

FAILURE ANALYSIS OF MINE CONVEYOR SHAFT

EXAMPLE REPORT

Modified from Original Report

OVERVIEW & OUTCOME

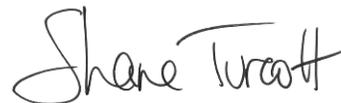
Conveyor shaft failure had resulted in significant lost production of a gold mine.

Failure analysis found that, although a sprocket gear misfit issue had been correctly shortly after shaft installation, the shaft had already formed fatigue cracks. Although loading was reduced during continued service, crack growth continued slowly until recent failure. Had the shaft been inspected at the time of sprocket gear correction, by magnetic particle or an equivalent method, the crack would likely have been detected and catastrophic failure prevented.

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FAILURE ANALYSIS OF MINE CONVEYOR SHAFT

SUMMARY

Fatigue failure of the conveyor shaft had been caused by misalignment between the shaft and a non-rotating component. The bending loading causing fatigue initiation matched with an historical dimensional misfit issue with the sprocket gear. Misalignment from the dimensional issues had applied consistent bending loading as the shaft rotated, forming fatigue cracks around the shaft circumference. Although the misfit issue had been corrected three years earlier, undetected fatigue cracks formed at that time eventually resulted in failure.

1.0 INTRODUCTION

██████████ gold mine based in ██████████ had experienced failure of an apron feeder conveyor shaft. The conveyor and its shaft had been installed in 2014. After only two months of service, the shaft had been removed and misfit issues with the drive side sprocket were corrected by re-machining of the shaft. After three years back in service, the shaft suffered failure. **Figure 1** displays provided photographs of the shaft prior to and after failure. The shaft was to comprise of hardened 4340 low alloy steel.

Steel Image was requested to determine the details of failure.

2.0 EXAMINATION

2.1 Examination of the Fracture

Figure 2 displays the submitted shaft. The drive side shoulder of the shaft had fractured off at the corner radius associated with the arm reduction in shaft diameter. **Figure 3a** displays the fracture surface as-received.

The shaft fracture region, plus the mirrored/opposite end of the shaft, was cut down in size to allow for cleaning of select regions of interest. Examination found that fracture had occurred during two different loading periods (**Figures 3b and 5**). The two phases of failure/loading can be described as:

Phase I High cycle fatigue cracks had initiated around the majority of the shaft perimeter (**Figures 4 and 6c,d**). These cracks had grown to a depth of 2.5 inches. Fatigue cracks around the shaft perimeter indicated an alignment issue between the shaft and a non-rotating component within this area of the shaft (ie. bearing, sprocket, drive chain, etc).

Phase II The loading responsible for Phase II was quite different from Phase I. Whereas the full perimeter of the shaft experiencing bending loading constantly as it rotating during Phase I, Phase II only experienced bending loading on one side during each revolution. Phase II transitioned between fatigue crack growth and brittle fracture (**Figures 6e,f and 7**). Thousands of fatigue cycles were observed between brittle fracture periods, suggesting occasional shock/impact loading during service.

2.2 Material Evaluation

Testing found the shaft material to be of reasonable quality. Failure was not attributed to a material quality issue. The only material property of note was that the material exhibited low toughness, common for such large components. This low toughness had contributed to the rate of crack growth during the second phase of failure. However, as fatigue cracks had already formed in Phase I, prior to brittle cracking having occurred, the low toughness had not contributed to crack initiation and therefore, was not the cause of failure.

Chemical analysis of the shaft material was performed in accordance with ASTM E415. **Table 1** lists the obtained results which conformed to common 4340 requirements such as AISI, SAE, ASTM A322, etc.

Table 1: Chemical Analysis Results of the Shaft

Sample	Composition (wt%)							
	C	Mn	Si	S	P	Cr	Mo	Ni
ASTM A322 4340	0.37- 0.44	0.55- 0.90	0.10- 0.35	0.040 Max	0.040 Max	0.65- 0.95	0.20- 0.35	1.55- 2.00
Shaft	0.43	0.68	0.27	0.003	0.011	0.81	0.26	1.79

Tensile testing of shaft material taken at mid-radius was performed in accordance with ASTM A370. **Table 2** lists the obtained results. The shaft exhibited high strength expected for such applications.

