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by Sidney Davy Miller

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December 9, 2014

SENT VIA EMAIL and OVERNIGHT MAIL
Cynthia Glass
Recall Management Division: NVS-215
Office of Defects Investigation, Enforcement
National Highway Traffic Administration
1200 New Jersey Avenue SE, Room W48-331
Washington, DC 205590

Re: EQ14-012 – Response of Williams Controls

Dear Ms. Glass:

Please allow this letter to serve as Williams Controls, Inc. ("Williams Controls"), second supplemental response to Jennifer Timian's letter of October 16, 2014.

As you know, on October 22, 2014, Williams Controls submitted its response to Ms. Timian's letter. On November 4, 2014, Williams Controls submitted a supplemental response to its October 22, 2014, letter. Today's second supplemental response, which is attached, relates to metallurgical examinations of two return springs that were contained in a WM-526 pedal assembly

Please contact me should you have any questions or if my client can be of further assistance.

Very truly yours,

Miller, Canfield, Paddock and Stone, P.L.C.

By: _____
Brian S. Westenberg

BSW

Attachment and Enclosure

Second Supplemental Response of Williams Controls, Inc.,
to NHTSA's Letter of October 16, 2014

This response supplements the October 22, 2014, and November 4, 2014, submissions by Williams Controls, Inc. ("Williams Controls"), in response to an October 16, 2014, information request from NHTSA's Recall Management Division ("RMD").

In its November 4, 2014, response, Williams Controls informed RMD that it requested Gillig LLC ("Gillig") to return the WM-526 pedals that were replaced during Gillig's aftermarket part recall campaign (14E-018), along with any available information about how the part was used in the field (months in service, vehicle mileage, etc.). To date, Gillig has returned 25 WM-526 pedal assemblies, but it has provided no usage information. Williams Controls has found no broken return springs among these 25 pedal assemblies.

Williams Controls also noted on November 4 that two springs were randomly selected from these returned WM-526 parts for a metallurgical analysis by an independent lab, and that it would share the lab results with the agency. The results have now been received and are attached as Enclosure B. The only information known about the two WM-526 pedal springs is that he springs were harvested from a WM-526 pedal that was assembled for sale by Williams Control during February 2008 and that the two springs were from the spring supplier's production lots of November and/or December 2007.

The metallurgical analysis showed that the pedal springs from the WM-526 returned during the Gillig recall campaign were not defective. These springs contained the correct composition of stainless steel and tensile strength. Moreover, the analysis showed no cracks, tears or other defects. (S*ee* Enclosure B, p. 15.) These results can be contrasted with the metallurgical analysis that was conducted on a spring analyzed from an Ireland WM-526 pedal assembly (March, 2011), where there was clear evidence of an edge manufacturing variation (limited skiving) that likely lead to a single spring fracture in the Ireland pedal assembly. (*See* Enclosure A, pp. 4 and 5.) This poor skiving on the edge of the springs was not found in the microscopic examination of the Gillig pedal springs, nor has this edge condition been detected in any other WM-526 pedal returned in the U.S. market.

This new metallurgical analysis further supports Williams Controls' belief that while a random and isolated manufacturing variation may have occurred during a low volume 2008 spring production run by the spring supplier, none of the affected return springs from this production were installed into WM-526 pedals used by OEMs in the U.S. market.

EQ14-012 - Enclosure A

Williams Controls
14100 SW 72nd Avenue
Portland, Oregon 97224
Phone: 503-684-8600
Fax: 503-624-3812

Field Complaint Analysis Report

Williams Controls

WM-526 [redacted] Complaint

February 17, 2013

Executive Summary:

In October 2010, [redacted] reported a broken power spring on a WM-526 pedal from India. In December 2010, another broken spring was reported by [redacted] on a pedal from Ireland. Neither of these pedals was returned to Williams Controls (WMCO). Between October 2010 and August 2011, 21 claims of pedals with broken springs were submitted to WMCO from [redacted]. Examination of the broken springs indicated that 8 of the springs (including one pedal with 2 broken springs) fractured prematurely due to local stress risers originating from pinched or lapped material on the radius edge of the spring material. The lapped condition appears to have been present prior to the winding of the springs and was likely caused by variation in skiving.

From October 2011 through August 2012, WMCO proactively replaced 280 pedals at [redacted] on fleets in Ireland, the UK and Portugal. All of the pedals were returned and analyzed for spring fracture. From the field replacement pedals, 2 additional broken springs were found that fractured from a similar edge condition due to variation in skiving. There were also 10 springs identified that exhibited similar poor edge condition but were still in tact. While these 10 springs did not fracture, they were considered to be at risk of a premature fracture.

All of the fractured and at-risk springs have been traced to select production lots from the spring former from November and December 2007. From the same production lots, there have also been 32 good springs analyzed with acceptable edge formation that do not exhibit the pinched or lapped condition. The data suggests this issue was caused due to variation in the skiving operation isolated to a small batch of springs.

There have not been any additional spring fractures reported by [redacted] or any of the other 100+ customers around the world that bought WM-526 pedals produced with springs from these lots. There have been no reports of crashes or injuries associated with broken power springs on a WM-526 pedal.

Williams Controls will continue to closely monitor the field data on WM-526 pedal performance. Should any additional broken power springs be confirmed in the field, additional investigation will be undertaken.

Pedal Safety Design

The WM-526 electronic throttle control has been in production at Williams Controls for over 20 years. Over 2.5 million pedals have been shipped since 1999. The pedal is designed with redundant power springs for safety, reliability and compliance to FMVSS-124 Return to Idle regulation. The pedal is fully operational with one spring, although with a lower actuation force that would offer advanced warning to an operator. If both springs were to fail, it could result in the pedal not returning to idle. The vehicles from which the field complaints were submitted are [redacted] equipped with a Brake Throttle Override (BTO) system. The BTO system is a safety system that will cut fueling should the brake be applied at the same time as the accelerator.

Chronology of Events

The investigation of this issue has spanned from October 2010 through December 2012. A graphical timeline can be found in Appendix 1.

