Report – Field service spring failures

Date: 31st July 2008

Written by: Bill Wilson

ITEC Spring Part Number 3533197-C91

BACKGROUND

International Truck and Engine Company reported a series of low mileage failures of a front steer axle spring installed on school buses and medium 4 x 2 trucks. The part number in question was 3533197-C91, and a total of 16 failures were reported. 15 vehicles were involved, 13 buses and two trucks. One bus had failed both springs; of these, one was discovered before delivery to the customer, and the other shortly after entering service. All the vehicles with reported failures were built between 14th August and 17th September 2007. 11 buses were built at Tulsa, two at Conway, and the two trucks were built at Springfield. Mileages at failure ranged from a low of 1244 miles and a high of 7898 miles. Days in service ranged from 0 to 210. No reports were received of any handling or safety incidents associated with the failures.

All springs actually returned either to Hendrickson or ITEC exhibited a fracture of the second (or wrapper) leaf at the forward end, the location varying from about 4 inches to about 8 inches from the wrap. Warranty claim data suggest that similar fractures affected those springs not recovered from dealers. No instances of failure were reported of the main leaf. All the springs were manufactured at Hendrickson's facility in Piedras Negras, Coahuila, Mexico. (HSM)

It should be noted that the spring in question was designed by Hendrickson for ITEC, and has been and will continue to be manufactured exclusively for that company.

INVESTIGATION

Metallurgical

Six springs were returned to HSM for analysis. It was immediately apparent that all the springs belonged to a single job lot, identified as HM-07-202, produced in late July and early August 2007. The job lot was 1600 pieces.

HSM carried out a basic metallurgical analysis in an attempt to identify the cause of failure. The results showed that hardness, cleanliness, decarburization and grain size all met specification, but the condition of the fracture surfaces was such that the equipment available to HSM could not conduct further analysis.

Two springs were therefore sent to Hendrickson Spring, Stratford, (HSS) where additional equipment could be brought to bear.

It was quickly determined through scanning electron microscopy (SEM) and energy dispersive X-ray analysis (EDS) that the failures occurred due to the existence of a single

small quench crack in each second leaf. The significant stress riser occasioned by the existence of the crack led to rapid fatigue crack propagation and ultimate fracture.
The complete report from HSS is attached to this report as Appendix B.

Process investigation

Design considerations

Part number 3533197-C91 was originally designed in 1999 and, until the reported incidents, had been trouble free in service. It is worth noting that as a standard design procedure with parabolic springs, the main leaf (having eyes and bushings) is designed to a fixed maximum eye stress to ensure axle alignment by precluding eye failure. This means that the eye section is thicker than that used for the wrapper, which is a "one time" redundancy feature. The wrapper leaf is usually reduced in thickness also to save weight and assist in lowering the vertical spring rate.

The implications of the design features when the parts are heat treated in a radiant heat furnace are as follows: elements of a part nearer the radiant heat source heat quicker than elements further away: thinner elements heat quicker than thicker. Thus, in the case of the wrapper leaf, the wrap, being thinner and nearer the heat source, would be the first to transform, followed by the thin section closest to it.

Since metallurgical grain size is influenced by time at temperature – i.e. the longer the time and the higher the temperature the coarser the grain – and because an increase in grain size results in an increase in hardenability, there would be a section of the wrapper leaf that would be more hardenable than the rest of the leaf – namely the thin section close to the wrap.

Heat-treating

The job lot in question was heat treated in two batches: 461 pieces were made on July 27th 2007 on heat treat line No.1, and the remaining 1139 pieces were processed on August 1st and 2nd on line No.7. No process discrepancies of any kind could be discovered in the first batch of springs that was produced on line No.1.

Records from the second batch process revealed some anomalies. While processing the job immediately before HM-07-202 some spring leaves were discovered to have quench cracks. The process was stopped, and the color and water content of the quench bath checked. (It should be noted that quench oil is checked weekly for water content, and a maximum of 0.1% is permitted) The line was stopped for some hours to allow any water to settle to the bottom of the quench tank, and several hundred gallons of an oil/water mixture was pumped out from the bottom. Agitation was resumed and the water content re-checked and found to be 0.1%. Processing of HM-07-202 was then begun. Water content was re-checked at two-hour intervals and on each of three occasions found to be zero.

Stress peening

During the stress peening process one wrapper leaf from the subject job is reported to have failed catastrophically. The pre-stress for both main and wrapper leaves is approximately 205,000 psi. Because of the failure it was decided to "pre-set" all spring assemblies.

The pre-setting operation

This operation involves deflecting the whole unclamped spring assembly to a pre-determined load. The usual objective is to check or adjust the loaded height of the spring. In this case it was intended to reveal any leaves cracked in quenching. Since the leaves had already survived a stress level of 205,000 psi without failure, one would assume that the stress level chosen for pre-setting would have been at least this value, or indeed greater. In fact the stress selected was below that of the stress-peening operation. Hence no further quench cracks were detected.

ANALYSIS

From the narrative above it seems clear that the root cause of the failures was the existence of a quench crack in the wrapper leaves. The crack would have an almost infinitely small root radius, and thus lead to rapid fatigue propagation once the vehicle was driven. It also seems clear that the quantity of leaves affected would have been small. Almost certainly the cracks originated in the first minutes of the start of the processing of the 1139 pieces of the job on line No.7 on the 1st August, since the water content of the oil was reduced from 0.1% to zero within two hours, and subsequent checks showed nothing.

The conclusion that this was a transient and marginal event is supported by the complete absence of failures in the main leaf, even though it was subjected to exactly the same conditions in heat-treatment.

In order to understand the potential extent of the problem Weibull analyses were performed on the failure data both for mileage and for days in service. In the days in service analysis two data points were omitted because of the lack of a valid DTU (delivery to user) date. This analysis predicts the performance of parts with quench cracks. The population not affected will give a perfectly satisfactory service life.

The mileage data analysis shows that 99% of parts affected by quench cracks would have failed by 10,000 service miles. Equally, 99% would have failed within approximately 220 days in service. The data would strongly suggest that, as long as the entire job was assembled on to vehicles within three months of the final shipment (28th August 2007), the problem is now behind us. The complete Weibull analyses are attached as Appendix A, together with a brief explanation of the analytical method.

IMPLICATIONS FOR VEHICLE HANDLING

The location of the failures means that some considerable proportion of the load-bearing capability of the forward cantilever of the wrapper leaf is preserved. Hence, in the event of failure on the road, the most likely effects noticed by a driver would be: a minor jolt approximating to encountering a one inch bump, probably accompanied by some transient steering wheel feedback. Thereafter he would sense a small vehicle lean to whichever side had failed, probably associated with slight, controllable steering pull due to the lean and caster increase on the failed side. The effects, certainly in terms of yaw control, are almost certain to be less severe than the failure of the main leaf and the engagement of the redundancy wrapper leaf. In this case the axle would normally move about one degree out of alignment due either to braking or rolling friction forces.

RECOMMENDATIONS

1) ITEC should immediately institute an inventory survey at all locations that received the affected job number to ascertain that no suspect parts remain. Any found should be returned to HSM for inspection. **NOTE: a complete list of shipments by date, quantity and location is given as Appendix C.**
2) HSM should immediately implement corrective actions to avoid a repetition of this incident. These should be agreed with ITEC.
3) Hendrickson and ITEC should agree, after the inventory valuation, the extent of the vehicle population potentially affected and assess the risk remaining and whether further action is required.

