25 HP Hydraulic Pump Shaft Failure – Case Study

By

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Failure analysis was conducted on a 25 horse power hydraulic pump shaft that failed in service to determine cause of failure. The failed pump shaft was examined by visual examination, scanning electron microscopic examination, hardness testing, and metallographic examination. The end-user experienced between one and ten of the pumps failing per week over a two year period before changing suppliers. This study shows just one of the heat treating problems involved in the many pump shaft failures that occurred during the two year period.

Visual Examination

Figure 1 shows the broken hydraulic pump shaft. Based on the visual examination, the shaft appears to have failed by torsional fatigue, Figure 2. This is indicated by a number of fracture origins and ratchet marks located around the shaft circumference.

Figure 1 – Complete Shaft

Figure 2 – Fracture Surface of Shaft

Scanning Electron Microscopic Examination

There was a small area near the center of the shaft that was not heavily corroded, and/or Brinelled during the shaft failure. Figure 3 shows beach marks at that location, which are a characteristic of fatigue.

Figure 3 – 40X Beach Marks Near Center of the Shaft

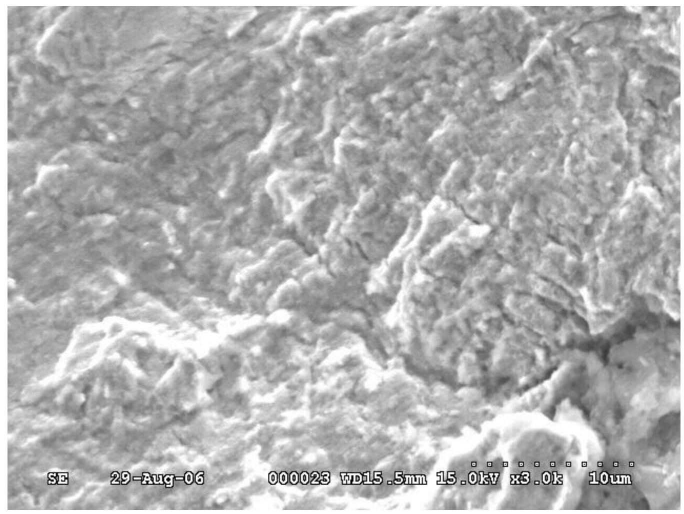

Figure 4 – 3000X Fatigue Striations

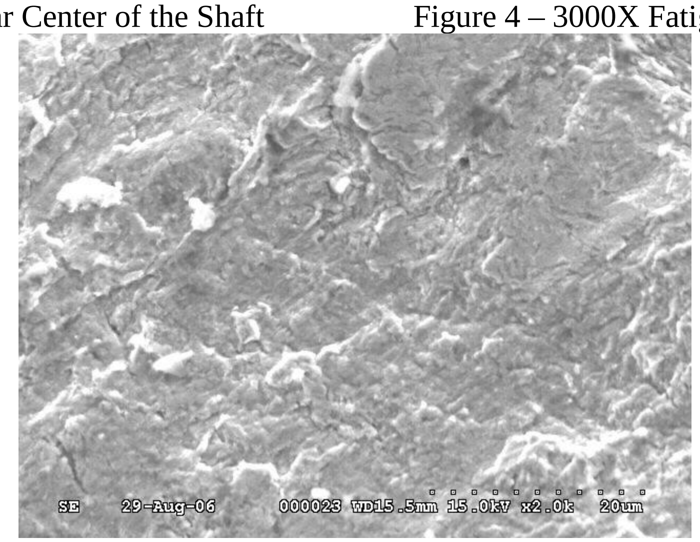

Figure 5 – 2000X Fatigue Striations

Figure 4 shows the fatigue striations. The spacing of the striations was determined to be 1.85 X 10^{-5} inches. Figures 4 and 5 show striations that were approximately perpendicular to each other, which is a common characteristic of torsional fatigue. Both locations show fissile fracture which results when the cyclic stress exceeds the tensile strength of the steel. The striation spacing shown in Figure 5 was determined to be 1.66 X 10^{-5} inches. The striation spacing at both locations indicates high cycle fatigue.

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.

The manufacturers heat treating specification stated: “1. Carbon content of the surface before grinding to be between 0.70 and 1.10%. 2. Surface hardness at the finished ground size to be 59 to 63 HRC. 3. Effective case thickness must be between 0.025” and 0.045” and is measured as the distance from the finished ground surface to the point where a hardness reading of 50 HRC is obtained. 4. Core hardness must be between 28 and 40 HRC from gear widths greater than 1” ….

