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FAILURE ANALYSIS OF MINE SHAFT HOIST BRAKE SPRINGS

EXAMPLE REPORT

Modified from Original Report

OVERVIEW & OUTCOME

Analysis found that the mine shaft brake springs had failed due to a quality issue with the spring steel. The full length of the steel coil used to make these springs would have been at risk of having unacceptable defects. Combined with the difficulties to thoroughly inspect the springs, in order to guarantee reliability, it was recommended that all springs from this lot be replaced.

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FAILURE ANALYSIS OF MINE SHAFT HOIST BRAKE SPRINGS

SUMMARY

The two mine shaft brake springs had failed due to a material quality issue. The steel wire comprised of entrained refractory from steel making. This entrained material and associated divets had acted as stress concentrators, initiating fatigue failure

Other springs made from this steel coil would also be at risk of having the same material defects. It is recommended that this lot of springs be replaced.

1.0 INTRODUCTION

Two failed springs from a mine shaft hoist brake were submitted for analysis. As part of a braking assembly comprising of forty-eight springs, these springs had been in service for six years. **Figure 1** displays a photograph of the braking system. No changes in the operation of the mine hoist were reported.

This hoist was used to transport of both personnel and equipment down the mile deep mine shaft. The braking system was deemed as safety critical. The springs were visually inspected annually which is how these two failed springs were found. Discussion with the inspection department had included that, due to the spring stacks and the springs having been painted, inspection was limited to visual efforts and recognized as difficult in finding cracks prior to spring failure.

Another mine had an almost identical brake system which has been in service for eight years (two years longer) without incident.

Steel Image was requested to determine the nature of failure.

2.0 EXAMINATION

2.1 Visual / Macroscopic Examination

Figures 2 and 3 displays the springs submitted for the investigation. Spring #1 had failed two and a half turns from one end. Spring #2 had failed one and a half turns from an end.

Crack initiation on both springs had occurred at the inner diameter of the springs at material flaws. **Figures 4 and 5** display the fracture surface of Spring #1 and material flaw from which crack initiation had occurred. The depth of the material flaw was approximately 0.028 inches (0.7mm). Embedded foreign material was present on both halves of the fracture initiation site within the material flaw cavity. The flaw cavity was painted which indicated that this feature had been present at the time of spring manufacture.

Crack initiation at the flaw, and crack growth through approximately a third of the spring's cross-sectional area, had occurred by high cycle fatigue cracking. The crack

propagation mode then changed to overload failure for the remaining two-thirds. SEM examination would later confirm this region had failed by brittle fracture. **Figure 6** provides a summary of the sequence of failure for Spring #1.

Spring #2 exhibited similar fracture features as Spring #1. Crack initiation had occurred at a small material flaw cavity. The depth of the cavity was measured to be approximately 0.3mm (0.012 inches). Crack propagation had initially occurred by high cycle fatigue cracking through approximately a third of the cross-section. The remainder of the fracture comprised of brittle overload fracture features. **Figure 7** displays the fracture surface of Spring #2.

2.2 SEM Fractography

SEM examination of the fractures of Springs #1 and #2 found similar fracture features (**Figures 8 and 9**). Energy dispersive spectroscopy (EDS) found the entrained material within the cavities to comprise predominantly of aluminium and oxygen (**Figure 8f**). This was consistent with entrained refractory accidentally introduced during steelmaking. It was presumed these cavities had once been fully filled with refractory which, during wire drawing and/or spring forming, the majority of the refractory had been knocked out.

In either case, these cavities located along the inner diameter coil had acted as stress concentrators. The initial fatigue fracture features did not exhibited defined fatigue striations at first. This indicated that the stress concentration effects of the cavities/refractory had only increased the amplitude of cyclic loading to only marginally above the fatigue limit of the material (i.e. without this stress concentration effect, fatigue crack initiation may not have occurred). Midway through the fatigue zone, fatigue striations became apparent.

After penetrating through approximately a third of the cross-sectional area, the remainder of the spring cross-section had fractured by brittle fracture (typical for this notch sensitive material).

2.3 Chemical Analysis

Chemical analysis of Spring #1 was performed in accordance with ASTM E1019, E1097(mod) and E1479 (**Table 1**). The spring material matched AISI 5160 alloy steel.

Table 1: Chemical Analysis Results

Composition (wt%)						
C	**Mn**	**Si**	**S**	**P**	**Cr**	**Ni**
0.58	0.77	0.29	<0.005	0.01	0.75	0.11
B	Nb	V	Cu	Sb	As	
<0.001	<0.01	0.03	0.15	<0.01	<0.01	

2.4 Optical Examination

Longitudinal and transverse cross-sections were taken near the fracture on Spring #1. Optical examination of the sections revealed the core structure to comprise of tempered martensite. Such a structure was typical of a quenched and tempered heat treated AISI 5160 spring steel. **Figure 9** displays the core structure of Spring #1.

