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Case Study: Shaft Failure

By

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Subject

Examination of carburized coupling shaft to determine cause of failure. The shaft failed within a few minutes after being put into service on a piece of off-road equipment. The shaft was examined by visual examination, hardness testing, and metallographic examination.

Visual Examination

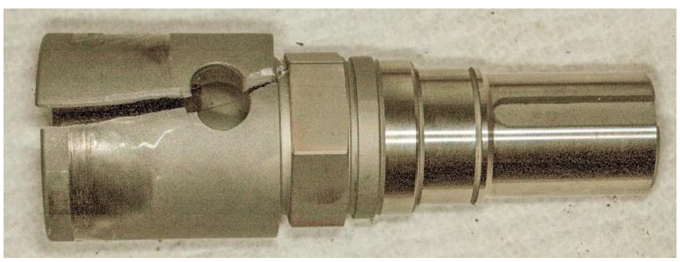

Figure 1 – Crack in Shaft

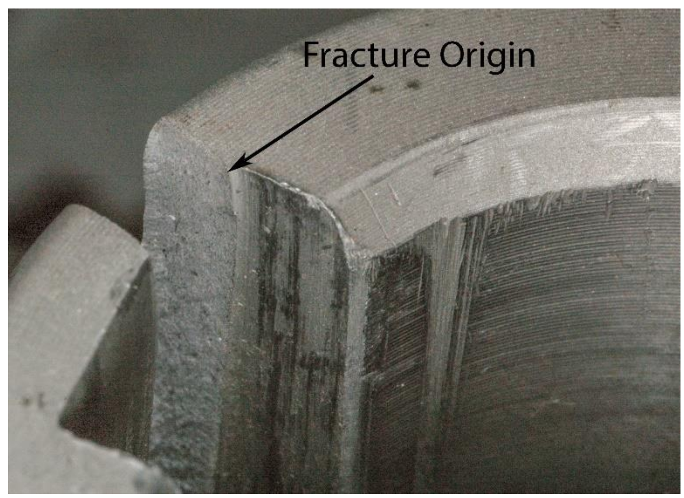

Figure 2 – Fracture Origin in Keyway

Figures 1 through 4 show the large cracks in the shaft. Figure 2 shows the fracture origin at the outer end of the keyway. Figure 3 shows additional cracking at the base end of the keyway. The coloration of the fracture surface and the outer surface of the shaft were identical, indicating that the fracturing likely occurred prior to tempering.

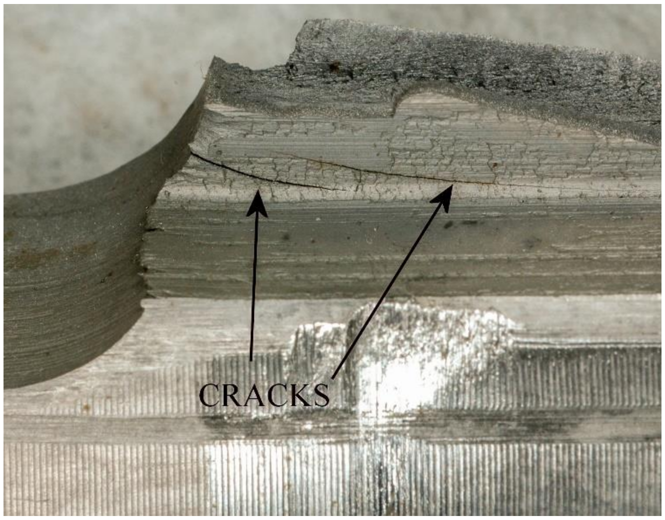

Figure 3 – Cracks at Base End of Keyway

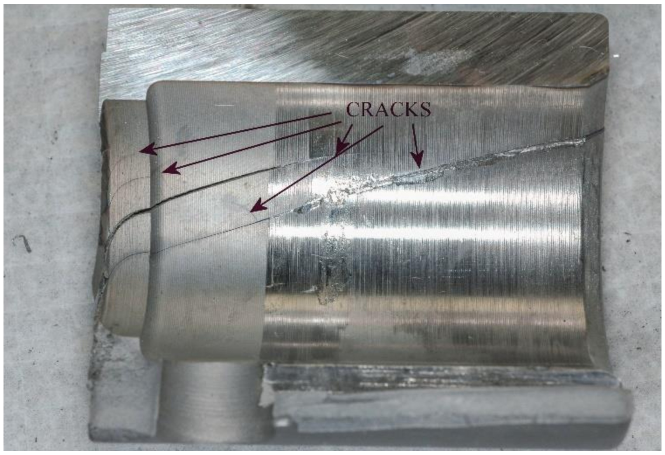

Figure 4 – Cracks Inside Diameter

Hardness Testing

The hardness testing was done according to ASTM E384, using a Knoop indenter and a 500 gram load. The results of the testing are given in the table that follows.