Shaft Hardness Profile (Rockwell C Scale)	
Depth (Inches)	**Shaft**
0.002	41.80 RC
0.004	45.90 RC
0.008	44.90 RC
0.012	44.00 RC
0.016	42.80 RC
0.020	42.50 RC
0.024	42.00 RC
0.028	41.10 RC
0.032	40.50 RC
0.036	39.60 RC
0.040	39.00 RC
0.044	38.00 RC

The shaft had neither the effective case depth, or the surface hardness specified by the manufacturer. The most likely cause of this was slack quenching during the heat treating process. Higher surface hardness’s resulting from the carburized case are intended to increase the resistance to fatigue in shafts. That did not happen with this shaft.

Core Hardness Pump Shaft (Rockwell C Scale)				
Location	Knoop	Std. Dev.	Range	Hardness
1	303.00	6.26	295.00 - 311.00	28.84 HRC
2	336.00	14.35	327.00 - 361.00	33.22 HRC

The core hardness of the shaft is within the specified 28 to 40 HRC hardness range.

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.

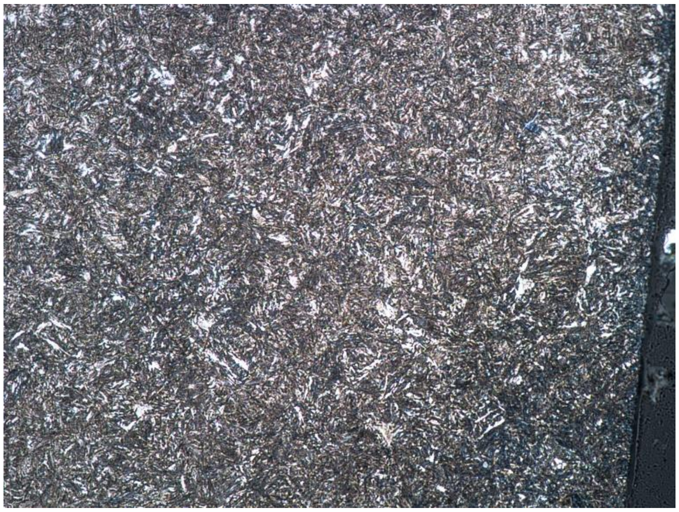

Figure 6 – 400X Case of Shaft

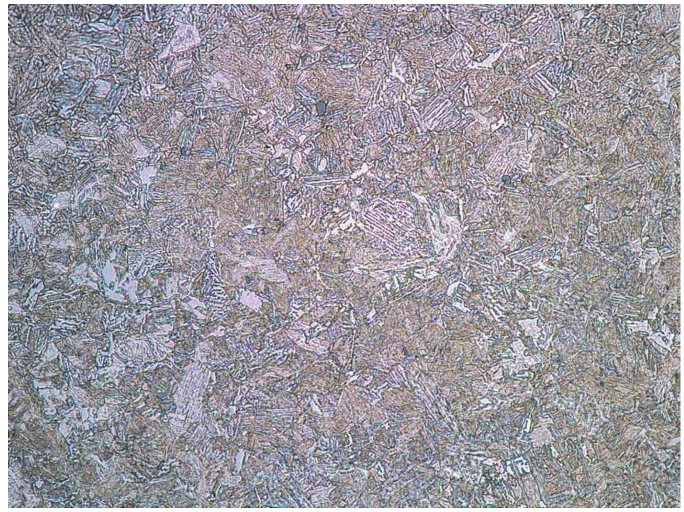

Figure 7 – 400X Microstructure Core of Shaft

There was ferrite in the carburized case of the shaft. The ferrite is the white areas in Figures 6. The presence of ferrite explains the low hardness and is a positive indicator of slack quenching, which increases the vulnerability of the shaft to fatigue failure. Ferrite is essentially pure iron and, being much weaker than the martensitic matrix, will act as fracture initiation sites.

The pump gear teeth were worn and had burrs, indicating that the carburized case hardness and microstructure on the gear teeth were similar to that on the drive end of the shaft.

The microstructure in the core of the shaft consisted of tempered low carbon martensite, Bainite, and acicular ferrite, Figure 7. The presence of acicular ferrite is a clear indicator of slack quenching.

Conclusions

1. The Shaft was not heat treated to manufacturer's carburizing specification.

2. The Shaft failed by high cycle fatigue.

3. The stress levels were not high enough to have caused the shaft to fail if it had been properly heat treated.