Table 2: Liner Tensile Test Results

Yield Strength (ksi)	UTS (ksi)	Elongation (%)
98.5	156.0	10

Charpy impact testing was conducted at 70°F (21°C) in accordance with ASTM E23. **Table 3** lists the obtained results. The material exhibited low toughness. Although not deemed as the cause of shaft failure, the low toughness had accelerated the rate of failure during Phase II.

Table 3: Liner Charpy Impact Test Results

Absorbed Energy (ft-lbs)		Avg. Lateral Expansion (mils)	Percent Shear (%)
Measurements	Avg. Abs. Energy		
10, 10, 11	10	4	10 (almost entirely brittle)

A Rockwell hardness profile was conducted in accordance with ASTM E18. The hardness profile was zeroed at the initiation region. **Table 4** lists the obtained results.

Optical microscopy found the shaft material at the crack initiation region to comprise of a mixture of martensite and bainite. The microstructure was consistent with the shaft material having been hardened and then machined to final shape. No irregular features or material quality issues were observed by optical microscopy.

Table 4: Hardness Profile Results

Distance from Initiation Region (mm)	Hardness (HRC)
0	31.5
5	30.5
10	31.0
15	31.5
20	31.0
25	29.5

3.0 CONCLUSIONS

Failure of the conveyor shaft had initiated by fatigue cracking caused by misalignment between the shaft and a non-rotating component. The bending loading causing fatigue initiation matched with an historical dimensional misfit issue with drive side sprocket. As a result of the misfit, misalignment between the shaft, sprocket and/or drive side bearing had applied consistent bending loading as the shaft rotated, forming fatigue cracks around the shaft circumference. This portion of loading and crack growth was referred to as Phase I.

At some point, marking the end of Phase I, the loading drastically changed. By this time, the deepest fatigue crack had grown to a depth of 2.5 inches. It was likely that this initial period of crack growth corresponded to loading during the first two months of service when issues with the sprockets had likely applied increased bending loading onto the shaft.

Note that had the shaft been inspected at the time of sprocket repair, such as by magnetic particle inspection (MPI), detection of the crack would have been probable and catastrophic failure likely prevented. It was unlikely that visual examination would have been able to reliably resolve the cracks at that time.

After Phase I, the loading changed to side bending loading applied onto only one side of the shaft. Whereas Phase I loading had formed cracks all around the shaft circumference, crack growth during Phase II had occurred from one side of the shaft and grew across it. The change in loading was suspected to have occurred at the time of re-installation after shaft/sprocket repair. During Phase II, crack growth was initially dominated by progressive brittle fracture yet later transitioned to include periods of fatigue crack growth.

All of the material testing performed to date found the shaft material to be of reasonable quality. The shaft conformed to the 4340 low alloy compositional requirements, had been properly heat treated and was of high strength. The only notable material property was that the shaft exhibited low toughness. The low toughness of the material had contributed to the rate of crack growth occurring during Phase II yet, as mentioned before, had not contributed to fatigue crack initiation.

It was noted that the shaft corner radius at the site of failure was relatively sharp, reducing the amount of misalignment/bending loading that the shaft could withstand prior to forming fatigue cracks. Further analysis/consideration of the corner radius is currently on-going. However, at this point in the investigation, the source of misalignment/bending loading appears to have been the primary cause of failure.