APPENDIX A

Weibull Analysis

The Weibull distribution has for many years been the standard analytical tool in the automotive and aerospace industries for predicting component and system life. By taking a relatively small sample of results and assigning a rank order to them it is possible to make a strong inference about the behavior of a much larger population. In the case below, both mileage and time were used to estimate the points at which 99% of the unknown population of defective springs would have failed.
As with all statistical methods, accuracy improves as sample size increases. It is common to base new component life predictions on a sample size of 6. In this case 16 and 18 data points were available and provide a more confident base for analysis.
It is usual to speak of the life of a component in percentages that are designated as, for example "B-10". This is the point at which 10% of the population would have failed. Equally, B-1 and B-50 would refer to 1% or 50% of the population being studied.
There are some symbols that should be briefly explained:

- "r" is the correlation coefficient – a measure of the goodness of fit of the data to the line drawn through it. 1 would be perfect correlation, and any value over 0.9 is taken as reliable. In the cases studied both sets give correlations of over 0.96, indicating a very good fit.
- "r^2" is the square of the correlation coefficient, and known as the coefficient of determination, preferred by some statisticians as a measure of fit.
- "ccc^2" is the critical correlation coefficient, used as a further check for goodness of fit. For good fit it must be less than the value of r^2.
- "Slope" is, as it implies, the slope of the line of best fit, but it is also a measure of scatter in the data. The higher the value of the slope, the lower the scatter. It should be noted that there is greater scatter in the time data, as one would expect. Slope is referred to as "Beta" in the charts.
- "Characteristic life" is the point at which 63.2% of the population will have failed. It is a scale parameter, and denoted in the charts as "Eta".

Warranty Data

BUSINESS	CUSTOMER	BUILD_DATE	FAIL_DATE	ODOM_READING	M_K	MODEL_DESC	VIN	DTU_DATE	COMMENTS	Days in Service
[redacted]	[redacted]	8/28/2007	11/21/2007	3365	M	4300 4X2	1HTMMAAL18[redacted]	10/19/2007	FRONT DRIVER SIDE LEAF SPRING CRACKED FOUND LEAF SPRING BROKEN,LOOSENED FUEL TANK MOVED BACK FOR REMOVEL OF SHACKLE PIN,REPLACED SPRING ASSEMBLY,ROAD TESTED OK	33
[redacted]	[redacted]	8/30/2007	3/28/2008	2214	M	4300 4X2	1HTMMAAN28[redacted]	12/17/2007	LEFT FRONT SPRING BROKE. JACKED TRUCK UP. R&R FRONT LEFT LEAF SPRING.	102
[redacted]	[redacted]	9/13/2007	1/14/2008	5875	M	CE S BUS	4DRBUAAN39[redacted]	11/7/2007	LEFT FRONT SPRING BROKEN, REPLACED - TRAVEL TO CUST YARD FORREPAIR; UNDER 90 DAYS.	68
[redacted]	[redacted]	8/15/2007	6/3/2008	8,811	M	CE S BUS	4DRBUAAN48[redacted]	1/16/2008	INSPECT FOR BROKEN FRONT SPRING FOUND BROKEN FRONT SPRING ON TRUCK R/R AND REPLACE COMPLETE WITH U-BOLTS.	139
[redacted]	[redacted]	8/15/2007	12/19/2007	2702	M	CE S BUS	4DRBUAAN48[redacted]	11/19/2007	CKED FOR FRONT SPRING BROKEN.FOUND RIGHT FRONT BROKEN.R&R FRNOT SPRING .CKED OK.	30
[redacted]	[redacted]	8/23/2007	11/6/2007	1413	M	CE S BUS	4DRBUAAN49[redacted]	10/15/2007	DRIVER SIDE FRONT LEAF SPRING BROKEN IN 2 PLACES REMOVED DRIVER SIDE FRONT LEAF SPRING & REPLACED WITH NEW LEAF SPRING	22
[redacted]	[redacted]	8/20/2007	2/8/2008	7142	M	CE S BUS	4DRBUAAN49[redacted]	11/8/2007	CHECK FRONT SPRINGS *SPRINGS* FOUND LEFT FRONT SPRING BROKEN. REPLACED BOTH FRONT SPRINGS. ISSUE RESOLVED.	92
[redacted]	[redacted]	8/20/2007	2/8/2008	5639	M	CE S BUS	4DRBUAAN59[redacted]	11/8/2007	CHECK FRONT SPRINGS *SPRINGS* PERFORMED DIAG, FOUND BOTH FRONT SPRINGS BROKEN. R&R BOTH FRONT SPRINGS. ISSUE RESOLVED.	92
[redacted]	[redacted]	8/14/2007	3/3/2008	2,092	M	CE S BUS	4DRBUAAN68[redacted]	2/12/2008	WCC/*2ND REVIEW, 118/LKH-RL LEAF SPRINGS BROKEN, DEFECTIVE, REPLACE SPRING	20
[redacted]	[redacted]	9/17/2007	2/4/2008	4443	M	CE S BUS	4DRBUAAN79[redacted]	10/30/2007	LEFT FRONT LEAF SPRING BROKEN.INSTALLED NEW LEAF SPRING.TEST OK	97
[redacted]	[redacted]	8/20/2007	2/6/2008	6362	M	CE S BUS	4DRBUAAN79[redacted]	11/8/2007	CHECK FRONT SUSPENSION *SPRINGS* T/S FRONT SUSPENSION, FOUNDRIGHT FRONT SPRING BROKEN. INSTALLED 2 NEW FRONT SPRINGS ANDU-BOLTS.	90
[redacted]	[redacted]	8/20/2007	10/15/2007	1583	M	CE S BUS	4DRBUAANX9[redacted]	10/29/2007	L/FRONT SPRING BROKEN CHECKED OUT & FOUND L/F SPRING TO BE BROKEN. R&R DEFECTIVE L/F SPRING ASSEMBLY.	NA
[redacted]	[redacted]	8/20/2007	11/30/2007	1658	M	CE S BUS	4DRBUAANX9[redacted]	10/29/2007	C/S CHECK RIGHT FRONT SPRING CHECKED OUT & FOUND R/F SPRING TO BE BROKEN. R&R DEFECTIVE R/F SPRING ASSY.	32
[redacted]	[redacted]	8/20/2007	11/19/2007	3091	M	CE S BUS	4DRBUAAP39[redacted]	10/5/2007	CONDITION: LEFT STEER AXLE SPRING LEAF BROKEN/HANGING LOOSECAUSE: DEFECTIVE SPRING LEAF/NOTE: EDGE RUSTY CORRECTION: REMOVE/REPLACE SPRING ASSY W/NEW	45
[redacted]	[redacted]	8/16/2007	1/2/2008	3129	M	CE S BUS	4DRBUAAP58[redacted]	10/9/2007	THE VEHICLES FRONT PASSANGER LEAF SPRING WAS BROKEN. R/R WITH NEW LEAF SPRING AND TEST.	85
[redacted]	[redacted]	8/23/2007	11/12/2007	1244	M	CE S BUS	4DRBUAAP69[redacted]		RIGHT FRONT LEAF SPRING BROKEN,PRODUCTION,R&R LEAF SPRING, TORQUE TO SPEC, FLAW IN METAL. HAD TO REMOVE WASHER BOTTLE FOR ACCESS, HAD TO MOVE OVER EXHAUST FOR ACCESS.	NA
[redacted]	[redacted]	8/14/2007	3/31/2008	5693	M	CE S BUS	4DRBUSKN48[redacted]	9/3/2007	LEFT FRONT BROKEN SPRING R AND R SPRING AND U BOLTS	210
[redacted]	[redacted]	8/15/2007	5/15/2008	7898	M	CE S BUS	4DRBUSKP18[redacted]	11/19/2007	LEAF SPRING BROKE. REPLACED SPRING.	178