A cross-section was taken through the crack initiation site on Spring #1 (location indicated in **Figure 10a**). **Figure 10b,c** displays the cavity. Entrained refractory material was present within the cavity. A layer of oxide beneath the paint was present.

2.5 Mechanical Testing

Hardness testing was conducted on material from Springs #1 and #2 in accordance with ASTM E18. **Table 2** lists the obtained hardness of the springs. The hardness values were typical for spring applications.

Table 2: Hardness Results

Sample	Measurements (HRC)	Avg. Hardness (HRC)
Spring #1	45.5, 45.5, 45.5	46
Spring #2	45.0, 45.0, 45.0	45

3.0 CONCLUSIONS

The two mine shaft brake springs had failed due to a material quality issue. The steel wire from which the springs had been made from had comprised of entrained refractory from steel making. This entrained material and associated divets/cavities had acted as stress concentrators causing fatigue crack initiation

In further detail, refractory associated with the ladles in molten steelmaking had been accidentally cast into the steel. Between the wire drawing and spring coiling, the majority of the entrained refractory at the surface of the wire had been knocked out yet recessions/cavities remained on the surfaces of the springs. Compression springs are inherently sensitive to stress concentrators at the inner diameter coil surfaces. The recessions/divets from the entrained refractory, located along the inner diameter of the springs, had provided a stress concentration effect sufficient enough to marginally surpass the fatigue limit of the steel, eventually causing fatigue crack initiation.

This steel quality issue would likely extend onto other springs produced from this wire lot. Therefore, other springs purchased at that time from the same lot would also be at risk of having similar material defects. Combined with the difficulties to inspect the springs in their assembly, it is recommended that the mine consider replacing these springs.

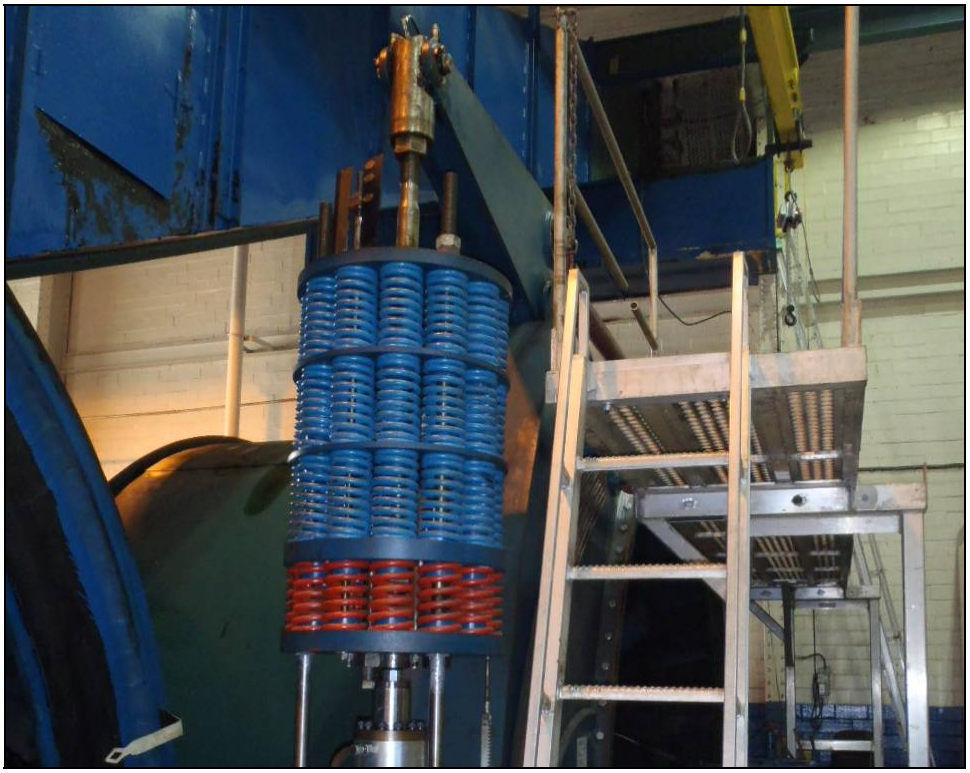


Figure 1: Provided photographs displaying the spring brake assembly at the head of a mine shaft.

Figure 2: Photograph displaying the two springs submitted for the investigation.