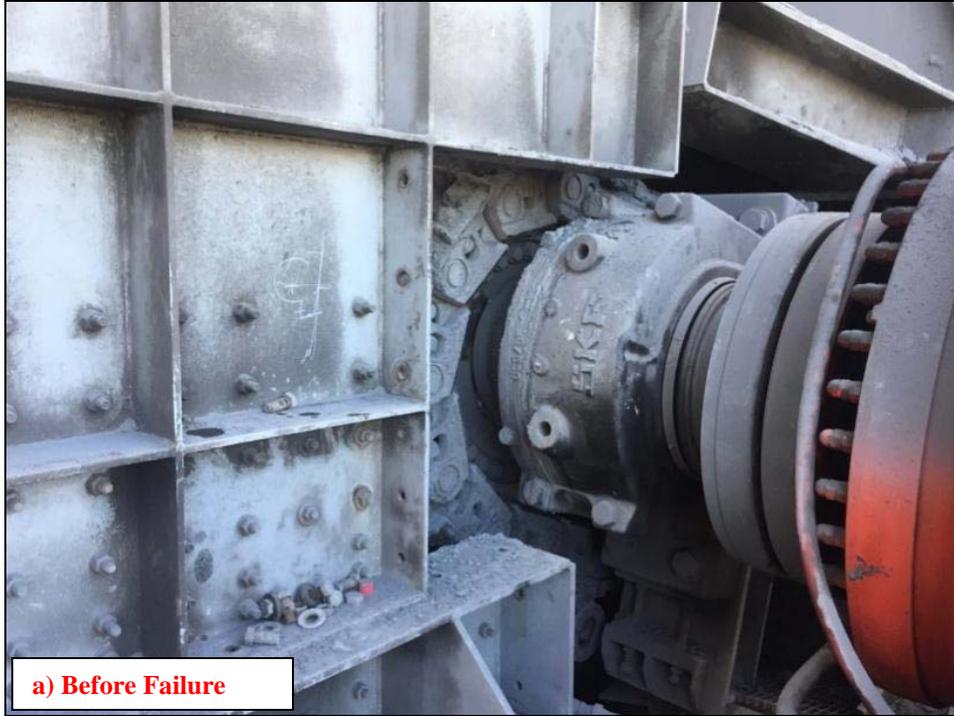


Figure 1: Photographs provided of the assembly (a) prior to failure and (b) after failure.



Figure 2: Photographs displaying the submitted shaft samples. The sprocket gears had been removed prior to submission.