MILEAGE

Weibull Analysis Report

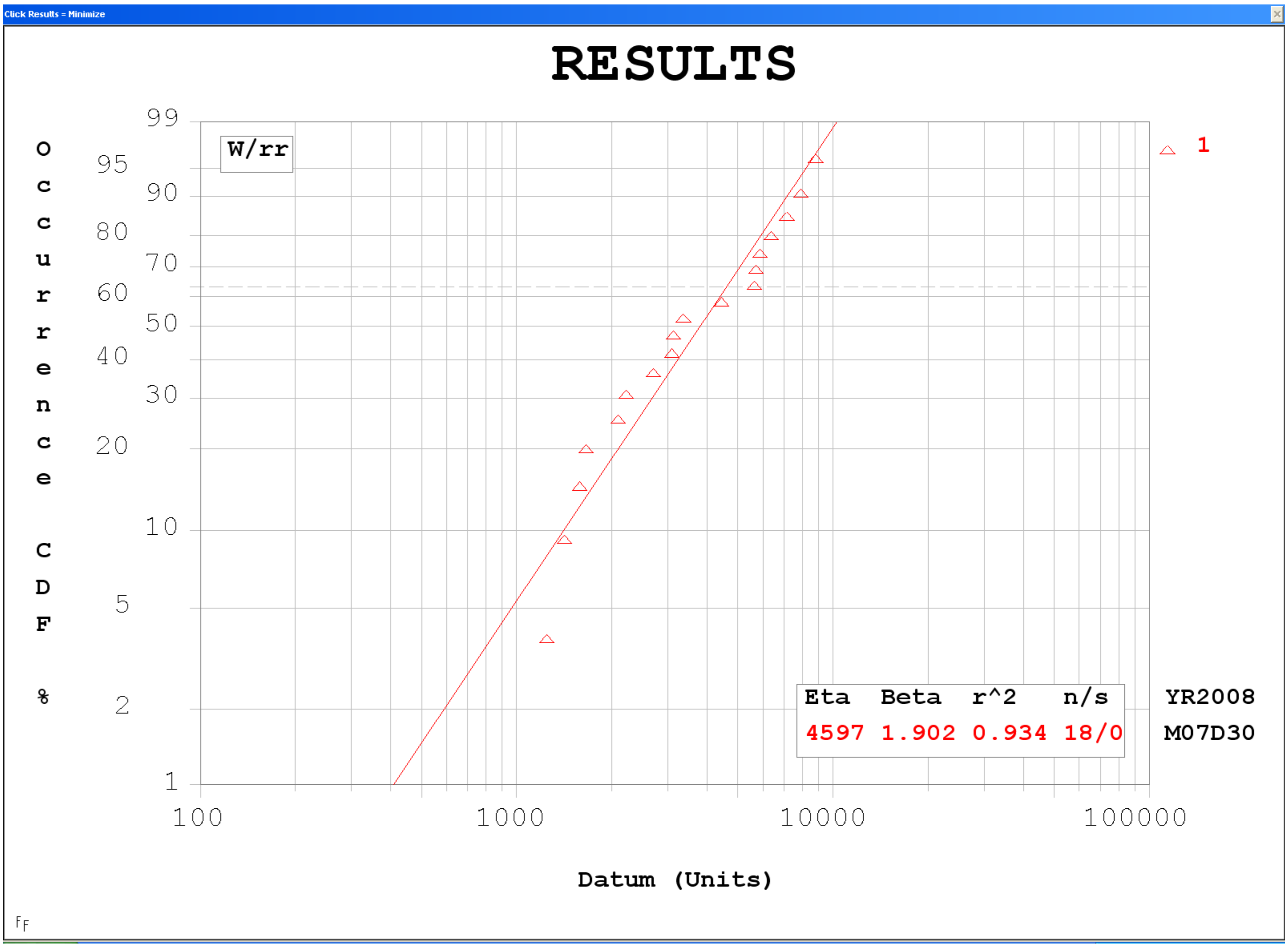
```
Set 1 -  1                                              Date: M07-D30-YR2008
RESULTS
Correlation(r)=.9664367  r^2=.934  ccc^2=.8979  r^2-ccc^2= .0361 (Okay)
Characteristic Value=4597  Weibull Slope=1.902  Method=rr
Mean=4079  Std. Deviation=2231
Point Quantity=18 (susp=0)
```

B%	Datum (Units)
1	409.3
2	590.9
5	964.4
10	1408
20	2089
50	3791

<WinSMITH(TM) Weibull 3.0C>

	Set 1: 1	
Point 1	1244x1	
Point 2	1413x1	
Point 3	1583x1	
Point 4	1658x1	
Point 5	2092x1	
Point 6	2214x1	
Point 7	2702x1	
Point 8	3091x1	
Point 9	3129x1	
Point 10	3365x1	
Point 11	4443x1	
Point 12	5639x1	
Point 13	5693x1	
Point 14	5875x1	
Point 15	6362x1	
Point 16	7142x1	
Point 17	7898x1	
Point 18	8811x1	
Point 19		
Point 20		

MILEAGE


Click Results = Minimize
RESULTS
W/rr
Occurrence CDF %
99
95
90
80
70
60
50
40
30
20
10
5
2
1
100
1000
10000
100000
Datum (Units)
1
Eta Beta r^2 n/s
4597 1.902 0.934 18/0
YR2008
M07D30

DAYS IN SERVICE

Weibull Analysis Report

Set 1 - 1 **Date: M07-D30-YR2008**

RESULTS

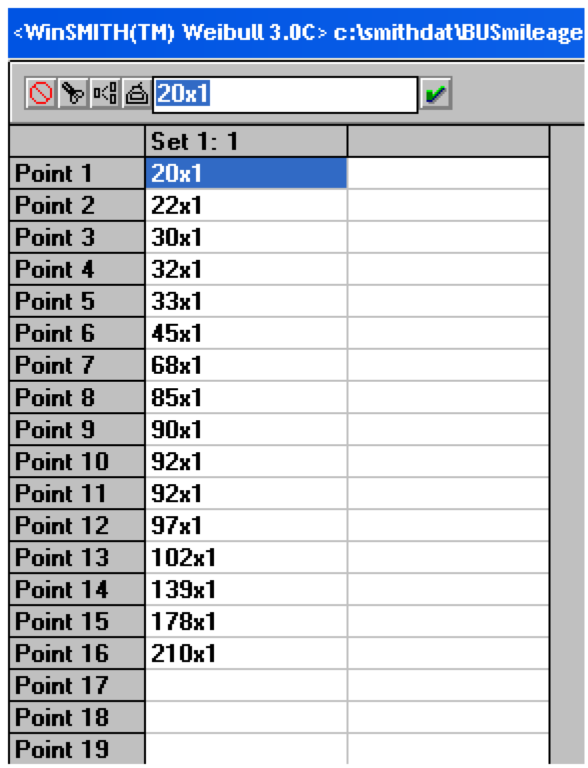
Correlation(r)=.9664367 r^2=.934 ccc^2=.8917 r^2-ccc^2= .0423 (Okay)

Characteristic Value=92.24 Weibull Slope=1.637 Method=rr

Mean=82.54 Std. Deviation=51.73

Point Quantity=16 (susp=0)