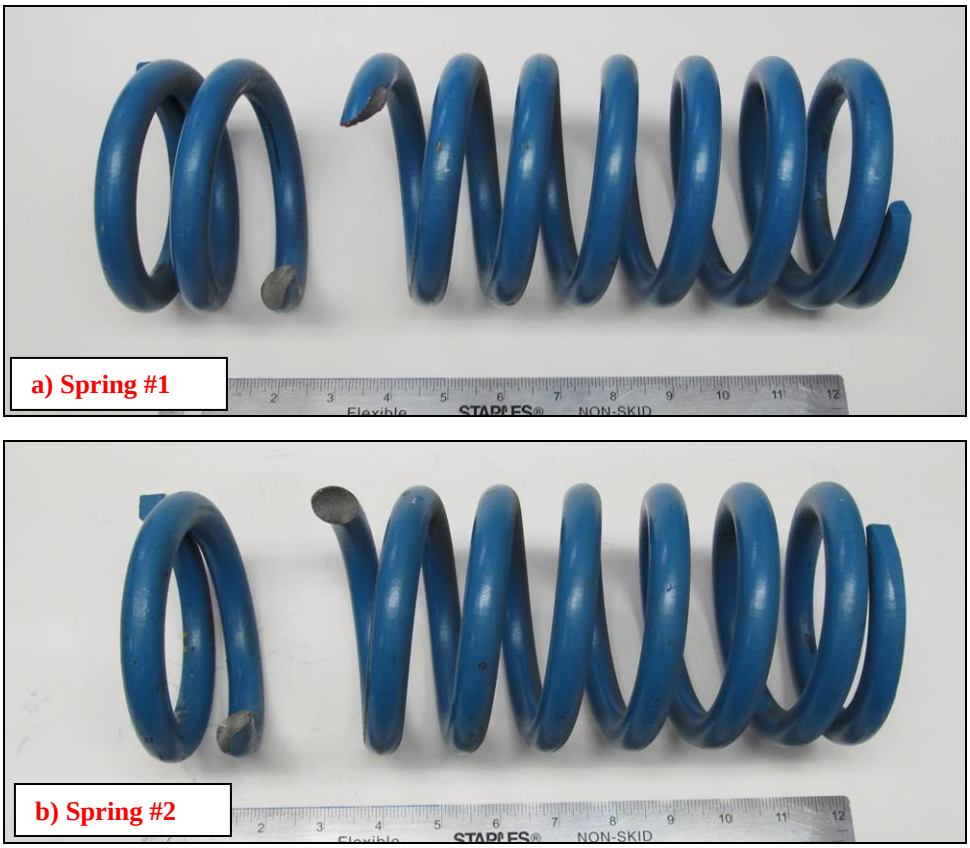
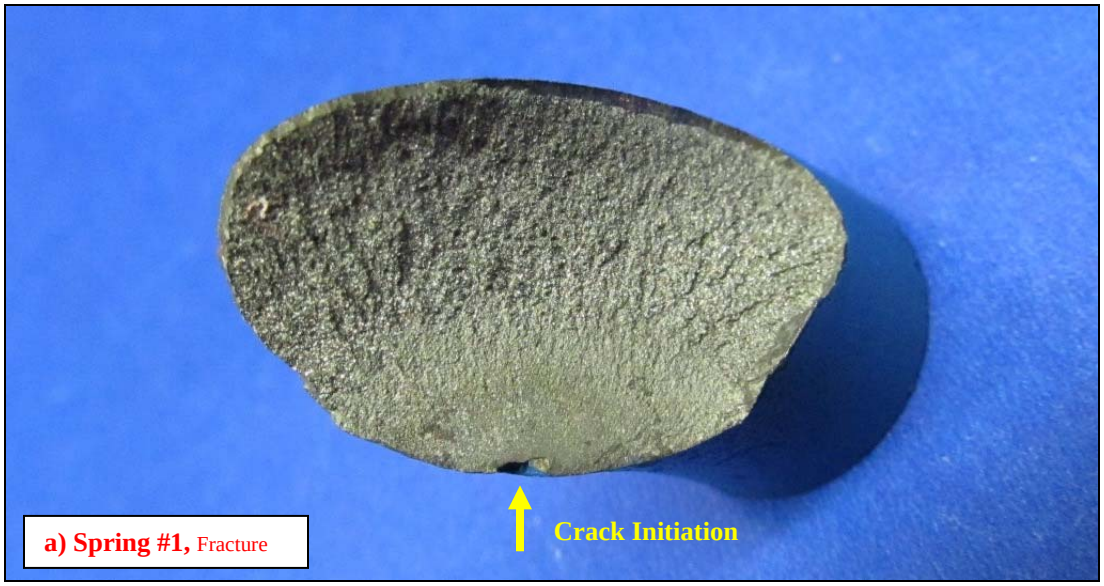


Figure 3: Photographs displaying the failed springs.



