Structure and Properties of an 8620 Steel Carburized in a Nitrogen-Base Gas

By D.L. Svec and D.E. Laughlin

IN A PREVIOUS ARTICLE in Metal Progress[1] a nitrogen-base gas system for carburizing (herein termed CAP for carburizing atmosphere process) was described from the process point of view. The system, which employs a gas blend of nitrogen, natural gas, and carbon dioxide, was developed by Air Products & Chemicals Inc.[2] In this article, we report on an investigation of the structure and properties of a steel carburized in the system, and compare the structure and properties to those of an identical steel carburized in the normal endothermic carrier gas atmosphere. Significant results are summarized below:

1. Fatigue properties of samples carburized in the CAP atmosphere are comparable to those of identical samples carburized in a conventional endothermic atmosphere.

2. The microstructure of samples carburized in both atmospheres was found to be essentially identical. Although the samples carburized in the endothermic carrier gas did exhibit slightly higher grain boundary oxide frequency and penetration depth, the fatigue life of such samples did not seem to be noticeably affected.

3. The fracture surface of endothermic and CAP carburized samples was examined and found to be identical at both high and low stress levels.

Description of Procedures Used in Study

Standard ASTM notched charpy bars for fatigue testing were machined from a single AISI 8620 ¾ in. (19.05 mm) rod. A 1 mil (0.025 mm) radius notch was milled into each charpy bar, which was surface ground to a ±2 mil (0.051 mm) tolerance prior to carburization. Bars received no further surface preparation prior to carburizing.

After a random sample selection and numbering, test samples were sent to Metallurgical Processing Inc., Ft. Wayne, Ind.[1] to be carburized. Standard test bars for carbon gradient analysis were also machined from another single AISI 8620 1 in. (24.4 mm) rod according to specifications provided by ASTM. Three of the standard bars were included during carburization with each of the sample groups. Both the endothermic and the CAP samples were processed in the same carburizing furnace at the same temperature (1700 F [926 C]) for 5 h and oil quenched at 1625 F (885 C). The carbon potentials during the processes were approximately equal.

Visual case depth measurements indicated an average 0.059 in. (1.50 mm) case in the endothermic samples and 0.060 in. (1.52 mm) in the CAP group. Microhardness determinations across a section of a randomly selected endothermic and CAP sample were also similar, as can be seen in Fig. 1. CAP samples, however, did show slightly higher hardness readings.

Because fatigue properties are structure sensitive, the pieces were cooled to −150 F (−101 C) for 1 h in a liquid nitrogen-methanol bath (the temperature being monitored by a copper-constantan thermocouple), then retempered at 350 F (176.7 C) for 1 h in a temperature controlled silicon oil bath. Samples treated in this way were examined metallographically to confirm that this treatment transformed all retained austenite to martensite and produced comparable microstructures (case and core) in both types of carburized fatigue test samples.

Several charpy samples were fatigue tested from each carburization group at six different preload stress levels. A three-point bending fatigue test, at 1800 cycles/min., was run on a BLH universal testing machine. This test consists of a repeated sinusoidal stress cycle. The preload on each sample in the test was 100 lb (45 kg) more than one-half of the cycling load.

Samples were tested in pairs (one endothermic, one CAP) at each stress level. An untreated carburized sample of each type was also fatigue tested at 750 lb (340 kg) preload along with each subgroup to provide a control data point for the comparison of fatigue tests.

Detailed Results of the Investigation

The mean fatigue life at each stress level is shown in Fig. 2. Error bars (of one standard deviation) represent the distribution of each sample population around the mean. Similar trends in the S-N curves of the CAP and the endothermic carburized groups are evident.

The nonparametric Mann Whitney U-Test was also used to test the null hypothesis that the two carburized sample groups were from the same population. This hypothesis proved true in subsequent statistical analysis. Therefore, fatigue life is independent of the method of carburizing.

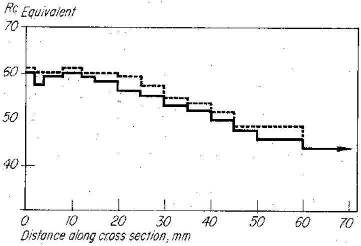

Fig. 1 — Microhardness examination across a random cross section of a CAP sample (broken line) and an endothermic sample (solid line).

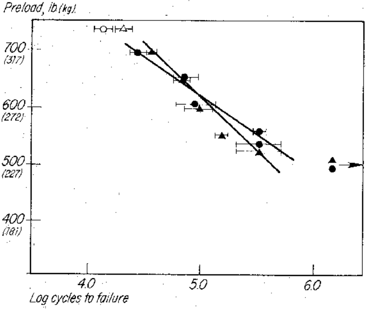

Fig. 2 — Mean fatigue life of endothermic samples (triangles) and CAP samples (circles).

