FAILURE ANALYSIS OF CRACKED PULLEY HUBS

EXAMPLE REPORT

Modified from Original Report

OVERVIEW & OUTCOME

This work was completed in less than 24 hours.

The conducted failure analysis found that the hubs had cracked due to a material quality issue. The original bar stock had contained seam flaw. This indicated that (a) only the hubs made from the affected material lot were at risk and (b) eddy current inspection was a viable method of sorting. This allowed the supplier to ship another batch of hubs to resume production and sort the quarantined lot with confidence.

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INVESTIGATION OF CRACKED PULLEY HUBS

SUMMARY

Cracking of the hubs was the result of pre-existing seam flaw(s) within the original bar stock material. The seams were the result of iron oxide scale having been entrained during original material processing. Cracks had initiated from the seam and propagated inwards.

No seams or cracks were observed on the hub which had passed eddy current testing.

1.0 INTRODUCTION

Four steel hubs were submitted for analysis, three of which exhibited cracks. Of these three cracked hubs, one was mounted in phenolic pulley. This hub was found to have cracked during installation of the pulley. The other two, cracked hubs remained un-mounted and had been found cracked during sorting by eddy current non-destructive. The fourth submitted hub had passed the eddy current testing.

The hubs were intended to be apart of a pulley assembly and comprised of C12L14 grade steel bar. The hubs had been machined and spray plated with zinc aluminium (the bore was masked during this spray coating).

Steel Image was requested to determine the nature of the cracks. The following report summarizes the observations and conclusions made during the course of the investigation.

2.0 EXAMINATION OF THE CRACKED HUBS

2.1 Visual/Macroscopic Examination

Figure 1 displays the four samples submitted. Examination of the hub mounted in the phenolic pulley found a crack within the hub which extended into the phenolic (Figure 2). The single crack within the hub extended along the full length of the hub and through the wall. It was reported the phenolic media had cracked during installation.

Both of the unmounted, cracked hubs consisted of one crack each (Figure 3). The cracks extended along the full length of the hub and through the wall thickness. Figure 4 displays the crack on one of the hubs.

One hub was cut in order to open up the fracture surface for examination. Figure 5 displays the mating fracture surfaces. The bulk of the surface exhibited a dark, rough texture. The black colouration indicated the fracture had experienced heat exposure after cracking.
The fracture surface at the outer diameter of the hub, corresponding to the knurling, exhibited a different surface texture than the remainder of the fracture surface. This surface area was further examined by scanning electron microscopy (SEM) techniques and is discussed in **Section 2.3**.

### 2.2 Optical Microscopy

A longitudinal cross-section was taken adjacent the fracture of the opened hub. Two transverse cross-sections of the second, cracked hub were also taken. The metallographic specimens were prepared in accordance with ASTM E3.

Optical examination of the core material of the cracked hubs revealed a microstructure typical of a C12L14 steel. The core structure comprised of an equiaxed ferritic and pearlitic structure with a ratio of 90:10 respectively. A large density of manganese sulphides inclusions, characteristic of 12L14 steel, was observed throughout the structure. **Figure 6** displays the core microstructure adjacent the crack.

Optical examination of the transverse sections taken through a crack revealed entrained material within the crack near the outer diameter. The entrained material was observed extending from the surface to an approximate depth of 2mm. **Figure 7** displays the entrained material within the crack.

### 2.3 SEM / EDS Analysis

The cross-section of the crack illustrated in Figure 4 was prepared and examined by scanning electron microscopic (SEM) techniques. Energy Dispersive Spectroscopy (EDS) analysis of the entrained material detected the presence of iron and oxygen. Therefore, the entrained material was identified as iron oxide. **Figure 8** displays examples of obtained spectrums of the entrained oxide at two locations.

The opened fracture surface was also examined using an SEM. Examination of the outer diameter region of the fracture surface, located at the hub knurling, did not reveal the presence of fracture features. Instead, EDS analysis of the surface detected large amounts of oxygen along with iron identifying this surface comprised of iron oxide. This region void of fracture features and comprising of iron oxide extended to a depth of approximately 1.5mm from the outer diameter. Note that this region corresponded to the portion of the crack examined in cross-section which also exhibited entrained iron oxide. **Figure 9** displays this region of the fracture surface and the EDS spectrum obtained.