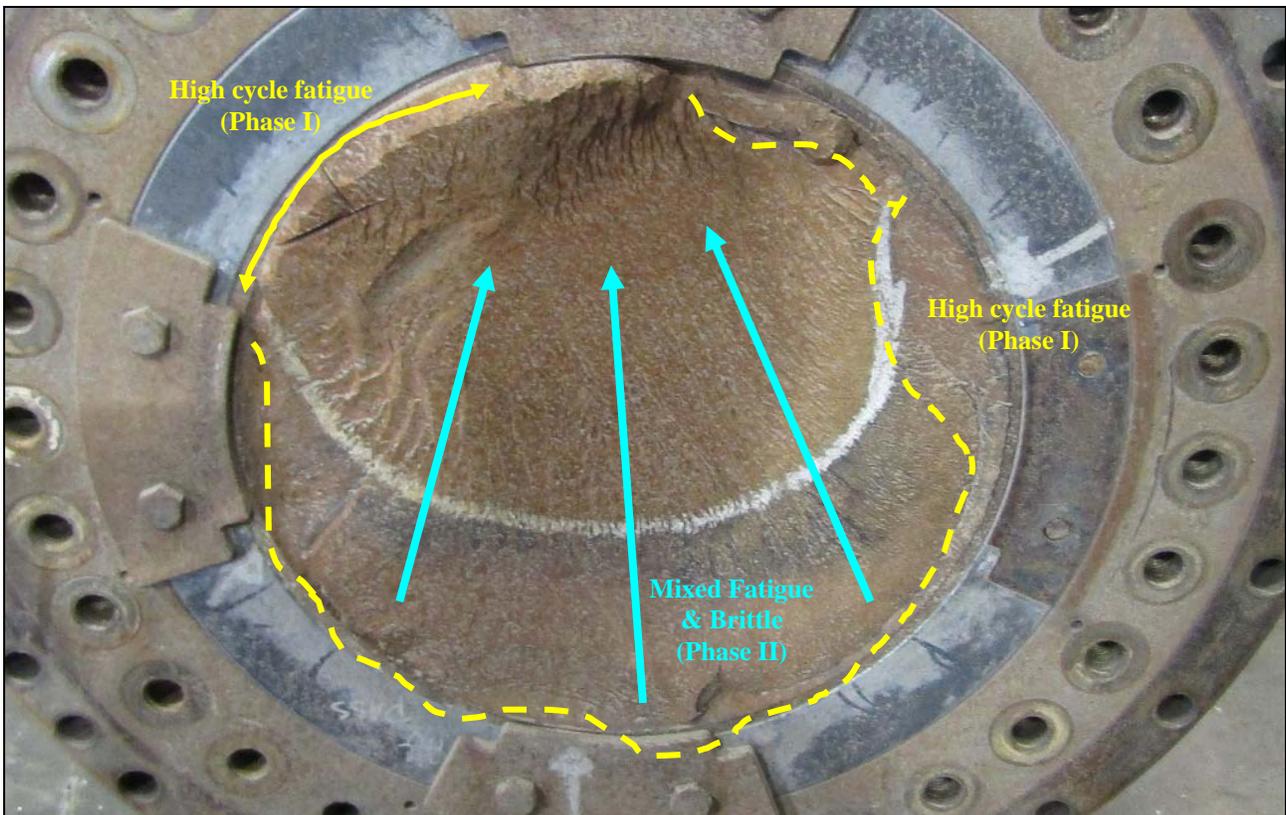


Figure 3: Photographs displaying the shaft fracture. Analysis would find that failure had occurred in two phases.

Phase I – High cycle fatigue cracking had initiated around the shaft circumference. Associated with an alignment issue between the shaft and a non-rotating component (ie. such as a bearing, sprocket, drive chain, etc).

Phase II – Loading very different from initial, Phase I loading. This loading comprised of asymmetric side bending loading applied during shaft rotation (ie. misalignment of rotating component). Crack growth occurred by mixed fatigue and brittle fracture. Phase II was deemed as secondary damage after crack initiation during Phase I.

