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Defective Carburized Shafts

By

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Introduction

Carburizing is one method of surface hardening of steel parts. When done correctly it improves the wear resistance and fatigue characteristics of a part. This case study involves investigation into the cause of cracking in carburized axle shafts that failed during life cycle testing. Field failures would not have shown up during the shafts' warranty period, but could result in destruction of the equipment, and/or, in injury to equipment operators from failures occurring after the warranty period. These shafts were machined from AISI/SAE 8620 steel, and carburized by using a heat treating process that had a furnace atmosphere with a carbon potential greater than one percent. The heat treating specification stated that the surface carbon on the shaft be less than 0.80 percent, and that the shaft be free of retained austenite, but that the shaft could not be cold treated to eliminate retained austenite. The required heat treating process is more expensive and technically more difficult than typical carburizing processes. These requirements are typical for heavy-duty on and off road equipment. The Broken and Good axles were from one heat treater, Lot I was from a second heat treater, and Lot K-1 was from a third heat treater.

Hardness Testing

The hardness testing was done according to ASTM E384, using a Knoop indenter and a 500 gram load. The two shafts were hardness tested in the area of the keyway. The broken shaft was also tested in the large diameter bearing area which had been ground to size. Table 1 that follows gives the core hardness values of the two finished shafts.

Table 1
Hardness Test Data Axle Shaft Core
(Rockwell C Scale)

Shaft	Knoop	Std. Dev.	Range	Hardness
Broken	293.00	7.82	286.00 - 304.00	27.32 RC
Good	325.00	24.72	307.00 - 366.00	31.74 RC

The lower core hardness of the broken shaft indicates that this shaft was not quenched as well as the good shaft. The difference in hardness is enough to show that numbers of parts in the heat treat furnace were overloaded. Overloading during heat treating, though it reduces heat treating cost, reduces part quality and performance, and is very hard to detect.

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The case hardness profiles are given in Table 2. The hardness profiles of the Good and Broken axles indicate the presence of retained austenite, which is indicated by the low hardness readings at the surface. The hardness profiles of Lots I and K-1 do not have significantly lower hardness readings at the surface, even though visible retained austenite was present. The K-1 hardness profile readings are lower than the other shafts. The lower readings could be the result of slack quenching due to furnace overloading, or to lower carbon potential in the furnace atmosphere at the time of heat treating.

Table 2
Case Hardness Profiles of Axle Shafts
(Rockwell C Scale)

Depth (Inches)	Broken Key	Good Key	Good Bearing	Lot I	Lot K-1
0.002	56.20*	56.80*	56.30*	60.00	57.30
0.004	60.70	62.30	60.00	61.60	58.80
0.008	61.80	61.80	60.00	60.80	58.80
0.012	61.10	60.50	59.00	59.00	58.10
0.016	60.00	61.30	59.50	57.20	56.60
0.020	58.80	60.50	56.60	56.50	55.30
0.024	57.90	58.30	53.50	55.10	51.20
0.028	56.20	55.90	52.40	52.20	50.30
0.032	52.60	54.70	50.50	48.80	45.80
0.036	47.20	51.60	44.70	46.20	43.40
0.040	44.00	49.50	38.80	42.50	40.00
0.044	42.10	48.40	37.30	42.20	37.50

*Indicates Retained Austenite.

Metallographic Examination

The magnification shown for the photos is the magnification at which the photos were taken. The photos shown in this report may be smaller or larger in size than the originals. The retained austenite was clearly visible in these axles at a magnification of 25X or greater. 1500X was used for the evaluation to allow for resolution of retained austenite to clearly show its presence in the photos, and to enable easier image analysis.

Figure 1 shows the retained austenite, white areas, of the carburized case of the broken axle. The amount of retained austenite is at least 14.5 percent, and the balance of the microstructure is plate martensite. This is a very brittle microstructure, and indicates that the surface carbon content is >1%.