The remainder of the surface comprised of microvoid coalescence fracture features typical of ductile overload. **Figure 10** displays examples of the fracture features at the bore surface and mid-wall thickness. EDS analysis detected trace amounts of oxygen typical for limited temperature exposure.
3.0 EXAMINATION OF THE “PASSED” HUB

Visual and macroscopic examination at ten times magnification did not find any cracks or notable features on the hub which had passed eddy current testing. A longitudinal cross-section was taken first and then a transverse section was made from the remainder of the hub. The samples were prepared for metallographic evaluation in accordance with ASTM E3.

Optical examination of the core microstructure found a structure similar to the failed hubs. The core structure comprised of equiaxed ferrite and pearlite. Copious amounts of manganese sulphide inclusions were observed throughout the specimens. Figure 11 displays an example of the core microstructure of the “Passed” Hub.

Transverse cross-sections are aligned perpendicular to any longitudinal features along the length of the bar and, therefore, examination of these sections would be able to detect the presence of cracks or seams on this plane. Examination of the transverse cross-section made from the “Passed” hub did not reveal the presence of any seams or cracks. Figure 12 displays an example of a knarl tooth.

4.0 CONCLUSIONS

The cracking experience by the three hubs examined were the result of a pre-existing seam flaw in the as-supplied C12L14 bar stock material. The seam was located on the outer diameter of the bar and was the result of entrained iron oxide scale. A crack had initiated from the seam and had propagated inwards. The presence of dark heat tinting on the crack surface indicated the crack had existed prior to the last heat treatment above 300°C.

The iron oxide responsible for creating the seam defect had likely been entrapped in the steel during either the casting process or, more likely, the bar rolling process. Due to the reduction processes when processing a cast billet into bar, seam flaws are longitudinally oriented. The lengths of seams can vary significantly. Seams can range from several inches in length to a significant portion of the total bar length.

Therefore, cracking was due to a material quality issue which was specific to a bar material lot. Hubs made from different material lots would be unlikely to be at risk of cracking.

No seams, cracks or notable features were observed on the hub which had passed eddy current testing. The “Passed” hub exhibited a similar microstructure as the cracked hubs. Based upon the location and nature of the flaw, eddy current testing of the hub faces would be a reliable method of detecting hubs containing this flaw.
Figure 1: Photograph displaying the as-received samples.

Figure 2: Photograph displaying the crack extending from the hub into the phenolic pulley.
Figure 3: Photograph displaying the two cracked, un-mounted hubs.
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Figure 4: Photographs displaying the crack on one of the hubs. The crack extended through the wall thickness along the entire length of the hub.
Figure 5: Photographs displaying the fracture surfaces of one hub after opening.

Figure 6: Micrographs displaying the core microstructure adjacent the fracture. Taken in the bar’s longitudinal orientation. The microstructure was typical for a C12L14 steel. Etched using 3% nital.
**Figure 7:** Micrographs displaying entrained material within the crack. As-polished condition.
Figure 8: SEM images and EDS spectrums of the material found within the crack. The material comprised of iron oxide. SE1, 20kV.
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Figure 9: SEM images and EDS spectrum of the fracture surface at the outer diameter. EDS analysis detected the presence of iron oxide covering this portion of the fracture surface. SE1, 20kV.
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Figure 10: SEM images displaying the remainder of the fracture surface exhibiting microvoid coalescence typical of ductile overload. Small amounts of oxygen was detected throughout the fracture surface. SE1, 20kV.
Figure 11: Micrographs displaying the core structure of the “Passed” Hub in the longitudinal orientation. The structure was typical of a C12L14 material. Etched using 3% nital.

Figure 12: Micrograph displaying an example of a knarl tooth from the “Passed” Hub. No cracks or seams were observed on the cross-section of this hub. As-polished condition.