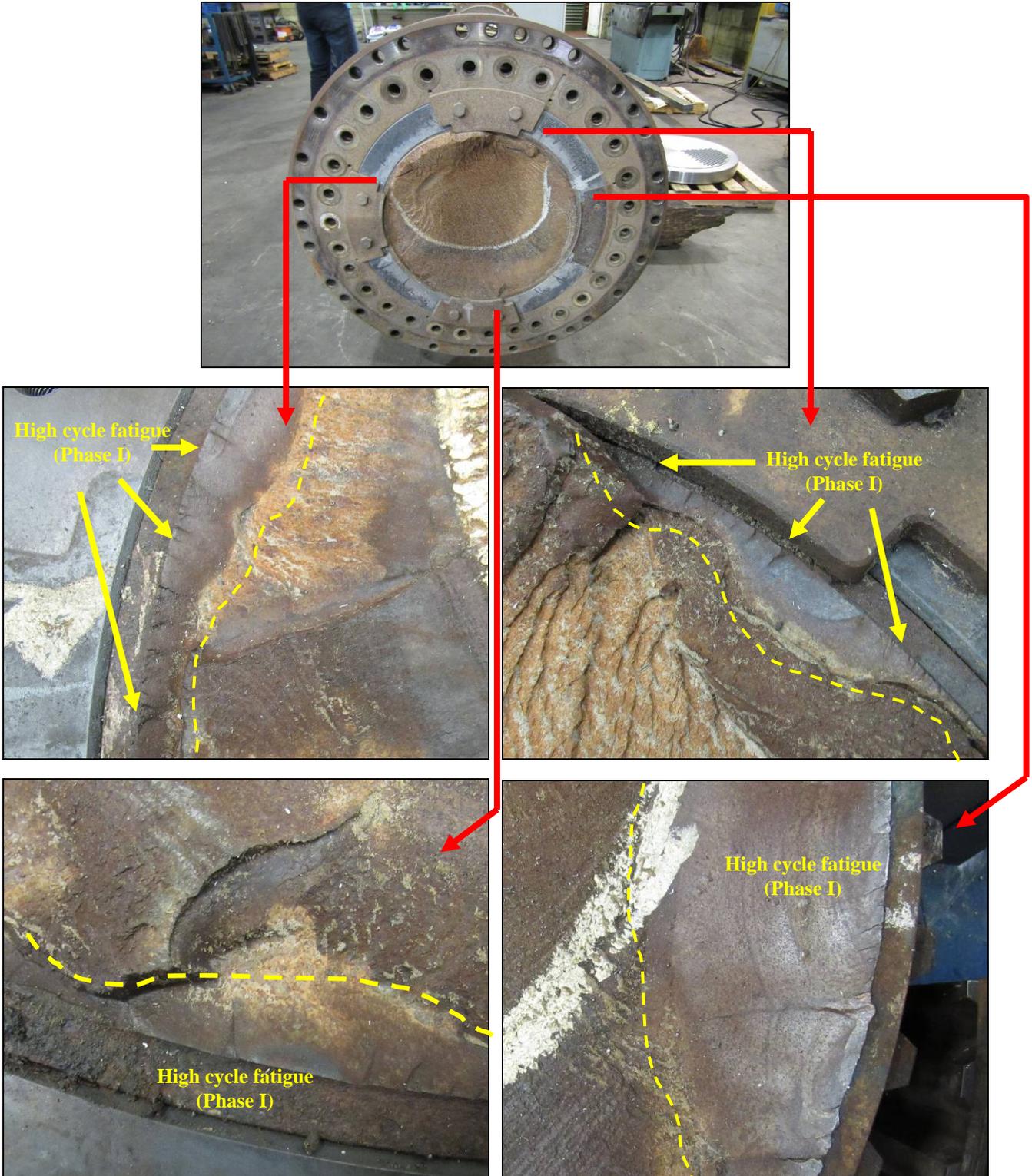


Figure 4: Photographs displaying high cycle fatigue cracks around the majority of the shaft circumference. These cracks had initiated at the corner radius associated with the reduction in shaft diameter.