The microstructure of both the endothermic and CAP samples were found to be identical. The core microstructure in each case was mostly bainite, mixed with some tempered martensite. Both exhibited a fine structure of tempered martensite. Transmission electron microscopy (TEM) was performed on the case regions of the CAP samples to ascertain if any nitrides were formed during carburizing. As expected, they were not observed.

Carbon Gradient Analysis: Analyses were made on standard test bars. The material was sampled at 0.01 in. (0.25 mm) intervals from the surface. Chemical analysis of the standard bars carburized by each process did reveal a slight difference in carbon gradient as shown in Fig. 3.

The CAP carburized standard has a slightly higher surface content which continues throughout the case region. These results are consistent with the slight variance in microhardness already observed between the sample groups, in that the CAP samples also show slightly higher microhardness through the carburized case (see Fig. 1).

Grain Boundary Oxidation: This condition has been thought to contribute to reduced fatigue life. Welchner and Roush[3] identified such oxide networks at the surface of carburized steels in 1943 and recent studies by Chatterjee-Fisher[4] confirm this finding. Other researchers report that elimination of internal oxidation can increase fatigue use by 35%.[5] It was therefore considered to be important to see if any difference in grain boundary oxide frequency existed between the two types of samples.

Samples which showed the largest fatigue life difference (at the same preload) were polished and photographed at random along the section edges. Counts and measurements were made on the resulting photo enlargements.

Figure 4 is a graphical representation of the collected data on grain boundary oxide frequency. Values range from 32±4 oxides per 100 μm in the CAP samples to 40±2 per 100 μm in the endothermic samples. This difference is small; and there is a region of overlap between the standard deviation of each population. The oxide penetration depth is also similar, the average being 19.1 μm ±4.0 μm for the endothermic samples and 16.4 μm ±3 μm in the CAP sample.

Examination of Fracture Surfaces

Macroscopic examination of fracture surfaces of both the endothermic and the CAP samples indicated that crack initiation began at or within the carburized case of the fatigue samples. Scanning electron microscope (SEM) examinations were performed to determine the site of crack initiation and to characterize the nature of the fracture surface across both the endothermic and the CAP carburized samples.

The endothermic and CAP sample pairs that had been tested at low stress levels were examined first. Although these fatigue sample pairs were those that showed the largest difference in fatigue life (see Fig. 2), no noticeable differences in fracture surface appearance was observed.

The fracture surface within the notch region of an endothermic and a CAP sample pair treated at identical stress levels consisted of an equal mixture of intergranular and transgranular modes. The fracture surfaces in the core regions of the endothermic and CAP sample pairs were also similar; again they were a mixture of intergranular and transgranular fracture. Inspection of the case regions at the end of the fracture surface of both samples also revealed a mixture of transgranular and intergranular fracture — although the intergranular fracture had now become more prominent.

Sample pairs tested at higher stress levels were also examined. As expected, their fracture surfaces were also comparable. Fracture at the higher stress levels began primarily as transgranular fracture, and fracture proceeding through the carburized case was a mixture of transgranular and intergranular fracture. Fracture through a core of both types of samples tested at the higher stress levels was ductile; voids seemed to be initiated by small ($\sim 1\mu$) inclusions. Final fracture through the ending case region was again almost exclusively intergranular.

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References

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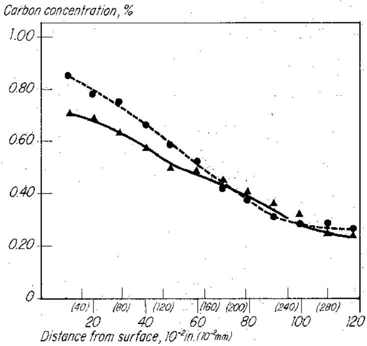

Fig. 3 — Carbon gradient analysis of standard test bars. Triangles indicate endothermic samples; circles indicate CAP samples.

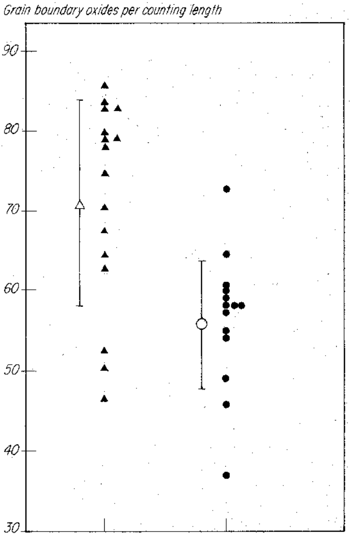

Fig. 4 — Grain boundary oxide frequency in endothermic samples (triangle) and CAP samples (circle).