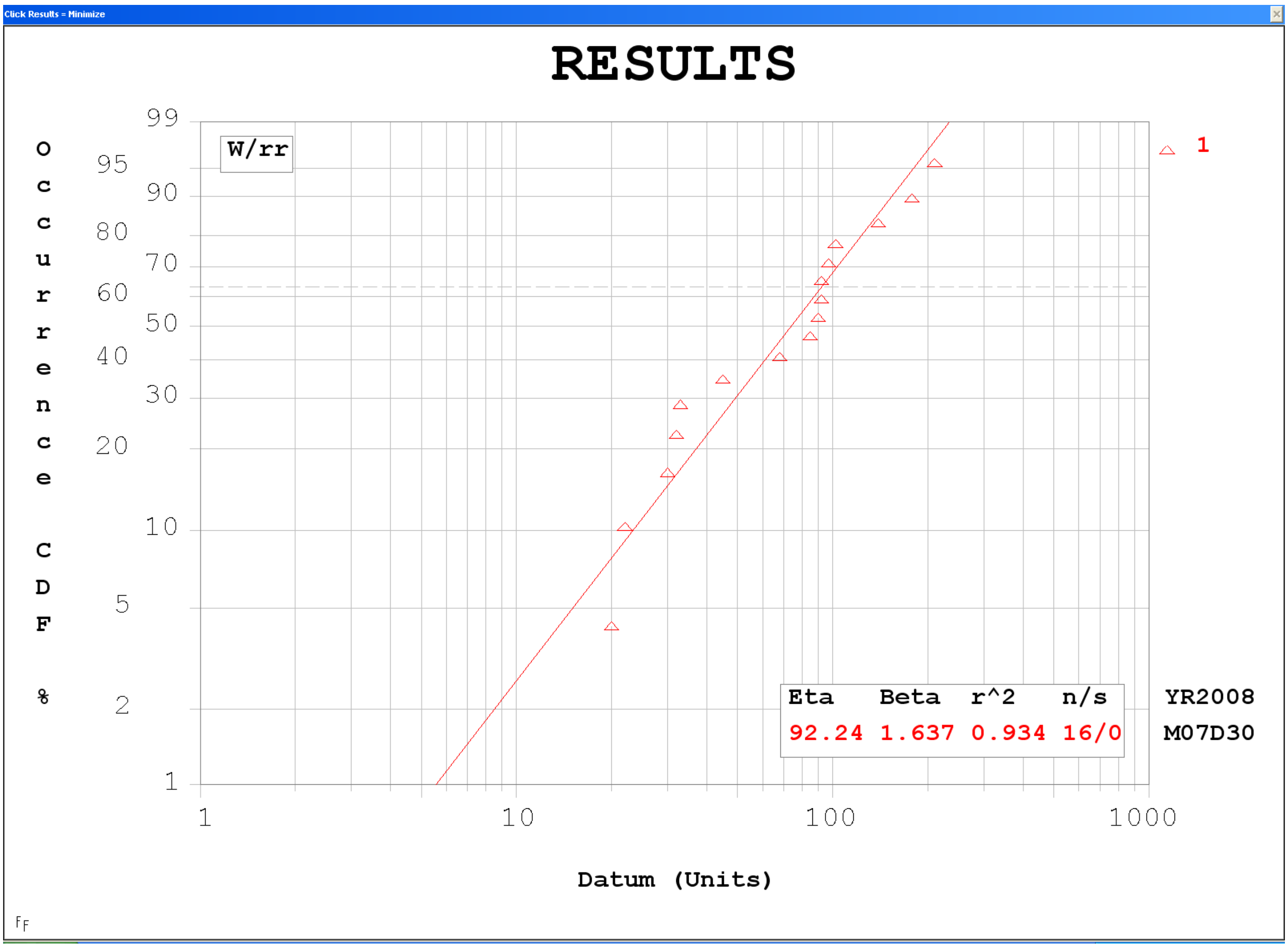
B%	Datum (Units)
1	5.551
2	8.504
5	15.03
10	23.33
20	36.89
50	73.73


<WinSMITH(TM) Weibull 3.0C> c:\smithdat\BUSmileage

20x1

	Set 1: 1	
Point 1	20x1	
Point 2	22x1	
Point 3	30x1	
Point 4	32x1	
Point 5	33x1	
Point 6	45x1	
Point 7	68x1	
Point 8	85x1	
Point 9	90x1	
Point 10	92x1	
Point 11	92x1	
Point 12	97x1	
Point 13	102x1	
Point 14	139x1	
Point 15	178x1	
Point 16	210x1	
Point 17		
Point 18		
Point 19		

DAYS IN SERVICE



APPENDIX B

MT08-029
Analysis Of Two Broken Springs
Part Number 3533197-C91
Prepared By: Brian Farrell
Date: 22nd July 2008

Summary:

Pieces from two broken springs were submitted to Hendrickson Spring, Stratford (HSS) for evaluation. Each piece was about 0.75 inches long and represented one half of each fracture face. The coupons had been previously cleaned of all primer and chassis paint. Red oxide corrosion was beginning to form on the samples. The samples arrived at HSS wrapped in dry paper towels.

Although both samples were clearly damaged by post-fracture mechanical impacts and corrosion enough evidence remained to indicate that the samples failed due to small transverse quench cracks.

Observations:

1. The primary origin was plane and extended about half an inch from the edge of the spring, perpendicular to the length of the leaf and the upper and lower surfaces.
2. A ductile shear lip seen on the compression surface where the leaf finally separated was not in evidence at the quench crack.
3. Intergranular features were visible on the primary origins but not on the secondary fracture faces.
4. Intergranular facets were covered with a tight layer of material identified by EDS as oxidized oil.

Sample 1:

Figure 1:
Tension surface

Figure 2:
Compression surface

Figure 3:
Fracture surface. Origin is at edge of spring. Note the lack of shear lip on the compression surface. Image acquired on as received surface before cleaning at HSS.

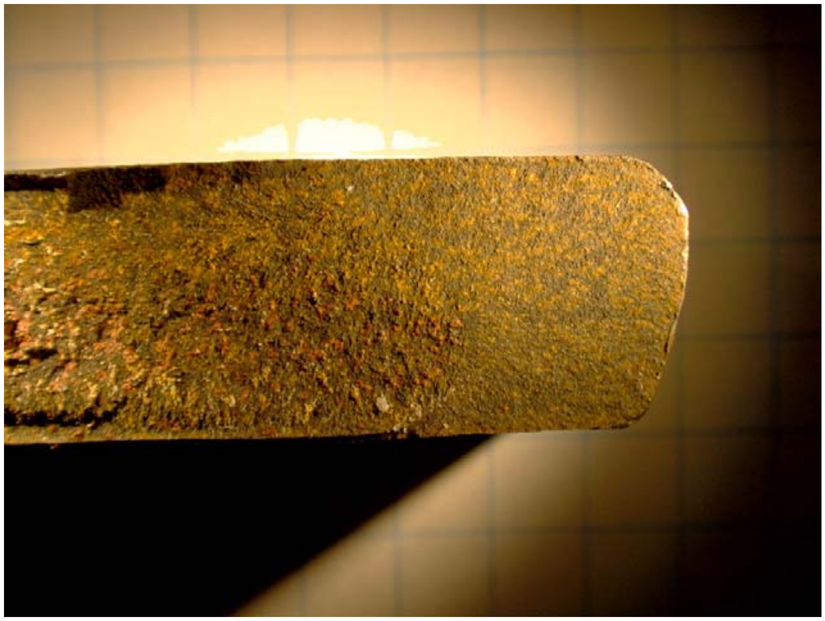


Figure 4:
Fracture surface. Note the lack of shear lip on the compression surface. Image acquired on surface after cleaning at HSS.

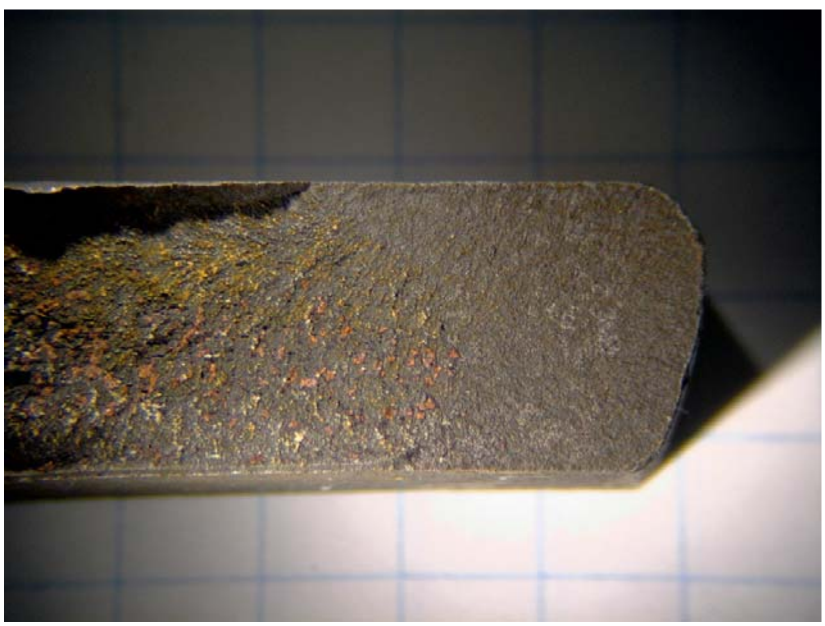


Figure 5:
Intersection between primary origin and shear lip on secondary origin.