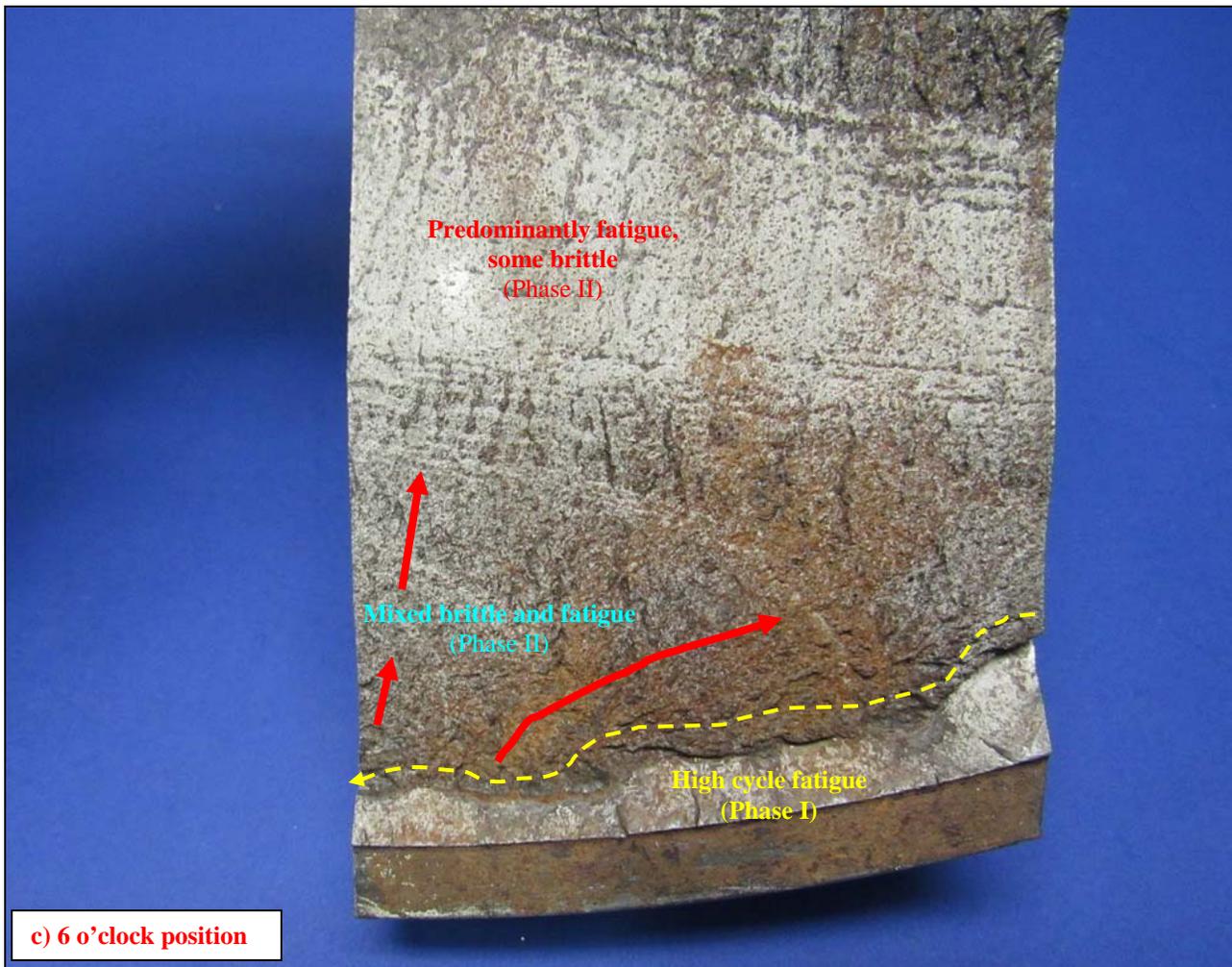
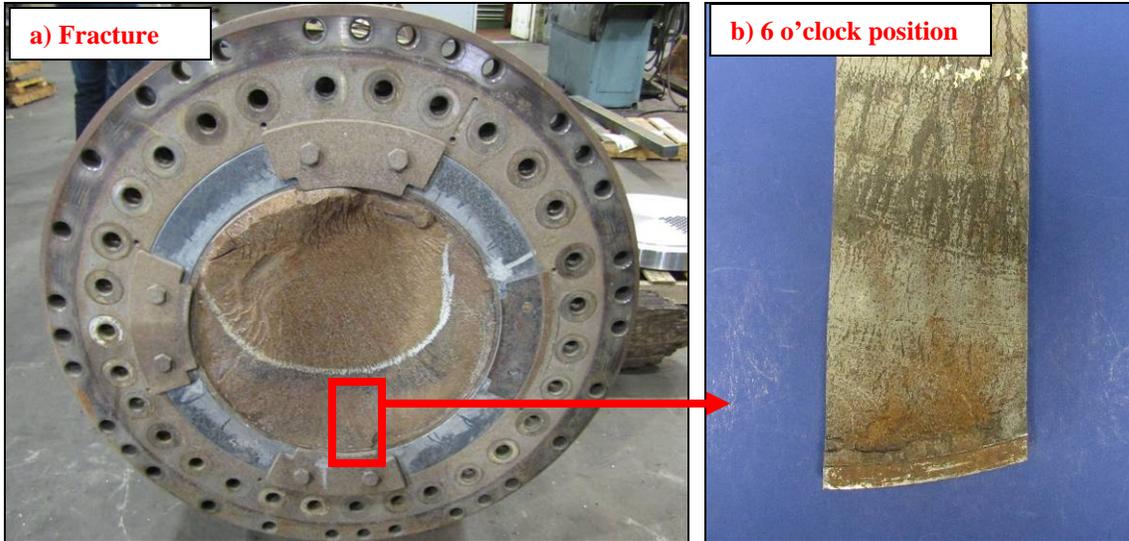


Figure 5: Photographs illustrating the Phase I high cycle fatigue and the Phase II mixed fatigue/brittle fracture. The beginning of Phase II was dominated by brittle fracture before becoming predominantly fatigue crack growth.