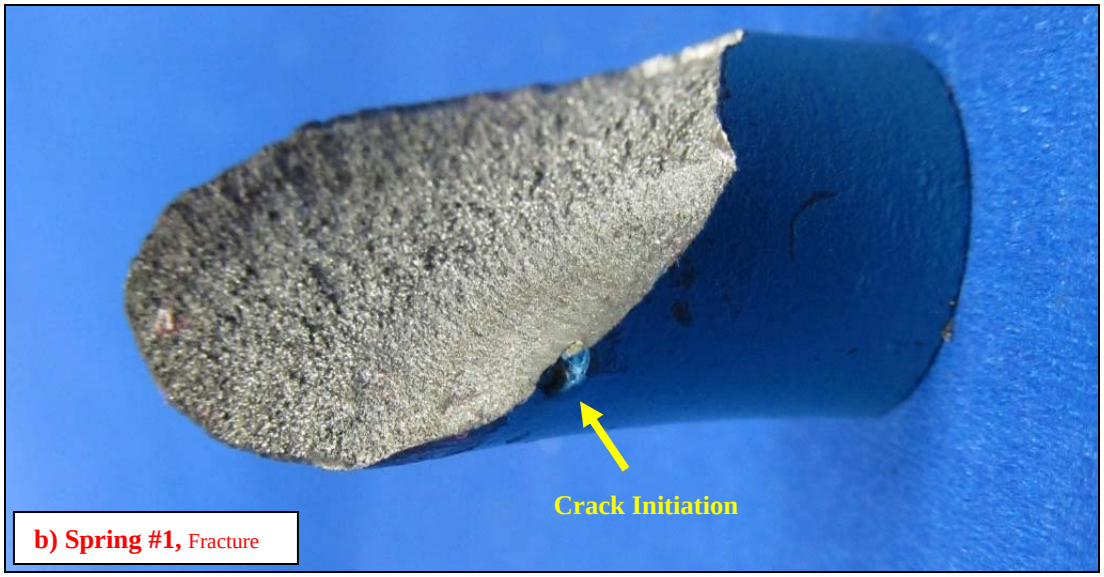


Figure 4: Photographs displaying the fracture surface of Spring #1. Fatigue crack initiation had occurred at a geometrical recession/surface cavity. The paint on the cavity indicated this feature had been present on the as-manufactured spring. Further examination would find that these cavities had been formed as a result of entrained refractory during steelmaking.

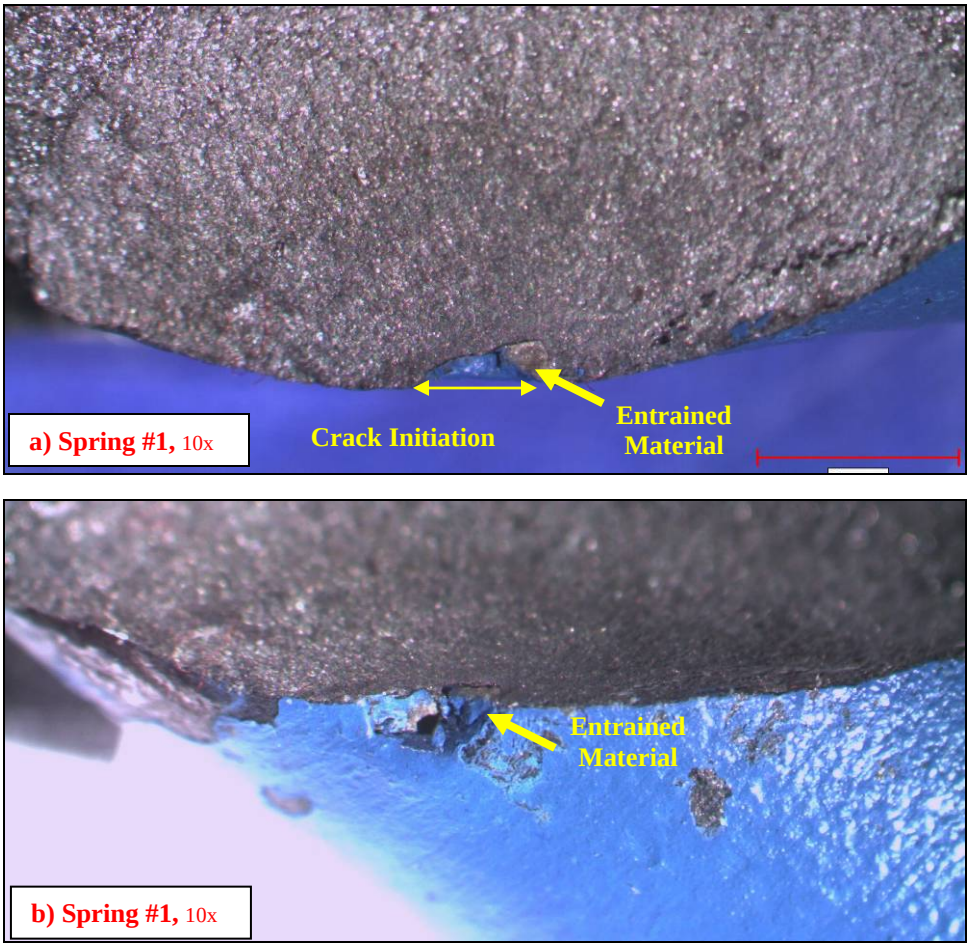
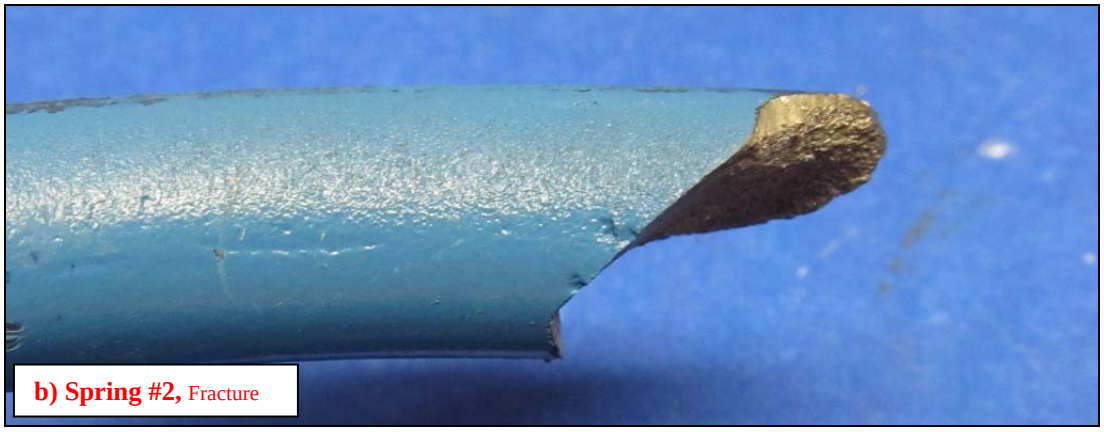