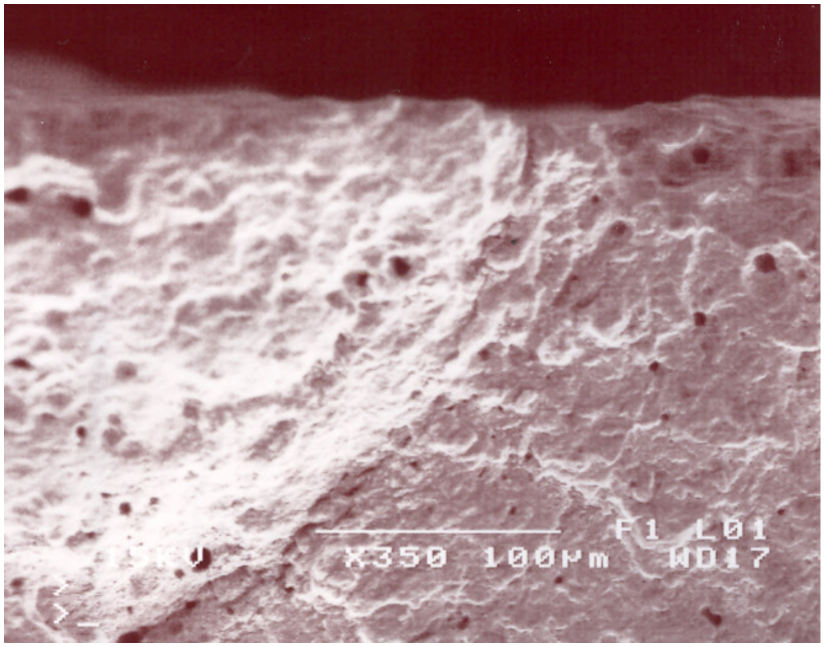


Figure 6:
Primary origin, intergranular facets partially obscured by corrosion.

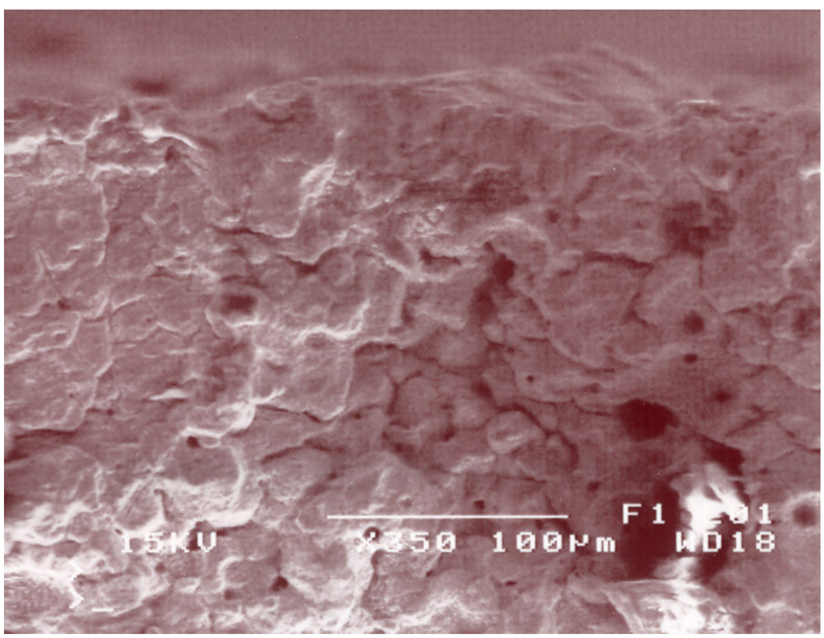


Figure 7:
Primary origin at compression surface. Intergranular facets are visible.

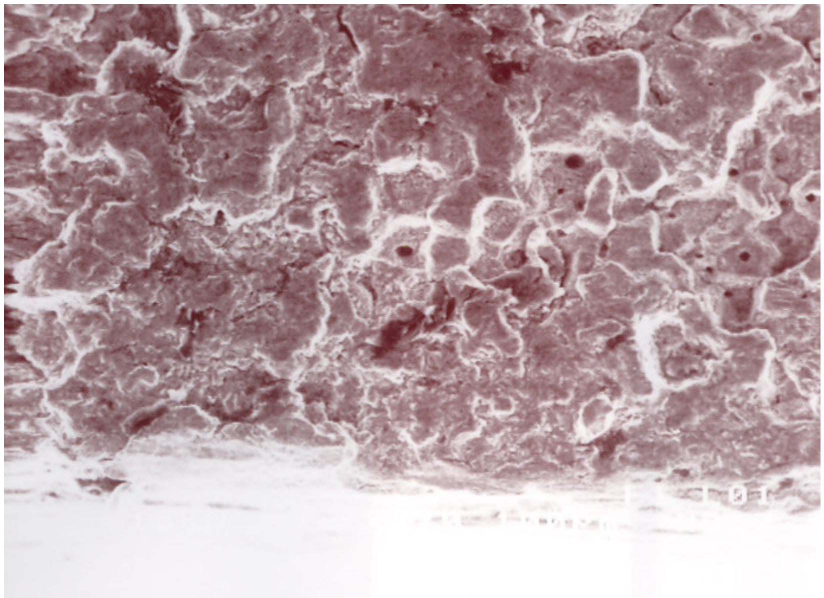


Figure 8:
Intergranular fracture on primary origin. Note the erosion/corrosion damage on the grain facets

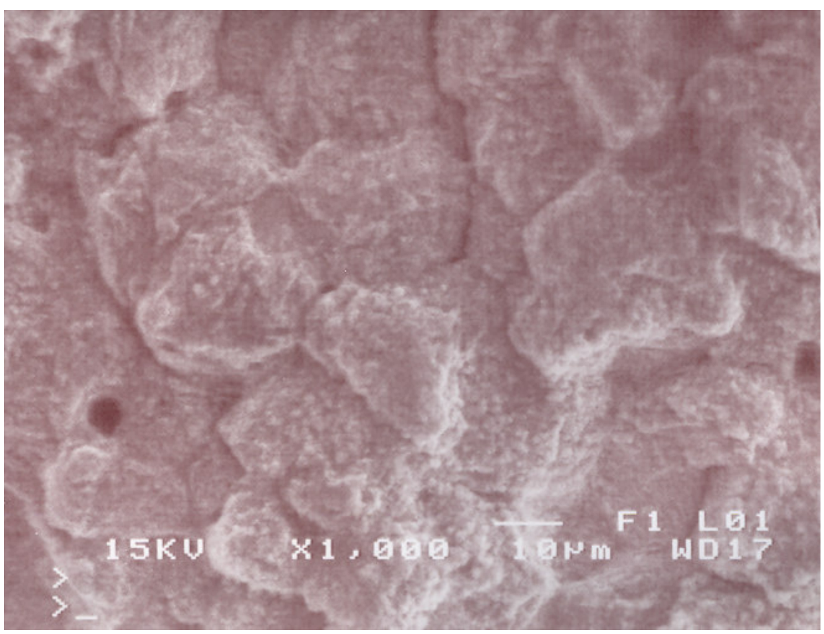


Figure 9:
Primary origin showing a tight non-metallic coating on the fracture surface using backscatter electron imaging. Area A is clean steel. Area B is oxidized oil.