Hardness Profile Coupling Shaft (Rockwell C Scale)						
Depth	#1 I.D.	#1 O.D.	#2 I.D.	#2 O.D.	#3 I.D	#3 O.D.
0.002	60.4	34.4	61.0	56.4	62.1	44.5
0.004	61.4	40.1	62.0	59.0	64.0	45.5
0.008	60.5	37.5	60.0	57.8	60.7	43.2
0.012	58.5		58.1	56.1	58.8	
0.016	55.6		55.5	54.0	55.9	
0.02	52.7		53.8	52.0	54.5	
0.024	52.8		52.0	50.5	52.8	
0.028	50.2		50.6	47.4	51.4	
0.032	48.1		49.2		49.2	
Core	35.5		40.5		39.4	

The hardness test profiles indicate that the effective case depth on the inside diameter of the shaft was 0.030 inches. The hardness near the surface indicated that the amount of retained austenite was very small. The outside diameter of the shaft had received no carburizing. There was no carburizing on the outside diameter of Samples 1 and 3. Sample 2 had a section about ¾ inches long that had been carburized.

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.

Figure 5 – 400X Tempered Martensite Case Sample 1

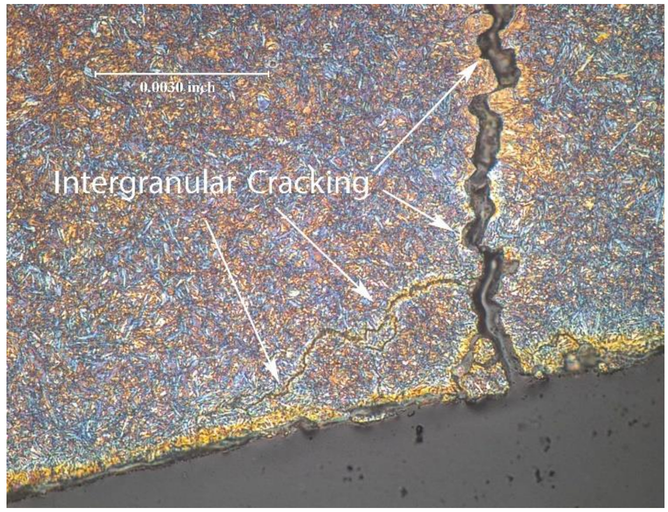

Figure 6 – 400X Intergranular Cracking in Case Sample 1

The microstructure of the carburized case shown in Figure 5 was tempered martensite. There was no visible evidence of retained austenite or undissolved carbides. Figure 6 shows the small crack on the inside diameter. The fracture is intergranular, and is typical of delayed quench cracking.

Figure 7 – 400X Intergranular Fracture and Case Microstructure

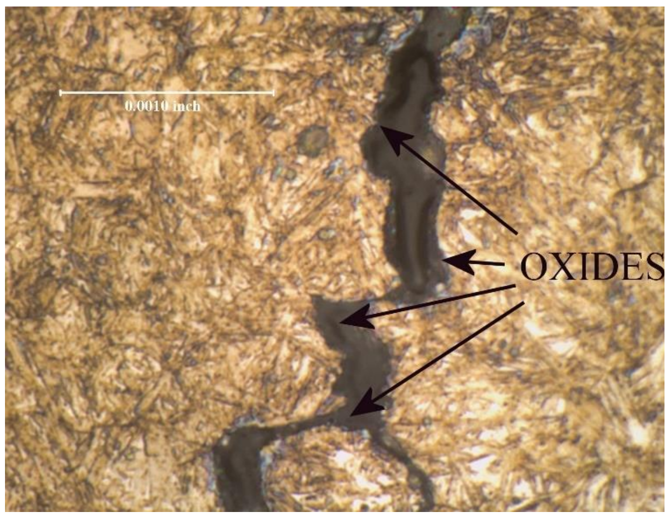

Figure 8 – 1500X Oxide Scale in Intergranular Crack

Figure 7 shows the intergranular fracture in the carburized case. This crack is also typical of delayed quench cracking. There was no evidence of retained austenite or carbides at this location. Figure 8 shows the oxide scale in the intergranular crack. The presence of oxide scale indicates that the crack was there prior to tempering, which indicates a significant time delay between quenching and tempering.

Conclusions

1. The case on the inside diameter of this shaft was free of retained austenite and carbides.

2. The crack initiations were intergranular fracture.

3. The most likely cause of fracture in the shaft was delayed quench cracking.

4. The primary cause of failure of the shaft was too long a tempering period between quenching and tempering.