on the fatigue crack surfaces. Locations nearer the crack origin were rubbed and damaged more than regions nearer the crack front. Near the crack tip on two fractures, i.e., in the fatigue region most recently formed, areas containing fatigue striations were observed. Although these striations were not observed on each specimen or in other areas on the crack surface, similar features were observed but without distinct fatigue striations. Worn or abraded features, such as those observed here, are typical of steel fatigue crack surfaces which have resulted from cycling between tension and compression.

These pre-existing flaws are clearly fatigue cracks. First, striations and rubbed fatigue areas were present over the entire crack surface. Second, no evidence of ductile dimples was observed between the graphite nodules. This strongly suggests that the maximum cyclic stress was below the ultimate tensile strength. In addition, it also suggests that major overloads were not responsible for crack extension. Finally, no cleavage was observed on the pre-existing crack surfaces. This again supports the evidence that these pre-existing flaws were the result of high cycle fatigue and not ductile or cleavage fracture processes.

METALLOGRAPHY

The ductile cast iron was examined metallographically. Small specimens were cut out from near the fatigue-cracked bosses. These were mounted, polished, and etched to reveal the microstructure. The microstructure consisted of about 10-volume-percent graphite particles in a matrix of pearlite and ferrite. The graphite nodules were somewhat less regular than ideal; however, this would have had no influence on the fatigue strength of the material. The matrix was about 80% pearlite and 20% ferrite; the ferrite appeared around the graphite particles, as expected. This microstructure is consistent with the heat treatment reportedly used by TDI.

CHEMICAL COMPOSITION

A sample of the number 2 AF piston skirt was removed and analyzed using various chemical analysis techniques. The reported analysis is shown in Table I.

TABLE I

Chemistry of Cast AF Piston

Element	Weight Percent
C	3.46
Si	2.43
Mn	0.53
Cr	0.11
Ni	0.76
Mo	0.038
Mg	0.072
S	0.005
P	0.027

This chemistry is typical for ductile cast iron.

HARDNESS

The hardness of several pieces of these cast piston skirts was measured using the Brinell Hardness Scale. Hardness values varied from 235 to 255 BHN. These hardness values fall within the reportedly specified hardness range of 217 to 270 BHN. These hardness values also suggest that the ultimate tensile strength of the ductile iron would be between 110 and 120 ksi. This strength correlation is consistent with the reported TDI cast iron grade of 100-70-03; where 100 represents a minimum tensile strength of 100 ksi.

CON LUSIONS

- The cracks in the piston skirts indicated by dye penetrant and eddy current examination proved to be fatigue cracks.

- The number of fatigue cracks in the AF-type piston skirts examined was high; almost all bosses in the samples examined had fatigue cracks.

- Hardness values and correlated ultimate tensile strengths are within the specifications attributed to TDI, and they are consistent with the observed composition and microstructure.