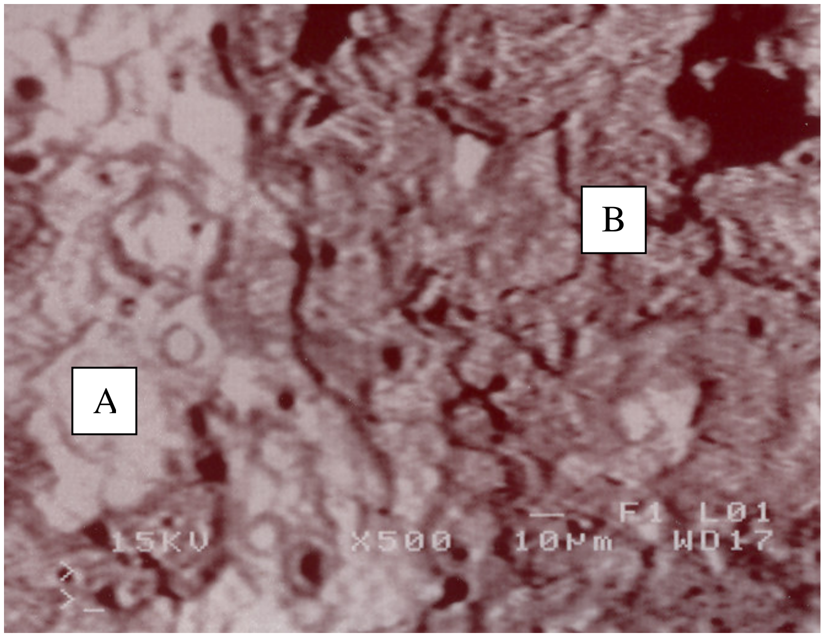


Figure 10:
Characteristic spectrum at Area "A" on image

Figure 9.

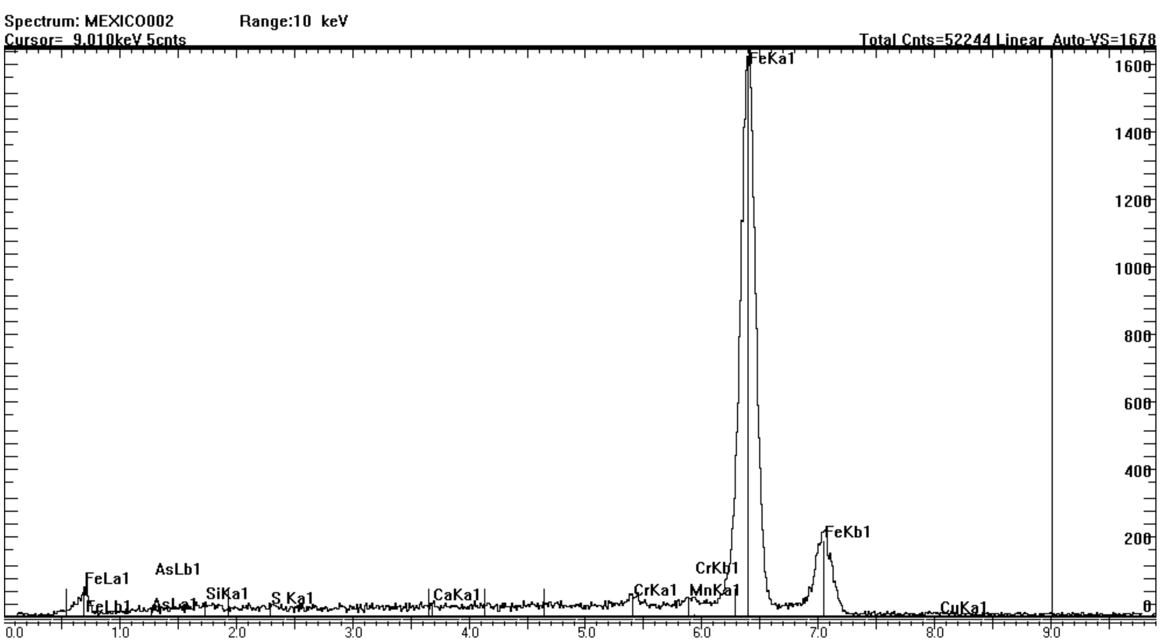


Figure 11:
Characteristic spectrum at Area “A” on image

Figure 9. Range decreased to show detail.

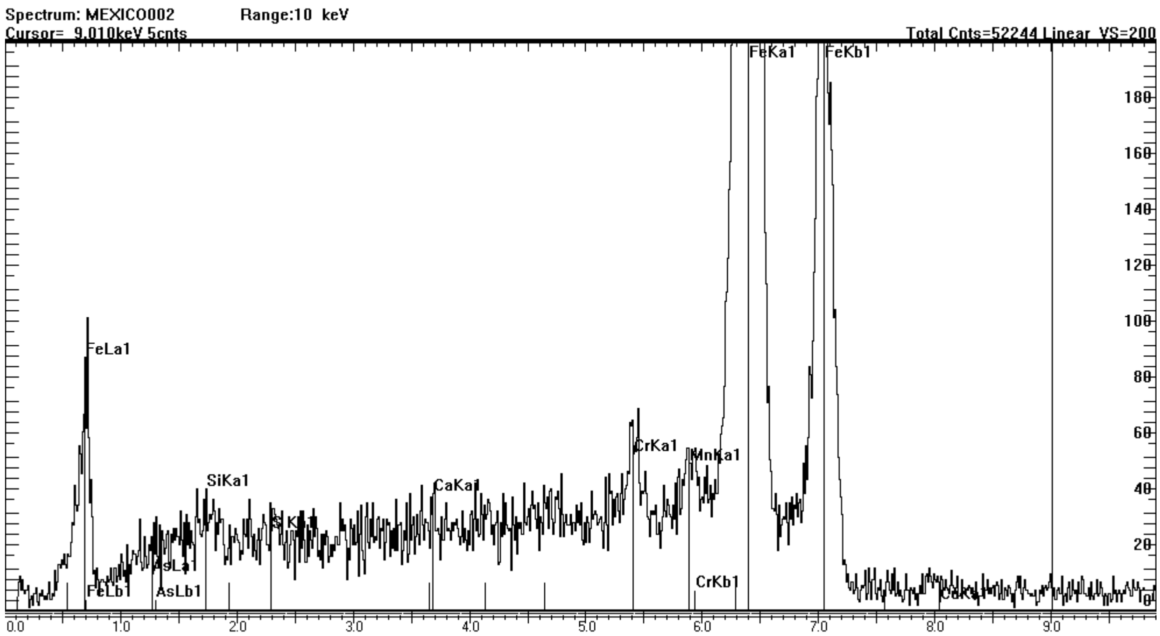


Figure 12:
Characteristic spectrum at Area “B” on image

Figure 9.