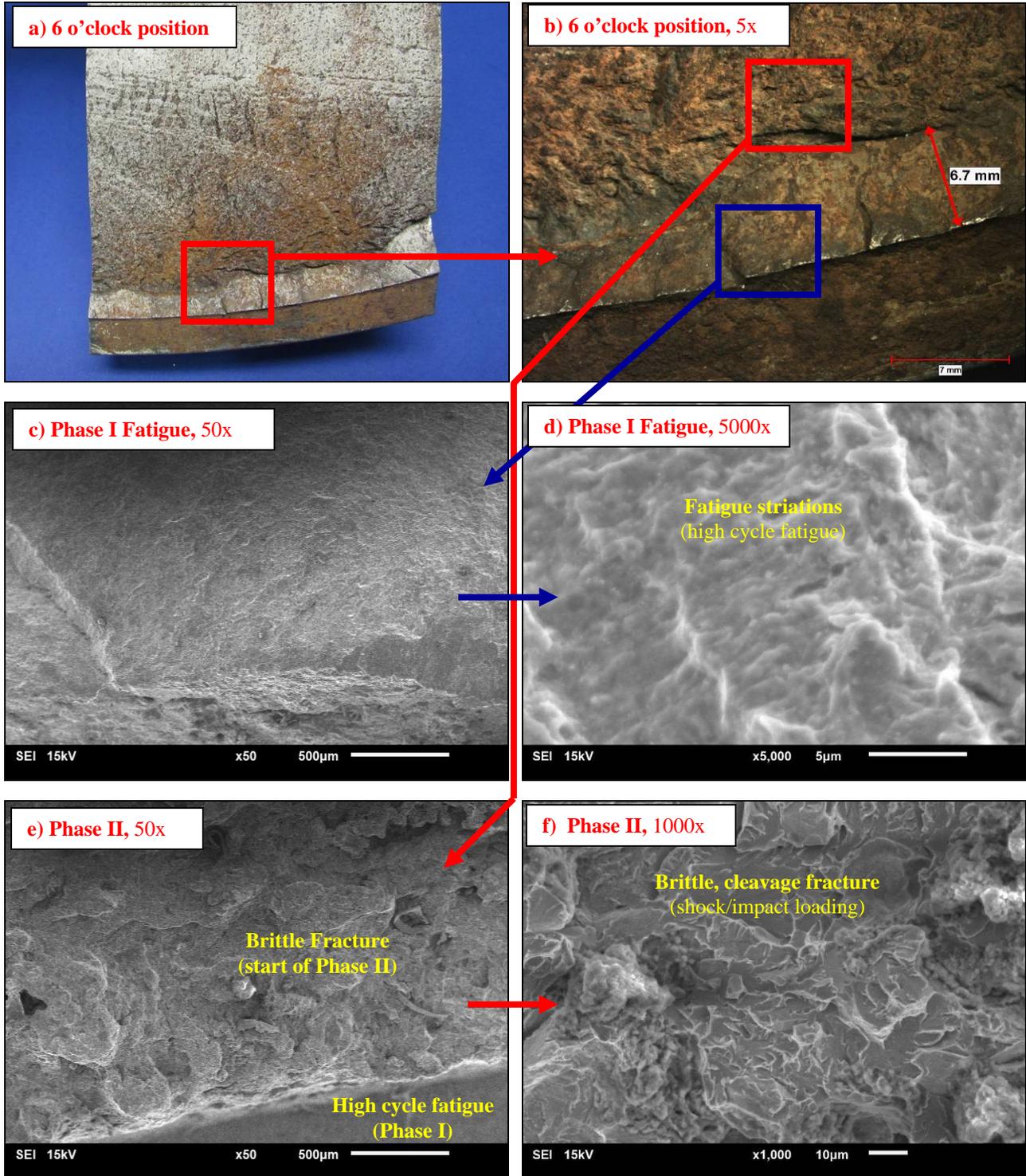


Figure 6: Photograph, macrograph and SEM images displaying (c,d) Phase I cracking had occurred by high cycle fatigue. (e,f) After high cycle fatigue, Phase II initiated by brittle fracture. Note again that the loading responsible for Phase II was quite different from Phase I, suggesting some adjustment/change had been made between phases (loading change suspected to correspond to re-installation of the repaired shaft in 2015). SEI, 15kV.