October 13, 2010	The first field complaint for a pedal with a broken spring was submitted by [redacted] to WMCO. The reported failure was in service in India. The pedal was not returned to WMCO for analysis.
December 3, 2010	The second field complaint for a pedal with a broken spring was submitted by [redacted] to WMCO from a bus in Ireland. The pedal was not returned to WMCO for analysis.
March 28, 2011	Two pedals with broken springs were returned from Ireland to WMCO for analysis.
August 30, 2011	7 [redacted] field complaints were received by WMCO, including one pedal with two broken springs. Broken springs are sent for analysis to an independent third party laboratory.
September 20, 2011	Material analysis report on broken springs is received from outside laboratory. The lab performed a range of analyses including visual inspection, scanning electron microscope (SEM), energy dispersive spectroscopy (EDS) examination and material hardness test. The report concluded that the broken springs failed from a variety of causes. The failures included fracture originating from a chlorine filled pit, weld splatter present on the spring, and 8 failures attributed to a pinched or lapped end. The pinched end is the result of variation in the skiving process that forms the rounded edges on the spring material after slitting and before spring winding.
October 28, 2011	In a proactive effort to gain more data, [redacted] and WMCO launch a joint effort to replace almost 200 pedals in the field at the bus fleet in Ireland. New pedals are supplied to replace those in service. The in service pedals are to be sent to WMCO for analysis.
March 12, 2012	The final shipment of replaced pedals is received at WMCO from Ireland. 193 pedals in total are replaced in the field. Upon receipt at WMCO, the pedals are systemically analyzed. The pedals are visually inspected, measured for mechanical characteristics, and disassembled for further visual inspection. The springs are visually inspected and the edge is screened using a cotton ball test. The test was recommended by an external export using the rationale that springs exhibiting the pinched edge condition would pull cotton fibers that would be visible to the naked eye. Any springs that pulled cotton fibers during this screening were sent to an outside lab for in depth analysis.

	From this study, 2 additional broken springs were found to be caused from variation in skiving. 34 springs were sent for analysis as a result of the cotton ball screening test. 10 springs were found to have edge condition that could be at risk for fracture, but none of these springs had actually fractured.
April 19, 2012	WMCO hires outside consultant to support investigation and statistical analysis of the issue.
June 8, 2012	To further understand the issue and collect additional data, a cooperative field survey is launched to replace pedals from the field in geographic regions outside of Ireland. WMCO supplied a range of chassis numbers based on the failed units. [redacted] identified 2 bus fleets with pedals suspected to be close to the same time range. The fleets in the UK and Portugal are sent replacement pedals to change out in service pedals for return to WMCO.
June 25, 2012	WMCO representatives visit supplier of raw material and witness skiving process.
August 5, 2012	47 pedals from a bus fleet in the UK are received by WMCO for field survey. All springs are intact and pass the cotton ball screening.
October 9, 2012	40 pedals from a bus fleet in Portugal are received and analyzed at WMCO. No additional skiving related fractures were found.

Skiving Process and Spring Failure

The in depth spring analysis revealed that on 10 of the fractured springs, and 10 at-risk springs, the edge of the spring material was characterized as having a pinched or lapped condition. In June 2012, WMCO visited the raw material supplier. The supplier receives sheets of the specified AISI 301 stainless steel material from the mill. The material is slit from the 24" wide master coil sheets to ribbons of the desired width. Skiving is performed to remove all burrs from slitting and produce the desired full round edge on the spring material. The skiving process is performed in two passes through carbide cutters in a submerged coolant bath at a speed of approximately 500 feet/minute. The material is monitored for width and camber prior to winding onto coils for shipment to WMCO spring formers.

This poor edge condition creates a local stress riser and a fracture origination point. The poor skiving on the edge of the spring material can be seen in Figures 1 and 2.

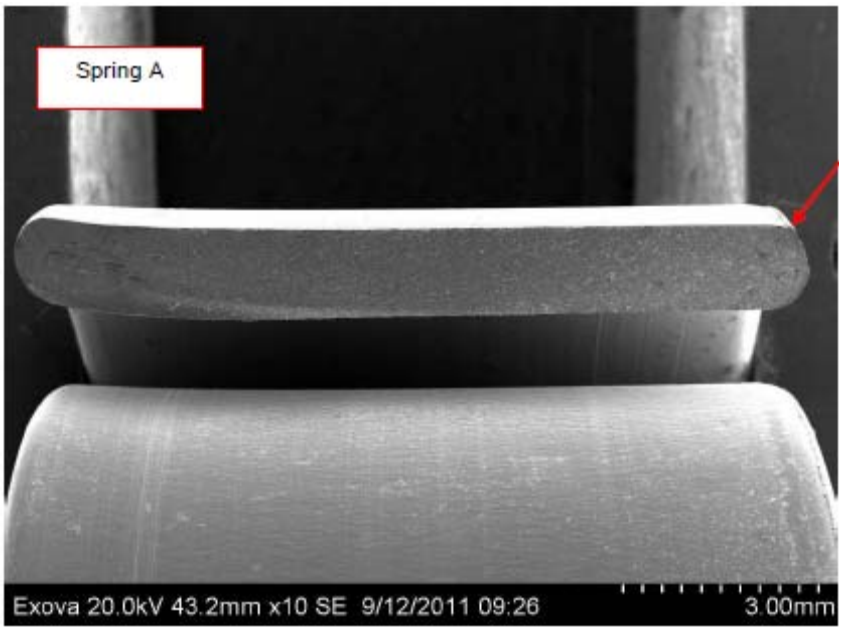


Figure 1: Spring from Ireland bus return. The red arrow shows the likely fracture origination point. Photo source report T116340.

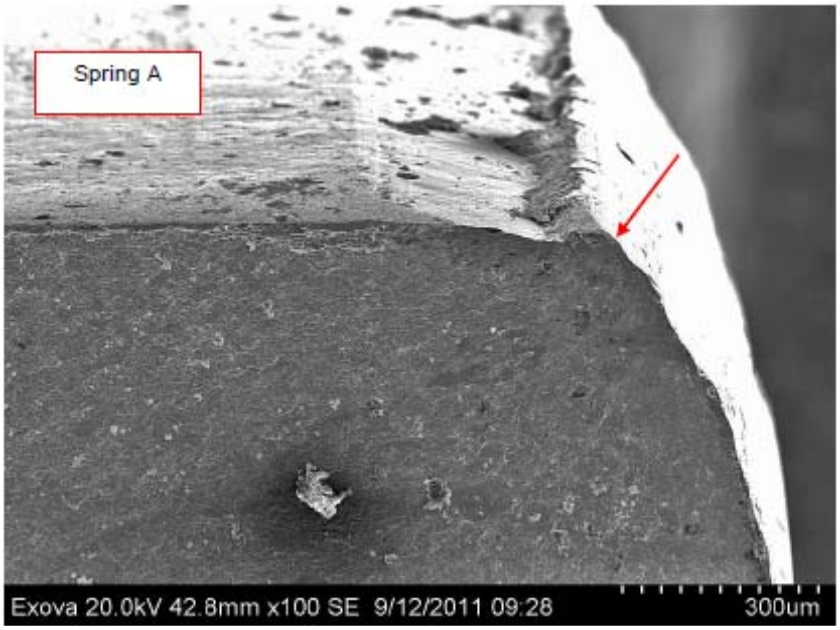


Figure 2: Spring from Ireland bus return. The red arrow shows the likely fracture origination point. Photo source report T116340.