Figure 5: Macrographs displaying the material flaw from which crack initiation had occurred. The 0.028 inches (0.7mm) cavity was painted. Within the cavity was foreign material embedded into the steel, later confirmed to be entrained refractory.

Figure 6: Photograph marked with the details of failure. Fatigue crack initiation had occurred at the cavity at the inner diameter coil of the spring. The fatigue crack had grown through approximately a third of the cross-sectional area before brittle, final failure.



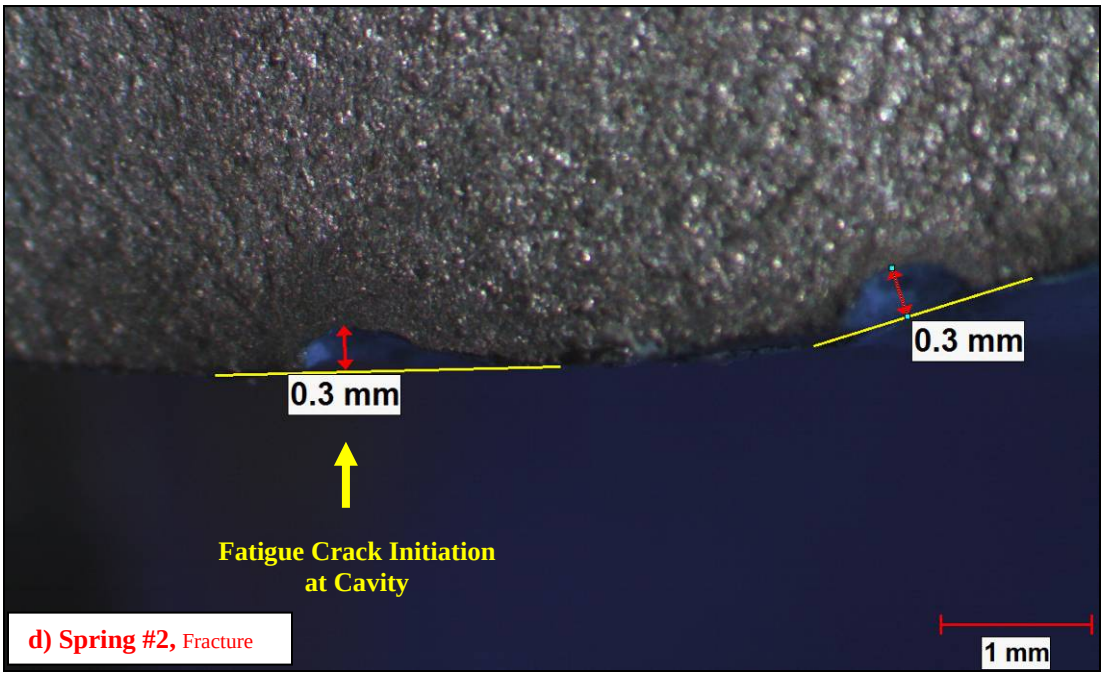


Figure 7: Photographs displaying the fracture on Spring #2. Similar to Spring #1, fatigue crack initiation had occurred at geometrical cavity located at the inner diameter of the spring.