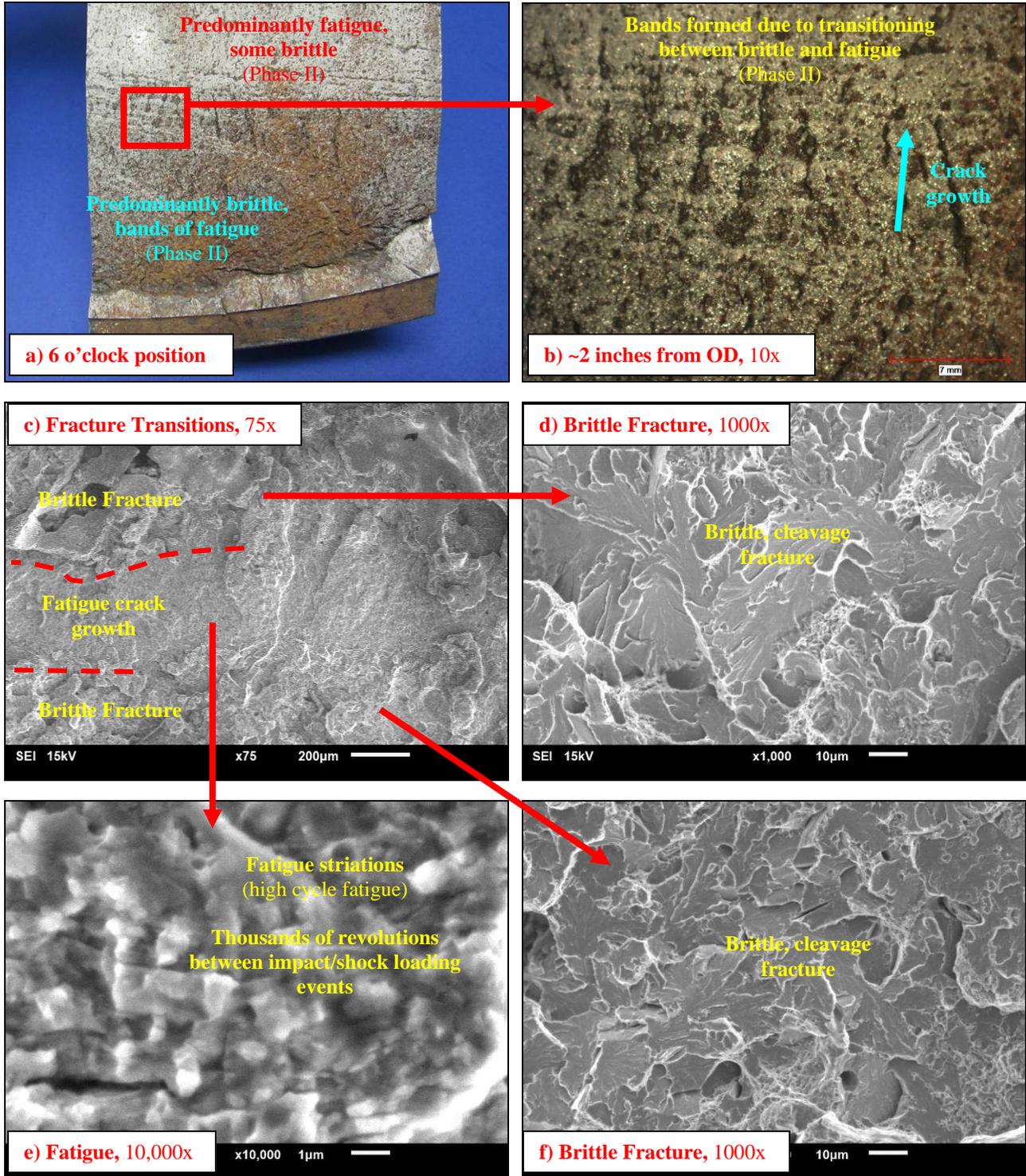


Figure 7: SEM images displaying the transitioning between brittle fracture and fatigue when the Phase II crack was approximately 2½ inches deep. This indicated that the shaft had experienced impact/shock loading, causing brittle crack growth, followed by periods of thousands of rotations before experiencing another impact/shock loading event. SE1, 15kV.