The pedals with springs that fractured from variation in skiving had an average of 130,252 miles with a standard deviation of 27,585 miles. Statistics for the fractured springs can be found in Table 1.

Table 1: Mileage statistics for fractured and at-risk springs

	Mileage			
	Average	Min	Max	St Dev
Fractured Springs	**130,252**	**88,717**	**168,202**	**27,585**
At-Risk Springs	**117,927**	**22,958**	**168,824**	**82,316**

The summary of the fractured and at-risk springs can be found in Appendix 2.

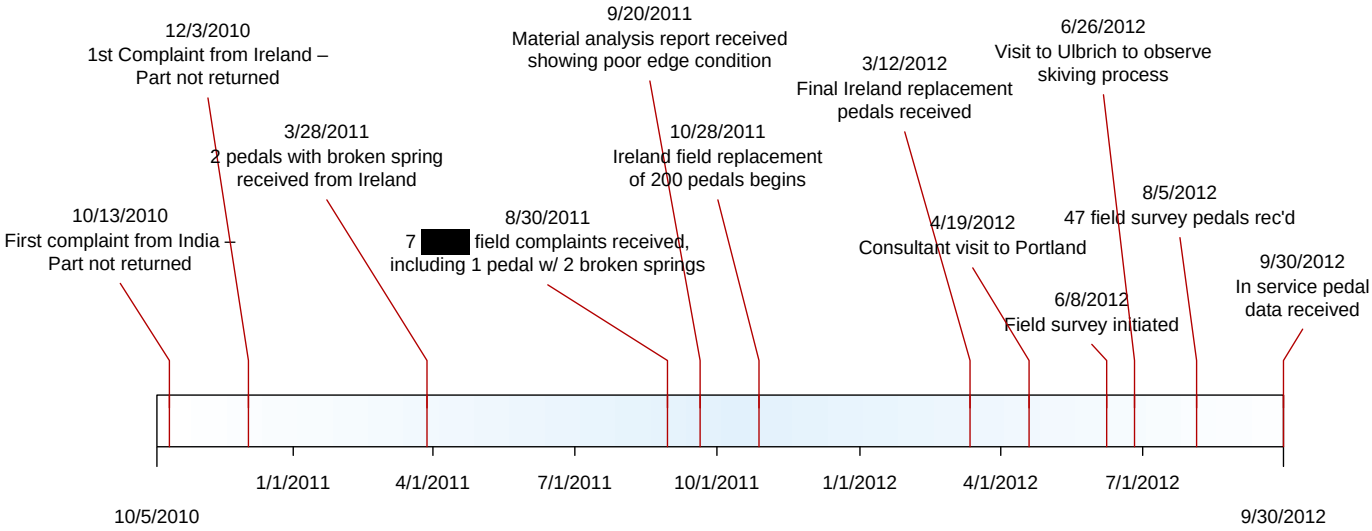
Ongoing monitoring

The confirmed spring conditions at [redacted] have been limited to 9 pedals with 10 broken springs (one pedal with two broken springs). Through the replacement pedal initiative and field survey, an additional 10 at-riskt springs have been identified but are in tact. All of the confirmed fractured and at-risk springs are found to have originated from spring lots from November or December 2007. Of the over 600 springs from the field that have been analyzed, an additional 32 springs from these production dates were examined and found to have no issue.

The WM-526 pedal platform is sold to over 100 customers all over the world in a variety of applications. No other field complaints of broken springs from this time period have been reported and there have been no reports of crashes or injuries associated with broken power springs on a WM-526 pedal.

Williams Controls will continue to closely monitor the field data on WM-526 pedal performance. Should any additional broken power springs be confirmed in the field, additional investigation will be undertaken.

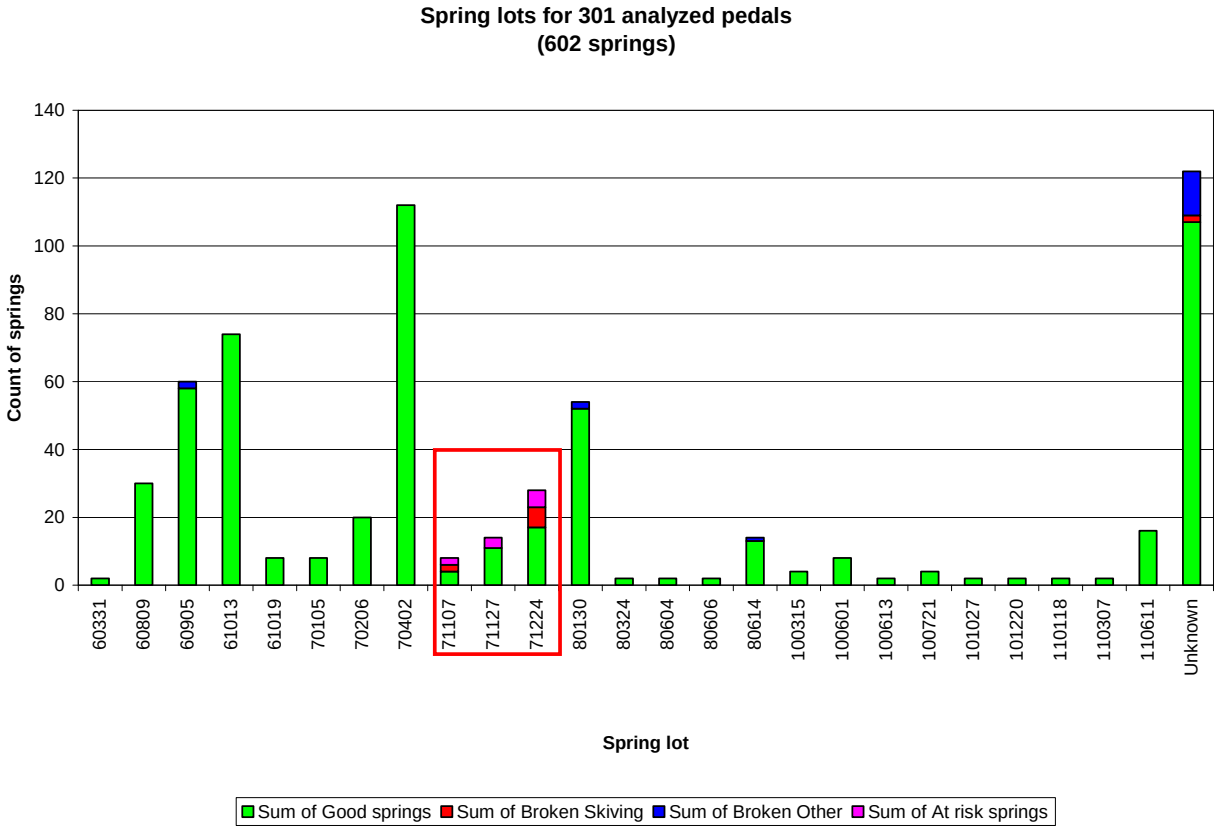
Appendix 1: Timeline of Events for WM-526 spring issue