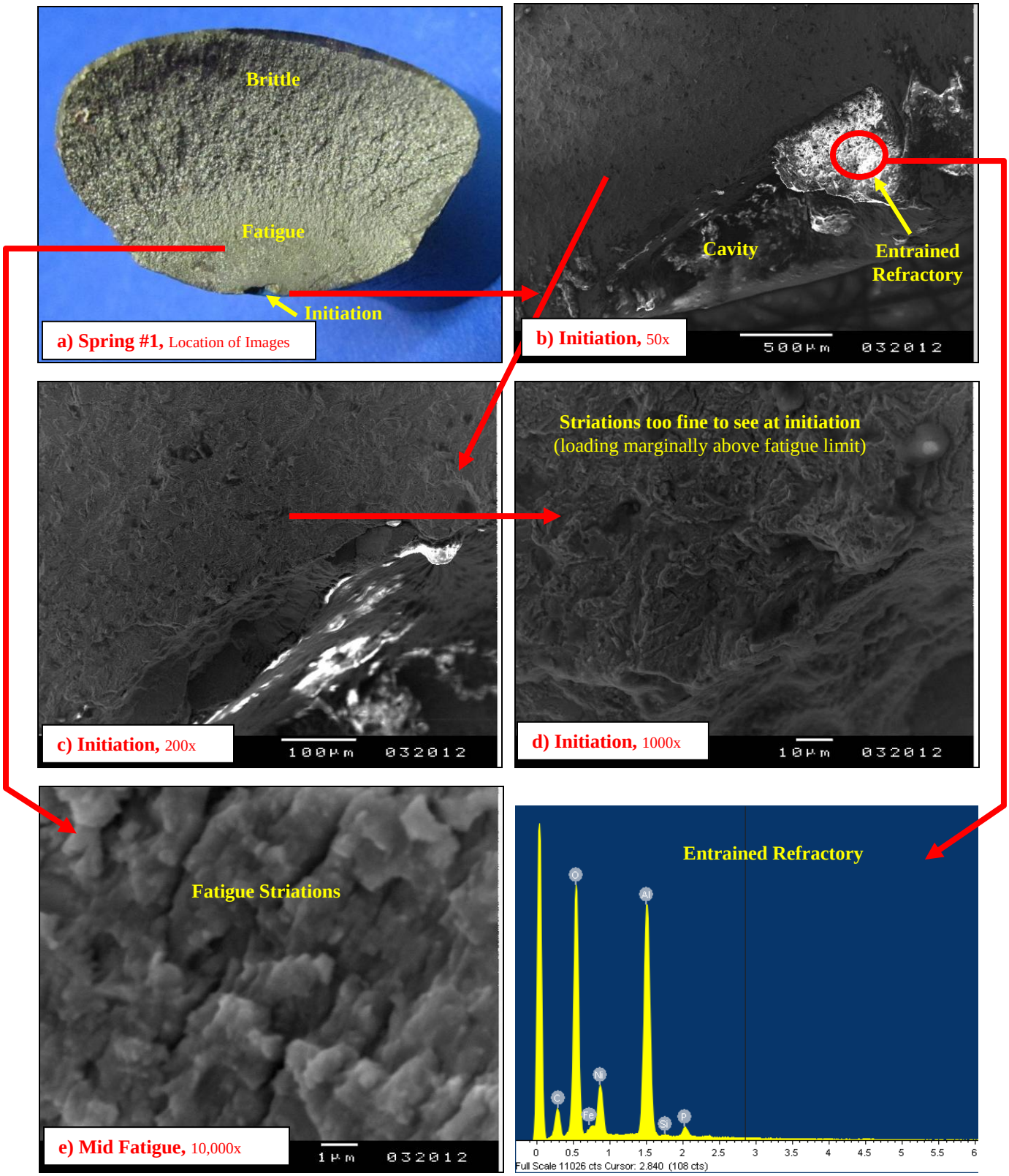


Figure 8: SEM images and EDS spectra displaying (b,f) the initiation site to comprise of entrained refractory (predominantly Al, O). (c,d) The refractory and cavity had marginally put the loading above the fatigue limit, apparent from no defined fatigue striations at the initiation site. (e) Fatigue striations become apparent mid-way through the fatigue zone. SE1, 20kV.