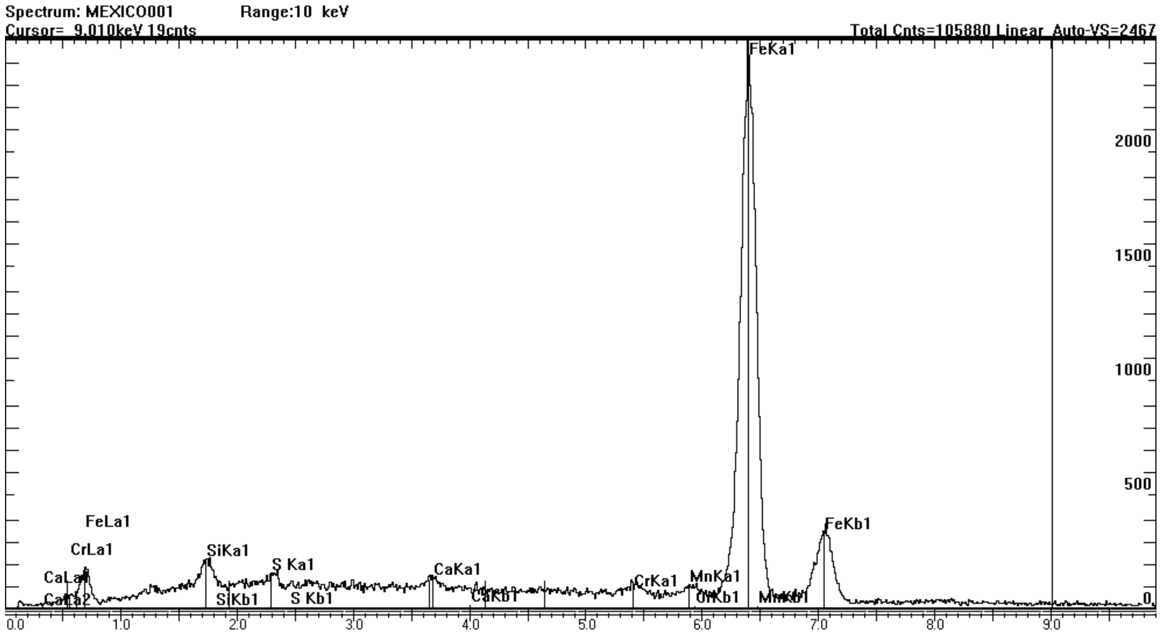
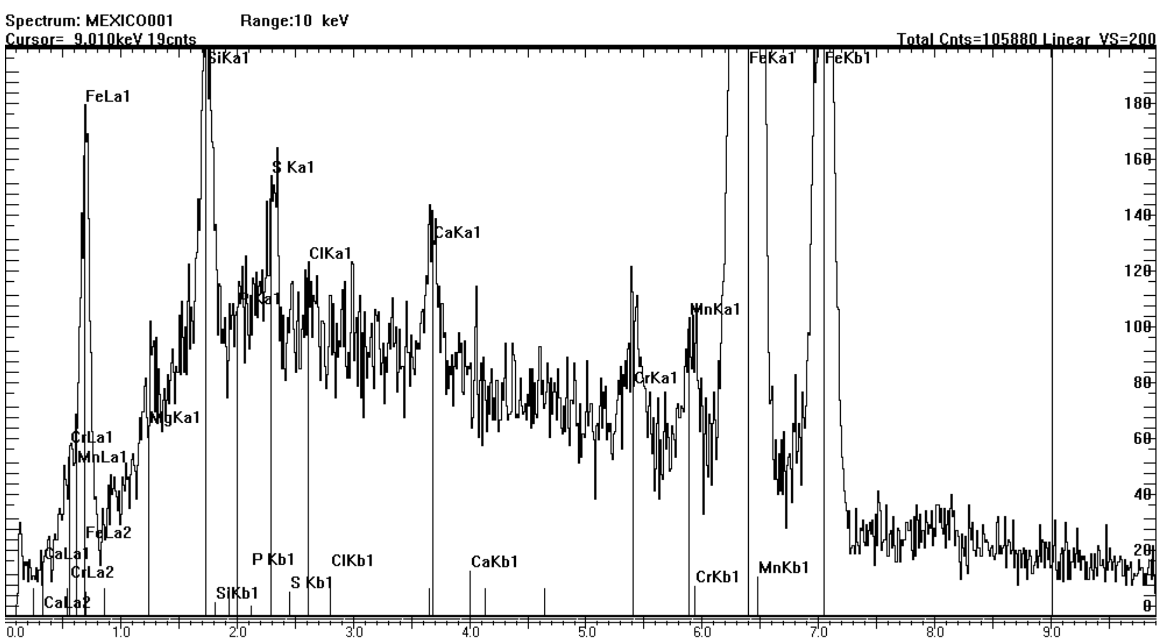


Figure 13:
Characteristic spectrum at Area "B" on image

Figure 9. Range decreased to show detail. Elements detected are representative of oxidized oil.



Sample 2:

Figure 14:
Fracture surface at origin. Post fracture ding mark is visible on upper edge. Transition between intergranular fracture to a shear lip is visible on bottom of image at “A”.

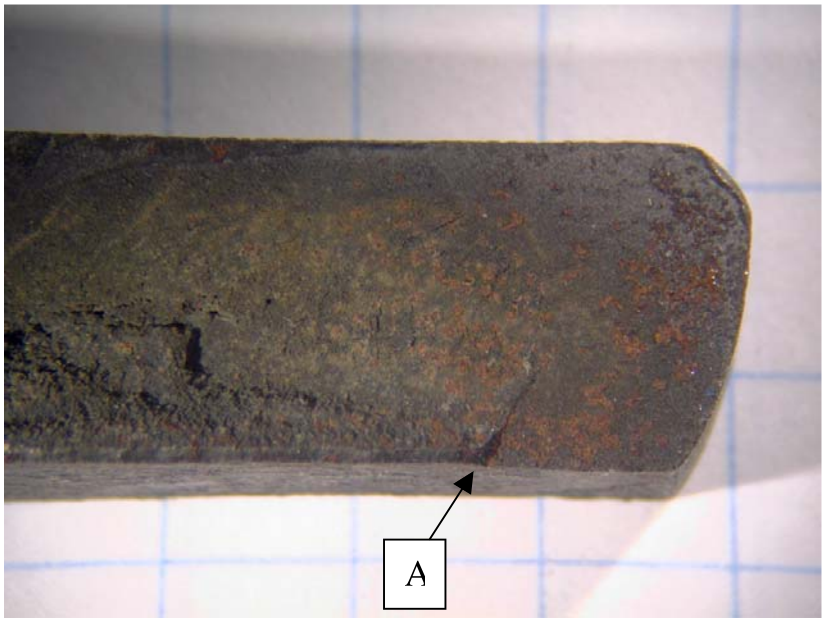


Figure 15:
Tension surface at primary origin.

Figure 16:
Compression surface at origin. Area "A" from Figure 14 is indicated by arrow.

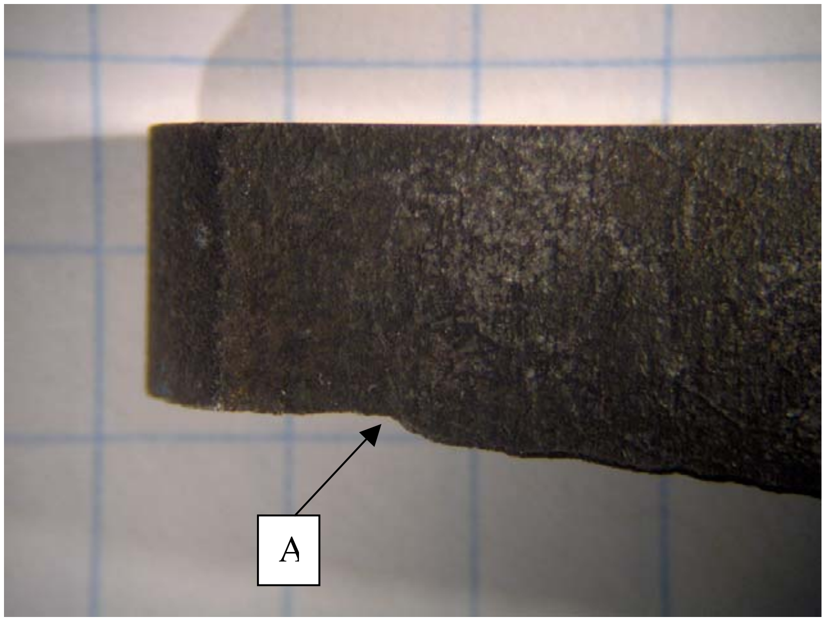


Figure 177:
Intersection between primary fracture and secondary fracture.