Appendix 2: Summary of Pedals with fracture or at risk springs due to improper skiving

Group	Claim Number	Pedal Build Date	Return Region	Mode	Spring Lot #	Miles	Good springs	Broken Skiving	At risk springs
1st Field Returns	[redacted]	Not available	India B9R	Skiving mark	N/A	168,202	1	1	0
1st Field Returns	[redacted]	02/15/08	Ireland	Skiving mark	71224	N/A	1	1	0
1st Field Returns	[redacted]	02/15/08	Ireland	Skiving mark	71224	101,257	1	1	0
1st Field Returns	[redacted]	12/28/07	Ireland	Skiving mark	71107	151,455	1	1	0
1st Field Returns	[redacted]	02/15/08	Ireland	Skiving mark	71224	88,717	1	1	0
1st Field Returns	[redacted]	02/15/08	Ireland	Skiving mark	71224	129,068	1	1	0
1st Field Returns	[redacted]	02/15/08	Ireland	Skiving mark	71224	132,669	0	2	0
Ireland Replace	[redacted]	12/28/07	Ireland	Skiving mark	71107	140,393	1	1	0
Ireland Replace	[redacted]	12/25/07	Ireland	At risk	71127	168,824	1	0	1
Ireland Replace	[redacted]	02/15/08	Ireland	At risk	71224	N/A	0	0	2
Ireland Replace	[redacted]	02/15/08	Ireland	At risk	71224	N/A	1	0	1
Ireland Replace	[redacted]	02/15/08	Ireland	At risk	71224	161,999	0	0	2
Ireland Replace	[redacted]B	12/28/07	Ireland	At risk	71107	N/A	0	0	2
Ireland Replace	[redacted]	12/25/07	Ireland	At risk	71127	22,958	0	0	2
Ireland Replace	[redacted]	Not available	Ireland	Skiving mark	N/A	N/A	1	1	0

Appendix 3: Spring lots for analyzed pedals



EQ14-012 Enclosure B

Testing. Advising. Assuring.

194 Internationale Boulevard, Glendale Heights, IL 60139
Phone: (630) 221-0385 Fax: (630) 221-0796

Report No. T422262, Issue 1
November 06, 2014

Williams Controls, Inc.
14100 SW 72nd Avenue
Tigqard, Oregon 97224

Attention: Chris DeVincenzi

S U B J E C T

METALLURGICAL EXAMINATION OF LEFT AND RIGHT TORSION SPRINGS PER ENGINEERING DRAWING 131309, BOTH TYPE 301 IN THE FULL HARD CONDITION PER PER ASTM A666-10

Purchase Order:	P29917
Samples Received:	October 27, 2014
Report Author:	Ted R. Wilken
	Senior Lead Metallurgical Engineer

BACKGROUND

Two intact flat coil torsion springs that were part of a set were submitted to our laboratory for examination. In this set, one as-received spring was marked “L” for “Left” and the second was marked as “R” for “Right”.

These springs were produced per Engineering Drawing Number 131309. The engineering drawing specifies that these springs are both made from cold worked Type 301 stainless steel in the full-hard condition per ASTM A666.

We were asked to examine and analyze the intact left and right torsion springs that we received. Our testing for the two springs was as follows:

1) Visual examination of the intact Left and Right torsion springs;
2) Chemistry analysis for both of the torsion springs per the current revision of ASTM E415, E1079 and/or E1479 as necessary;
3) Scanning electron microscopy of the edges of these intact torsion springs;
4) Microstructural examination of a cross-section through the roughest area on each of these intact torsion springs, prepared per the current revision of ASTM E3; and
5) Knoop micro-indentation hardness testing on each of the two cross-sections per the current revision of ASTM E384.

Visual Examination

We visually examined the edges of the flat strip used to make the intact torsion springs that were submitted to our laboratory using a stereomicroscope at magnifications up to 60X. We were looking for evidence of cracks, tears or other edge defects. Both edges of both springs were examined and neither spring looked particularly rough, cracked or defective.

Photograph 1 provides an overall view of the left spring that we received. A short green line across the outer turn indicates where we made a cut to remove material for quantitative elemental analysis in our chemistry lab. The section we removed is labeled as “CHEMISTRY”.

Photograph 2 provides an overall view of the right spring that we received. A short green line across the outer turn indicates where we made a cut to remove material for quantitative elemental analysis in our chemistry lab. The section we removed is labeled as “CHEMISTRY”.

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Approach

After our visual examination, we cut of a portion of the outer turn from each spring. These pieces were submitted to our chemistry lab for quantitative elemental analysis to verify that the material classified as AISI 301 per ASTM A666.

We examined the edges of both sides of the two springs in the scanning electron microscope (SEM) to look for evidence of tears, cracks or other defects. We concentrated our examinations at the inner turns since experience has shown that springs of similar design are most susceptible to failure in this area.