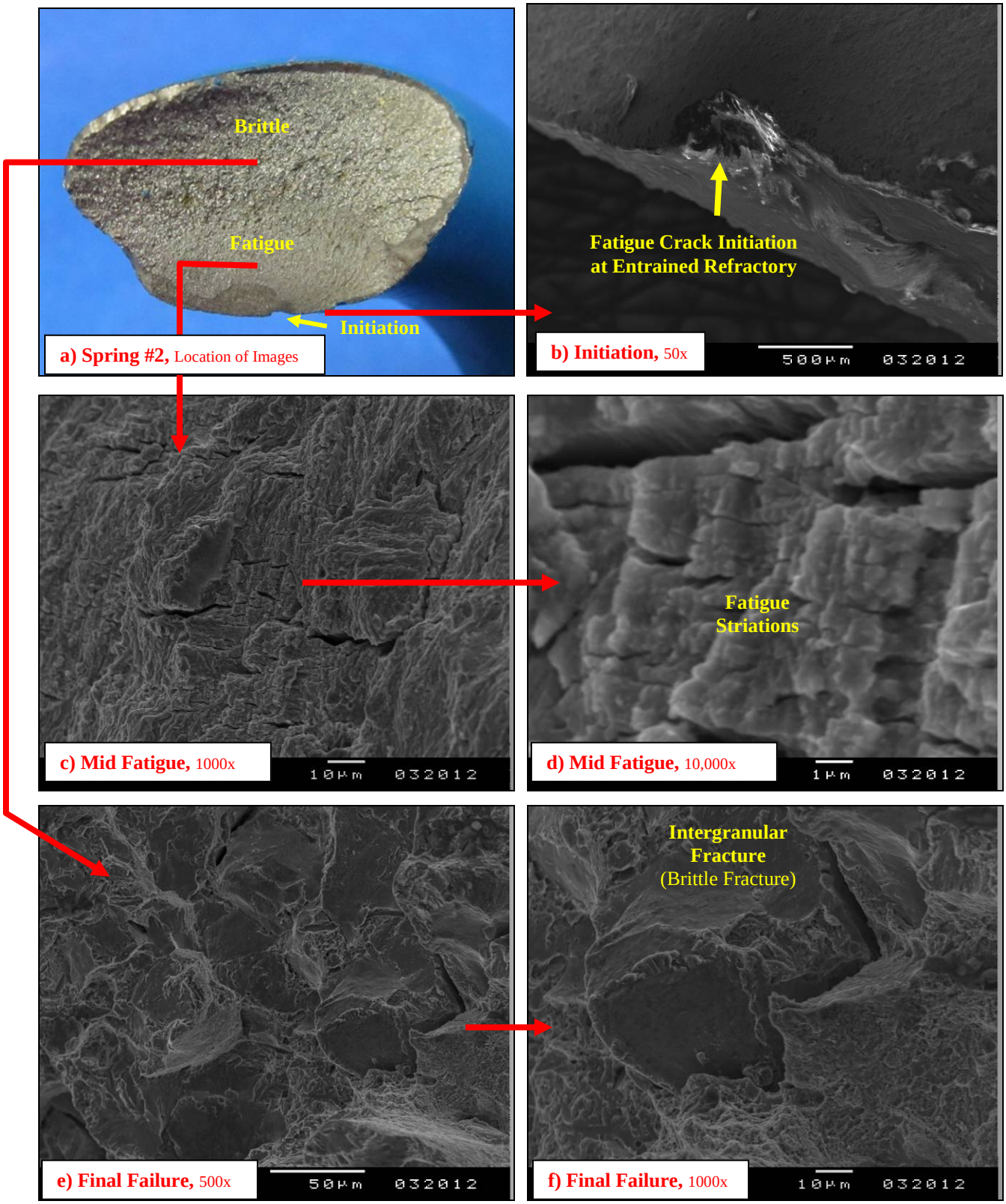


Figure 9: SEM images of Spring #2 displaying features similar to Spring #1. Crack initiation had occurred by high cycle fatigue at a cavity containing entrained refractory. Fatigue striations were became midway through the fatigue zone which changed to mixed, intergranular brittle fracture features. SE1, 20kV.