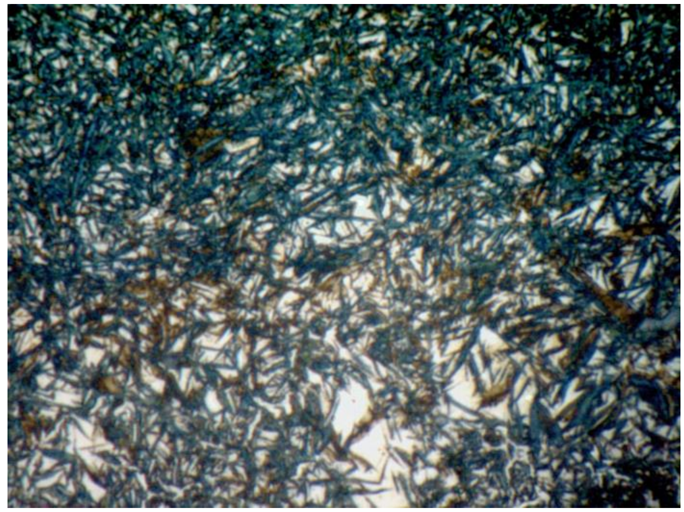

Figure 1 – 1500X Retained Austenite Keyway, Broken Axle

Figure 2 – 1500X Retained Austenite Keyway, Good Axle

The Good axle that did not break during torque testing had 11.3% retained austenite in the keyway. The balance of the microstructure was plate martensite, Figure 2. This microstructure is also very brittle, and indicates a surface carbon content higher than 1%.

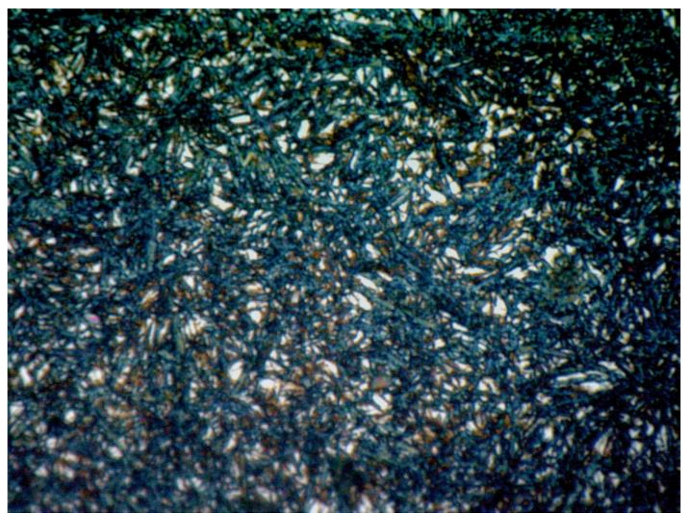

Figure 3 – 1500X Retained Austenite, Good Axle Bearing Surface

Figure 4 – 1500X Retained Austenite, Axle Lot I Bearing Area

The percentage of retained austenite in the case on the ground bearing surface was 8.1. The microstructure was plate martensite, Figure 3.

Figure 4 shows the microstructure at the surface of the axle from Lot I. The amount of retained austenite is less than that found in the Good and the Broken axles.