After completing our SEM examinations, we prepared a transverse cross-section through each of the two torsion springs so that we could examine the cross-section of the edges of both springs for tears, cracks or other defects.

After completing our microstructural examinations, we performed micro-indentation hardness testing on the transverse cross-section for each of the two springs.

RESULTS

Quantitative Elemental Analysis

We performed quantitative chemical analyses on the left and right springs per current revision of ASTM E415. Our results are presented in Table I. Table I also includes the chemistry requirements for AISI 301 stainless steel wire per ASTM A666-10.

The two flat strip torsion springs that we analyzed classify as AISI 301 stainless steel per ASTM A666-10.

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Table I Chemistry Analysis Results for the Left and Right Springs

Elements	Left Spring (Weight %)	Right Spring (Weight %)	ASTM A666-10 AISI 301 (Weight %)
Carbon	0.12	0.12	0.15 max.
Manganese	0.82	0.81	2.00 max.
Phosphorus	0.027	0.028	0.045 max.
Sulfur	0.004	0.004	0.030 max.
Silicon	0.47	0.47	1.00 max.
Nickel	6.91	6.87	6.0 to 8.0
Chromium	17.10	17.06	16.0 to 18.0
Molybdenum	0.21	0.21	-----
Copper	0.23	0.23	-----
Titanium	<0.01	<0.01	-----
Niobium	0.02	0.02	-----
Tantalum	<0.01	<0.01	-----
Aluminum	<0.02	<0.02	-----
Nitrogen	0.04	0.03	0.10 max.

Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS)

We placed the left spring into the specimen chamber of our SEM so that we could examine the edge surface of the strip. We initially examined one side (Side 1) and then turned the spring over so that we could examine the other side (Side 2). We then examined the right spring in a similar fashion. Our Results are presented in separate sections.

A) Left Spring, Side 1

Photograph 3 is a low magnification view that shows the edge surface of several turns for the left spring. We arbitrarily designated the edge shown here as Side 1. The green line indicates our cross-sectioning plane location for the transverse cross-section that we prepared after completing the SEM examination. The white arrow indicates the portion that was mounted.

Photograph 4 is a closer view of the first area that we examined on Side 1 of the left spring. Area 1 is at the bend made for the inside hook of the left spring.

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Photograph 5 is an even closer view of the first area that we examined on Side 1 of the left spring. Area 1, which is at the bend made for the inside hook of the left spring, shows a kink in the steel surface at the inside radius of the bend. No cracks or tears are visible.

Photograph 6 is a closer view of the second area that we examined on Side 1 of the left spring. Area 2 shows a slight kink in the inside radius surface of the left spring.

Photograph 7 is an even closer view of the second area that we examined on Side 1 of the left spring. Area 2, which further from the inside hook of the left spring, shows a slight kink in the inside radius surface of the steel. No cracks or tears are visible.

Photograph 8 is a closer view of the third area that we examined on Side 1 of the left spring. Area 3 shows uniform curvature on the inside radius surface of the left spring.

Photograph 9 is an even closer view of the third area that we examined on Side 1 of the left spring. Area 3, which is even further from the inside hook of the left spring, shows uniform curvature. No cracks or tears are visible. We do, however, see dark residue rubbed into the surface.

Photograph 10 is a closer view of the fourth area that we examined on Side 1 of the left spring. Area 4 shows uniform curvature on the inside radius surface of the left spring. Some residue is sticking out from the inside surface.

Photograph 11 is an even closer view of the fourth area that we examined on Side 1 of the left spring. Area 4, which is even further from the inside hook of the left spring, shows uniform curvature. No cracks or tears are visible. We do, however, see dark residue sticking out from the surface. We used the EDS system to identify the elements present in the “X” point for the residue and a clean area on the steel surface (the area surrounded by the orange box).

The EDS is a system of the SEM that can be used to identify the elements present in an area on a surface. When the electron beam of the SEM strikes a surface, x-rays are emitted and these can be detected for elements with atomic number 5 and higher (our EDS system does not detect beryllium).

The x-rays from elements with atomic number 5 and higher have characteristics of the elements from which they are emitted. The EDS system can recognize these x-ray characteristics and thereby identify the elements present.

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The EDS system records a spectrum for an area analyzed. This EDS spectrum consists of a series of peaks that are associated with specific elements. The X-axis of an EDS spectrum indicates the x-ray energy, while the Y-axis of the EDS spectrum is the number of x-ray quanta detected with a given energy. In general, higher peak heights indicate that more of a given element is present.

Figure 1 shows the EDS spectrum that we recorded for point location "X" in the residue on the ID surface in Photograph 11. The main elements detected were carbon (C), oxygen (O), aluminum (Al), silicon (Si), sulfur (S), chromium (Cr) and iron (Fe). Lesser amounts of nickel (Ni), zinc (Zn), sodium (Na), magnesium (Mg), phosphorus (P), chlorine (Cl), potassium (K), calcium (Ca) and manganese (Mn) were also present.

The iron, chromium, nickel and manganese are attributed to AISI 301 steel residue. The remaining elements carbon, oxygen, sodium, zinc, magnesium, aluminum, silicon, phosphorus, sulfur, chlorine, potassium and calcium are consistent with a grease residue formulation but other sources are possible.

Figure 2 shows the EDS spectrum that we recorded for the area surrounded by the orange box in Photograph 11. The main elements detected were chromium (Cr) and iron (Fe). Lesser amounts of carbon (C), oxygen (O), aluminum (Al), silicon (Si), manganese (Mn) and nickel (Ni) were also present.

The detected iron, chromium, nickel, manganese and silicon are attributed to the AISI 301 stainless steel. The carbon and oxygen are contaminants such as oil.

B) Left Spring, Side 2

We opened the SEM specimen chamber so that we could turn the left spring over so that we could examine the other edge.

Photograph 12 is a low magnification view that shows the edge surface of several turns for the left spring. We arbitrarily designated the edge shown here as Side 2.

Photograph 13 is a closer view of the first area that we examined on Side 2 of the left spring. Area 1 is at the bend made for the inside hook of the left spring.

Photograph 14 is an even closer view of the first area that we examined on Side 2 of the left spring. Area 1, which is at the bend made for the inside hook of the left spring, shows a rough steel surface at the inside radius of the bend. No cracks or tears are visible.

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Photograph 15 is a closer view of the second area that we examined on Side 2 of the left spring. Area 2 shows a slight kink in the inside radius surface of the left spring.