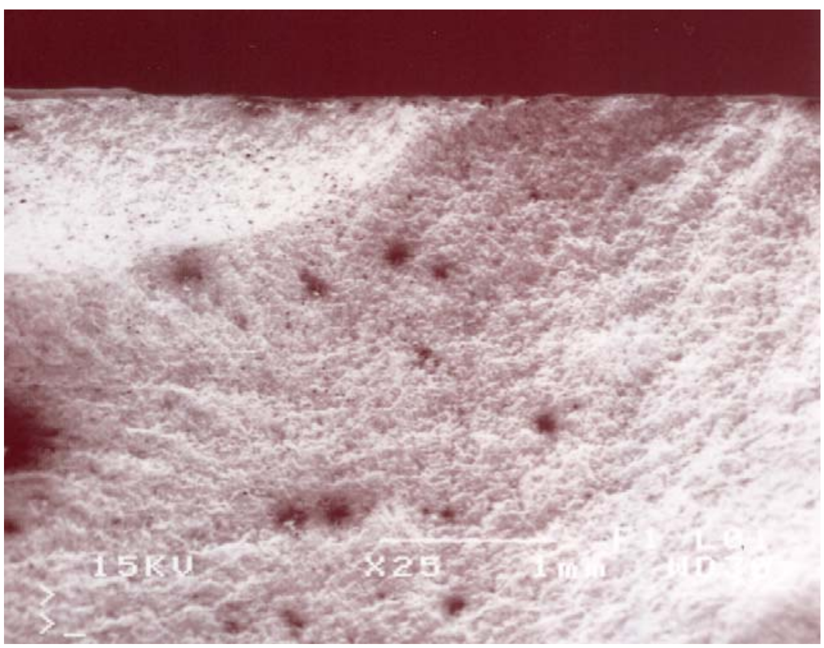


Figure 18:
Erosion / corrosion damage on primary fracture face.

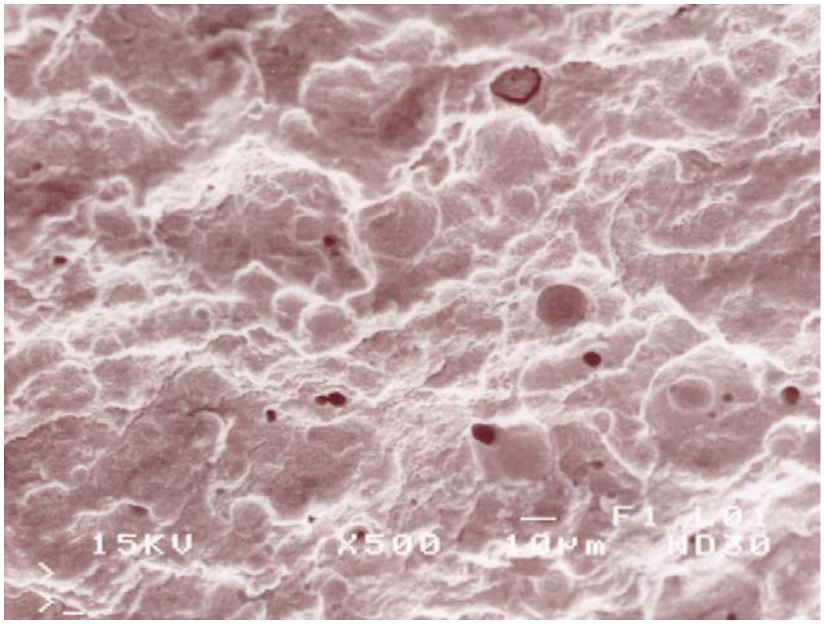
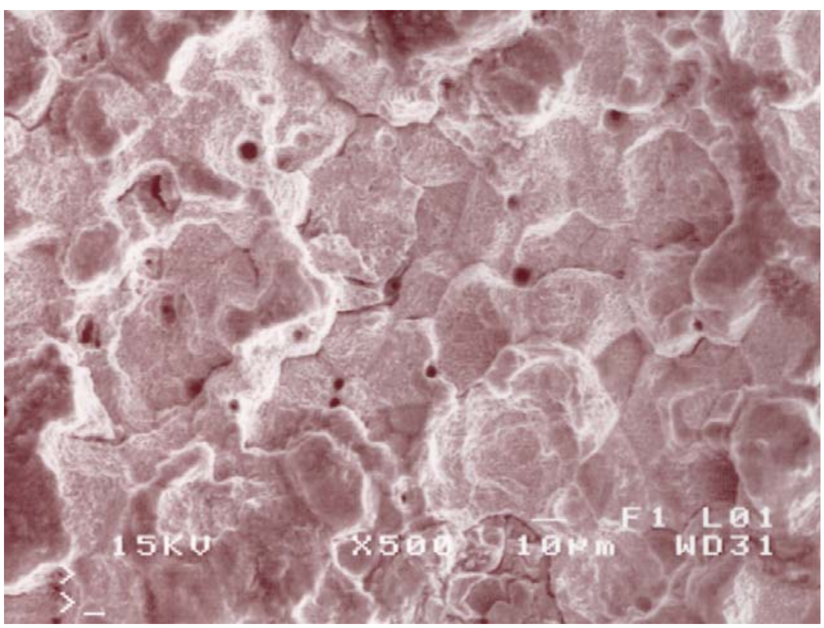


Figure 19:
Intergranular fracture on primary origin.



APPENDIX C

Shipment history

Blue Diamond, Conway and Springfield

# PIECES	QA SKID #	PROFORMA	SID #/BOL #	DATE	LOCATION	
42	0534865	N.4734	N.4734	7/8/2007	BLUE DIAMOND	
8	0534866	N.4734	N.4734	7/8/2007	BLUE DIAMOND	
44	0535450	N.4739	N.4739	8/8/2007	BLUE DIAMOND	94
44	0535446	H22779	19306	08/22/2007	CONWAY	
44	0535449	H22779	19306	08/22/2007	CONWAY	
44	0534816	H22645	19197	08/15/2007	CONWAY	132
44	0534957	H22652	19128	9/8/2007	GARLAND	44
44	0534302	H22590	18983	07/30/2007	SPRINGFIELD	
44	0534316	H22590	18983	07/30/2007	SPRINGFIELD	
44	0534323	H22591	18983	07/30/2007	SPRINGFIELD	
44	0534327	H22590	18983	07/30/2007	SPRINGFIELD	
17	0534405	H22590	18983	07/30/2007	SPRINGFIELD	
44	0534354	H22606	19012	07/31/2007	SPRINGFIELD	
44	0534371	H22617	19012	07/31/2007	SPRINGFIELD	
44	0535444	H22779	19273	08/20/2007	SPRINGFIELD	
44	0535445	H22779	19273	08/20/2007	SPRINGFIELD	
44	0535447	H22726	19188	08/14/2007	SPRINGFIELD	
44	0535448	H22779	19273	08/20/2007	SPRINGFIELD	
44	0535451	H22726	19188	08/14/2007	SPRINGFIELD	
44	0536933	H22821	19364	08/27/2007	SPRINGFIELD	
27	0534303	H22590	18983	07/30/2007	SPRINGFIELD	572
						842

Shipment History

Tulsa

# PIECES	QA SKID #	PROFORMA	SID #/BOL #	DATE	LOCATION
44	0534353	H22652	19190	08/14/2007	TULSA
33	0534387	H22652	19190	08/14/2007	TULSA
11	0534388	H22652	19190	08/14/2007	TULSA
44	0534796	H22652	19105	7/8/2007	TULSA
44	0534803	H22645	19190	08/14/2007	TULSA
44	0534810	H22645	19190	08/14/2007	TULSA
44	0534815	H22645	19190	08/14/2007	TULSA
44	0534829	H22645	19190	08/14/2007	TULSA
44	0534855	H22652	19105	7/8/2007	TULSA
44	0534944	H22669	19105	7/8/2007	TULSA
44	0534945	H22669	19105	7/8/2007	TULSA
44	0534956	H22669	19105	7/8/2007	TULSA
44	0534968	H22669	19105	7/8/2007	TULSA
44	0534971	H22669	19105	7/8/2007	TULSA
44	0534974	H22669	19105	7/8/2007	TULSA
44	0535008	H22652	19190	08/14/2007	TULSA
44	0535443	H22779	19301	08/21/2007	TULSA
44	0536932	H22822	19332	08/23/2007	TULSA
44	0536962	H22822	19377	08/28/2007	TULSA

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All in total for all plants is 1634. The discrepancy between the 1630 pieces processed and the 1634 shipped is accounted for by the inclusion of 4 pieces of another job number to satisfy the shipping requirement.