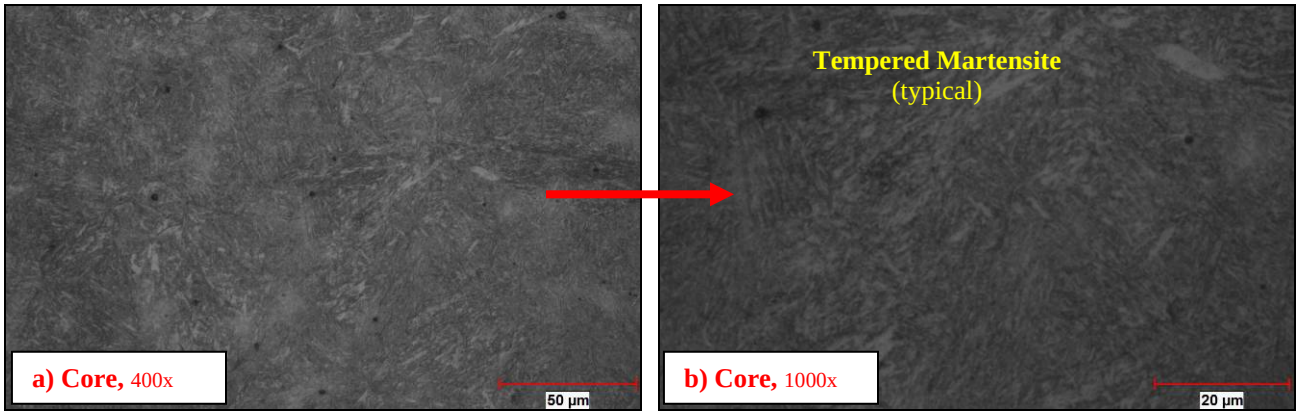


Figure 10: Micrographs displaying the core structure of Spring #1 to comprise of tempered martensite typical for a quenched and tempered 5160 alloy steel. Etched using 3% nital.

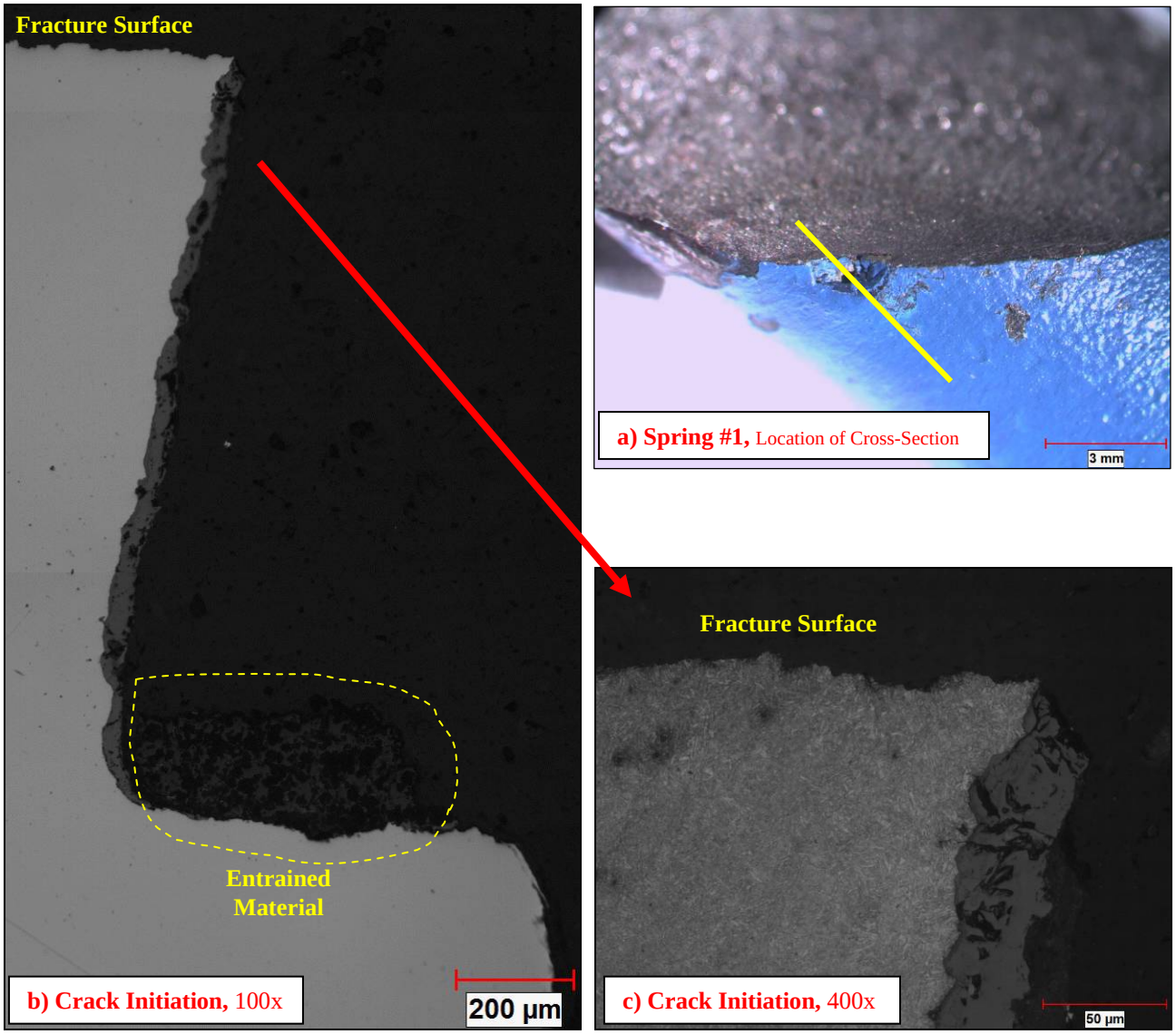


Figure 11: Micrographs displaying the entrained refractory within the cavity of Spring #1. It was presumed the cavity had once been filled with refractory during steelmaking and the majority of it knocked out during wire drawing and spring forming.