Photograph 16 is an even closer view of the second area that we examined on Side 2 of the left spring. Area 2, which further from the inside hook of the left spring, shows a slight kink in the inside radius surface of the steel. No cracks or tears are visible.

Photograph 17 is a closer view of the third area that we examined on Side 2 of the left spring. Area 3 shows uniform curvature on the inside radius surface of the left spring.

Photograph 18 is an even closer view of the third area that we examined on Side 2 of the left spring. Area 3, which is even further from the inside hook of the left spring, shows uniform curvature. No cracks or tears are visible. We do, however, see fine contamination particles the surface.

Photograph 19 is a closer view of the fourth area that we examined on Side 2 of the left spring. Area 4 shows uniform curvature on the inside radius surface of the left spring. Some residue is sticking out from the inside surface.

C) Right Spring, Side 1

We opened the SEM specimen chamber so that we could install the right spring and examine one edge. We arbitrarily designated this edge as Side 1.

Photograph 20 is a low magnification view that shows the edge surface of several turns for the right spring. We arbitrarily designated the edge shown here as Side 1. The green line indicates our cross-sectioning plane location for the transverse cross-section that we prepared after completing the SEM examination. The white arrow indicates the portion that was mounted.

Photograph 21 is a closer view of the first area that we examined on Side 1 of the right spring. Area 1 is at the bend made for the inside hook of the right spring.

Photograph 22 is an even closer view of the first area that we examined on Side 1 of the right spring. Area 1, which is at the bend made for the inside hook of the right spring, shows a kink in the steel surface at the inside radius of the bend. No cracks or tears are visible.

Photograph 23 is a closer view of the second area that we examined on Side 1 of the right spring. Area 2 shows a slight kink in the inside radius surface of the right spring.

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Photograph 24 is an even closer view of the second area that we examined on Side 1 of the right spring. Area 2, which further from the inside hook of the right spring, shows a slight kink in the inside radius surface of the steel. No cracks or tears are visible.

Photograph 25 is a closer view of the third area that we examined on Side 1 of the right spring. Area 3 shows uniform curvature on the inside radius surface of the right spring.

Photograph 26 is an even closer view of the third area that we examined on Side 1 of the right spring. Area 3, which is even further from the inside hook of the right spring, shows uniform curvature. No cracks or tears are visible.

Photograph 27 is a closer view of the fourth area that we examined on Side 1 of the right spring. Area 4 shows uniform curvature on the inside radius surface of the right spring. Some residue is present on the inside surface.

Photograph 28 is a closer view of the fifth area that we examined on Side 1 of the right spring. Area 5 shows uniform curvature on the inside radius surface of the right spring. Some residue is present on the inside surface.

D) Right Spring, Side 2

We opened the SEM specimen chamber so that we could turn the right spring over so that we could examine the other edge.

Photograph 29 is a low magnification view that shows the edge surface of several turns for the right spring. We arbitrarily designated the edge shown here as Side 2.

Photograph 30 is a closer view of the first area that we examined on Side 2 of the right spring. Area 1 is at the bend made for the inside hook of the right spring.

Photograph 31 is an even closer view of the first area that we examined on Side 2 of the right spring. Area 1, which is at the bend made for the inside hook of the right spring, shows a rough steel surface at the inside radius of the bend. No cracks or tears are visible.

Photograph 32 is a closer view of the second area that we examined on Side 2 of the right spring. Area 2 shows a slight kink in the inside radius surface of the right spring.

Photograph 33 is an even closer view of the second area that we examined on Side 2 of the right spring. Area 2, which further from the inside hook of the right spring, shows a slight kink in the inside radius surface of the steel. No cracks or tears are visible.

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Photograph 34 is a closer view of the third area that we examined on Side 2 of the right spring. Area 3 shows uniform curvature on the inside radius surface of the right spring.

Photograph 35 is an even closer view of the third area that we examined on Side 2 of the right spring. Area 3, which is even further from the inside hook of the right spring, shows uniform curvature. No cracks or tears are visible. We do, however, see contamination on the surface.

Photograph 36 is a closer view of the fourth area that we examined on Side 2 of the right spring. Area 4 shows uniform curvature on the inside radius surface of the right spring. Some residue is present on the inside surface.

Photograph 37 is an even closer view of the fourth area that we examined on Side 2 of the right spring. Area 4, which is even further from the inside hook of the right spring, shows uniform curvature. No cracks or tears are visible. We do, however, see contamination on the surface.

Photograph 38 is an even closer view of the fifth area that we examined on Side 2 of the right spring. Area 5, which is even further from the inside hook of the right spring, shows uniform curvature. No cracks or tears are visible. We do, however, see contamination on the surface. We used the EDS system to identify the elements present in area surrounded by the red box.

Figure 3 shows the EDS spectrum that we recorded for the area surrounded by the red box in Photograph 38. The main elements detected were carbon (C), oxygen (O), aluminum (Al) and silicon (Si). Lesser amounts of iron (Fe), copper (Cu), sodium (Na), sulfur, chlorine (Cl), chromium (Cr), manganese (Mn) and nickel (Ni) were also present.

The detected iron, chromium, nickel and manganese are attributed to the AISI 301 stainless steel. The carbon, oxygen, aluminum, silicon, sulfur and chlorine are consistent with a grease residue formulation but other sources are possible.

We placed the left and right springs into the specimen chamber of our SEM so that we could examine both edge surfaces for each spring. WE did see some kinks on the inside surface of the springs near the inside hook and we did see some contamination on the surfaces. We did not, however, see any cracks, tears or other defects.

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We used the EDS system of the SEM to analyze the fracture surface in the area of the main origin and many elements were detected. The iron, chromium, nickel and manganese are attributed to AISI 301 steel residue. The remaining elements carbon, oxygen, sodium, zinc, magnesium, aluminum, silicon, phosphorus, sulfur, chlorine, potassium and calcium are consistent with a grease residue formulation but other sources are possible.

Microstructural Examination

After completing the SEM and EDS examinations, we prepared a transverse cross-section through the left torsion spring and a similar transverse cross-section through the right torsion spring, both cross-sections prepared per the current revision of ASTM E3. The cross-sections were mounted in Bakelite®-type medium and then ground and polished in accordance with the standard practices of the current revision of ASTM E3.