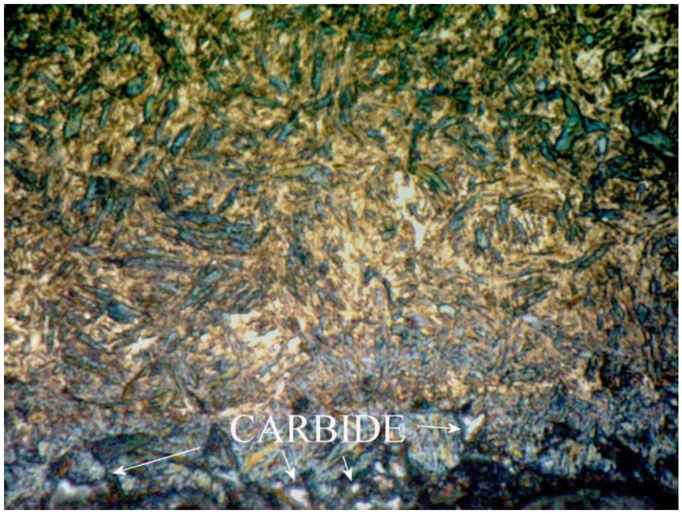

Figure 5 – 1500X Tempered Martensite and Carbides, Lot K-1

The carburized case on the axle from Lot K-1 had a microstructure of lathe martensite with a few carbides at the surface, Figure 5. Lathe martensite is formed during quenching if the carbon level is 0.80 percent or less. Lathe martensite has a higher fracture toughness than plate martensite. The microstructure explains the lower hardness readings on the hardness profile shown in Table 2.

Discussion

Plate martensite is a very brittle microstructure and is very likely to crack under normal loading conditions. This is exactly what happened in the case of the axle that broke during torque testing. Figure 6 shows cracks in the plate martensite, indicated by arrows. The bulk of the fractures appear to have been along the interface between plate and lathe martensite. Even without the presence of the retained austenite, the microstructure present in this carburized case would have been problematic. The interface between the plate and lathe martensite was between 0.008 and 0.016 inch depth. It is possible that, under load, the plate martensite layer could separate from the underlying lathe martensite. This is a possible occurrence even if the retained austenite were not present.

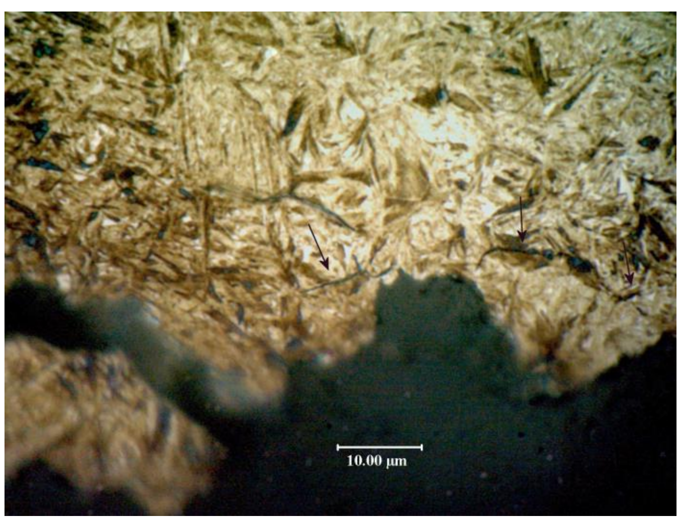

Figure 6 – 1500X Micro-Cracking in Plate Martensite

Heavy equipment manufacturers do not like to have carburized parts cold treated to remove retained austenite because of micro-cracks that form in the case. They control the retained austenite by controlling the carbon level in the case. The lower carbon level also insures that the case is free of plate martensite. Plate martensite can spontaneously produce micro-cracking, as shown in Figure 6.

The microstructures indicate that the Broken axle, the Good axle, and the Lot I axle, were heat treated with very high carbon potentials of over one percent. These axles did not receive cold treating, were likely only snap-tempered, and bearing races were ground to size. The maximum as-quenched hardness in steel is obtained at a carbon level of 0.80 percent, which was located at a depth of 0.004 to 0.008 inches below the finished surface. As the carbon level increased near the surface, the as-quenched hardness dropped off. To achieve the desired carburizing carbon level of 0.80% on the surface and a 99.9 percent lathe martensitic structure, the heat treating process needs to be tailored to this application. If this is not done, the manufacturing processes following heat treatment need to remove the objectionable surface microstructures. This is usually much more expensive to do. In the case of these axles, it would mean grinding all carburized surfaces, including spline and keyway, to remove the plate martensite layer.

It is generally accepted that retained austenite of 5 percent or less is not detectable by metallographic examination. Also, that when the retained austenite is less than 5 percent, it is not usually a problem, except for very close tolerance parts. The actual amount of retained austenite in the axle is quite likely at least 5% higher than the measured values. Any visually detectible retained austenite is too much for this application.