The finished cross-sections were examined in the as-polished condition using a metallurgical microscope at magnifications up to 1000X. In particular, we examined the cross-section at the two edges of the strip used to make each spring. The results for each spring is presented in a separate section

A) Left Spring

Photograph 39 is a low magnification view of the cross-section of the edge on one side of the strip used to make the left spring. We arbitrarily designated this edge as corner A. The lower portion of corner A does not have a fully radiused profile.

Photograph 40 is a closer view of the lower portion of corner A of the cross-section for the strip used to make the left spring. This area does not show a full radius profile as expected for a fully polished strip edge. Material appears to have chipped out.

Photograph 41 is a high magnification view of a part of the lower portion of corner A of the cross-section for the strip used to make the left spring. This area does not show a full radius profile as expected for a fully polished strip edge. Material appears to have chipped out.

Photograph 42 is a high magnification view of another part of the lower portion of corner A of the cross-section for the strip used to make the left spring. This area does not show a full radius profile as expected for a fully polished strip edge. Material appears to have chipped out.

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After completing the SEM and EDS examinations, we prepared a transverse cross-section through the left torsion spring and a similar transverse cross-section through the right torsion spring. The finished cross-sections were examined in the as-polished condition using a metallurgical microscope at magnifications up to 1000X. In particular, we examined the cross-section at the two edges of the strip used to make each spring.

Photograph 43 is a low magnification view of the cross-section of the center of the strip used to make the left spring. One can see the elongated indentations produced during subsequent Knoop micro-indentation hardness testing.

We then examined the cross-section of the other edge of the strip used to make the left spring.

Photograph 44 is a low magnification view of the cross-section of the edge on the other side of the strip used to make the left spring. We arbitrarily designated this edge as corner B. Corner B essentially shows a fully radiused profile.

Photograph 45 is a high magnification view of a part of the lower portion of corner B of the cross-section for the strip used to make the left spring. This area does show a full radius profile as expected for a fully polished strip edge, with a slight bump in the surface.

Photograph 46 is a high magnification view of the upper portion of corner B of the cross-section for the strip used to make the left spring. This area is just past the full radius profile. The orange line is provided to show that the surface is slightly dished out in one area while a bump is seen on the left side.

B) Right Spring

Photograph 47 is a low magnification view of the cross-section of the edge on one side of the strip used to make the right spring. We arbitrarily designated this edge as corner A. The lower portion of corner A does not have a fully radiused profile.

Photograph 48 is a high magnification view of a part of the lower portion of corner A of the cross-section for the strip used to make the right spring. This area does show a full radius profile as expected for a fully polished strip edge, with a slight bump in the surface.

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Photograph 49 is a high magnification view of the lower portion of corner B of the cross-section for the strip used to make the right spring. The orange line is provided to show that the surface is slightly dished out in one area.

Photograph 50 is a low magnification view of the cross-section of the center of the strip used to make the left spring. One can see the elongated indentations produced during subsequent Knoop micro-indentation hardness testing.

We then examined the cross-section of the other edge of the strip used to make the left spring.

Photograph 51 is a low magnification view of the cross-section of the edge on the other side of the strip used to make the right spring. We arbitrarily designated this edge as corner B. Corner B essentially shows a fully radiused profile.

Photograph 52 is a high magnification view of a part of the upper portion of corner B of the cross-section for the strip used to make the right spring. This area does show a full radius profile as expected for a fully polished strip edge, with a slight bump of deposits on the surface as outlined by orange lines.

Photograph 53 is a high magnification view of the lower portion of corner B of the cross-section for the strip used to make the left spring. This area does show a full radius profile as expected for a fully polished strip edge.

After completing the SEM and EDS examinations, we prepared a transverse cross-section through the left torsion spring and a similar transverse cross-section through the right torsion spring. The finished cross-sections were examined in the as-polished condition using a metallurgical microscope at magnifications up to 1000X. In particular, we examined the cross-section at the two edges of the strip used to make each spring.

The right spring showed that the cross-section of the edges were essentially fully radiused by edge preparation. The left spring showed one of the edges was essentially fully radiused by edge preparation. The other edge was mostly radiused by edge preparation, with an area where material had apparently chipped out

Micro-Indentation Hardness Testing

After completing the microstructural examination, we performed micro-indentation hardness testing on transverse cross-sections of the left spring and the right spring using a 500 gram test load per the current revision of ASTM E384. Five readings were made for each cross-section at progressively greater distances from the outside surface to the center of the strip. Our results were recorded in Tables II and III.

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The measured Knoop (HK) values for the left spring are summarized in Table II, while the measured Knoop (HK) values for the right spring are summarized in Table III. Both tables also list approximate equivalent Rockwell "C" scale (HRC) values. Strictly speaking, there is no accepted conversion between the Knoop and Rockwell "C" scale values per the current revision of ASTM E140. The approximate Rockwell "C" scale values are given for informational purposes only

Table II Summary of Results from Knoop Micro-Indentation Hardness Testing Of the Transverse Cross-Section of the Left Spring

Distance from Strip Surface (in.)	Hardness	
	Knoop (HK)	Rockwell (HRC)
0.0015	399	40
0.003	421	42
0.005	434	43
0.010	450	44
0.025	437	43

Table III Summary of Results from Knoop Micro-Indentation Hardness Testing Of the Transverse Cross-Section of the Right Spring

Distance from Strip Surface (in.)	Hardness	
	Knoop (HK)	Rockwell (HRC)
0.0015	364	37
0.003	400	40
0.005	462	45
0.010	454	44
0.025	416	41

ASTM A666-10 requires that AISI 301 stainless steel in the full hard condition have an UTS of 185 ksi minimum. When AISI 301 stainless steel was specified to have an ultimate tensile strength of 185 ksi minimum, it effectively required the AISI 301 to be in the severely cold-worked condition. Using Table 2 of the current revision of ASTM A370 as a guide, the material would be expected to have a hardness of about 40 HRC minimum.

Our results indicate that the strip used for the left spring and the right spring has hardness consistent with the required value of ultimate tensile strength for AISI 301 in the full hard condition per ASTM A666-10.

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DISCUSSION

We visually examined the left and right springs that were submitted to our laboratory. We examined both of the springs visually and with a stereomicroscope. In particular, we examined the edge surfaces of the steel strip used to make the springs for evidence of any cracking, tearing or defects since such features can initiate fracture. No cracks, tears or other defects were seen on edges of the strip used to make the torsion springs.

We performed quantitative chemical analyses on the left and right springs per current revision of ASTM E415. The two flat strip torsion springs that we analyzed classify as AISI 301 stainless steel per ASTM A666-10.

We placed the left and right springs into the specimen chamber of our SEM so that we could examine both edge surfaces for each spring. WE did see some kinks on the inside surface of the springs near the inside hook and we did see some contamination on the surfaces. We did not, however, see any cracks, tears or other defects.

We used the EDS system of the SEM to analyze the fracture surface in the area of the main origin and many elements were detected. The iron, chromium, nickel and manganese are attributed to AISI 301 steel residue. The remaining elements carbon, oxygen, sodium, zinc, magnesium, aluminum, silicon, phosphorus, sulfur, chlorine, potassium and calcium are consistent with a grease residue formulation but other sources are possible.

After completing the SEM and EDS examinations, we prepared a transverse cross-section through the left torsion spring and a similar transverse cross-section through the right torsion spring. The finished cross-sections were examined in the as-polished condition using a metallurgical microscope at magnifications up to 1000X. In particular, we examined the cross-section at the two edges of the strip used to make each spring.

The right spring showed that the cross-section of the edges were essentially fully radiused by edge preparation. The left spring showed one of the edges was essentially fully radiused by edge preparation. The other edge was mostly radiused by edge preparation, with an area where material had apparently chipped out

After completing the microstructural examination, we performed micro-indentation hardness testing on transverse cross-sections of the left spring and the right spring.

ASTM A666-10 requires that AISI 301 stainless steel in the full hard condition have an UTS of 185 ksi minimum. Our results indicate that the strip used for the left spring and the right spring has hardness consistent with the required value of ultimate tensile strength for AISI 301 in the full hard condition per ASTM A666-10

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CONCLUSIONS

As a result of our examination of the failed spring, it is the opinion of Exova, Inc. that:

1) The two flat strip torsion springs that we analyzed classify as AISI 301 stainless steel per ASTM A666-10;
2) Our results from micro-indentation hardness testing indicate that the strip used for the left spring and the right spring has hardness consistent with the required value of ultimate tensile strength for AISI 301 in the full hard condition per ASTM A666-10;
3) The SEM examination did not show any cracks tears or other defects in the edge surfaces of the left spring and the right spring; and
4) The metallographically prepared cross-sections we made showed that the cross-section of the edges of the right spring were essentially fully radiused by edge preparation. The left spring showed one of the edges was essentially fully radiused by edge preparation. The other edge was mostly radiused by edge preparation, with an area where material had apparently chipped out.

Respectfully submitted for and on behalf of,

Exova, Inc.

Ted R. Wilken

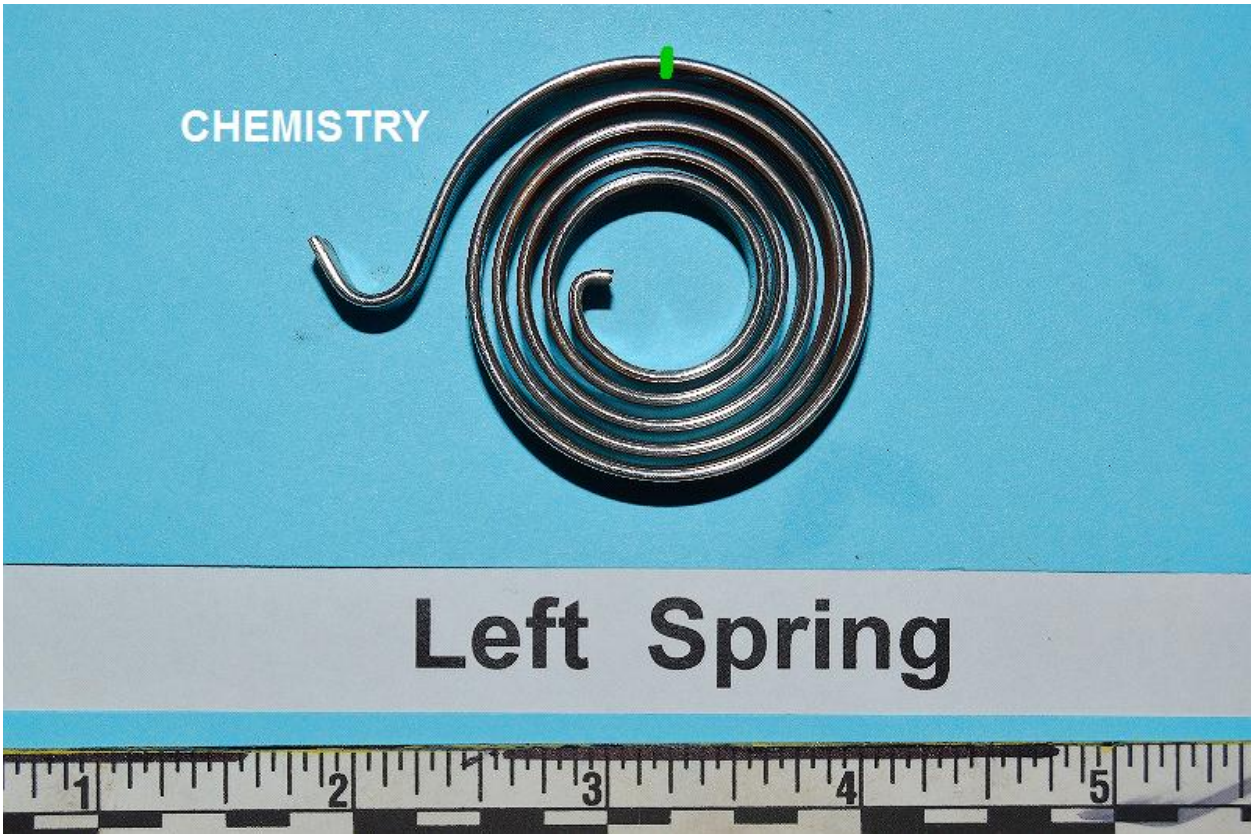
Ted R. Wilken
Senior Lead Metallurgical Engineer

TRW / CGS

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Photograph 1



This is an overall view of the left spring that we received. A short green line across the outer turn indicates where we made a cut to remove material for quantitative elemental analysis in our chemistry lab. The section we removed is labeled as “CHEMISTRY”.

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Photograph 2

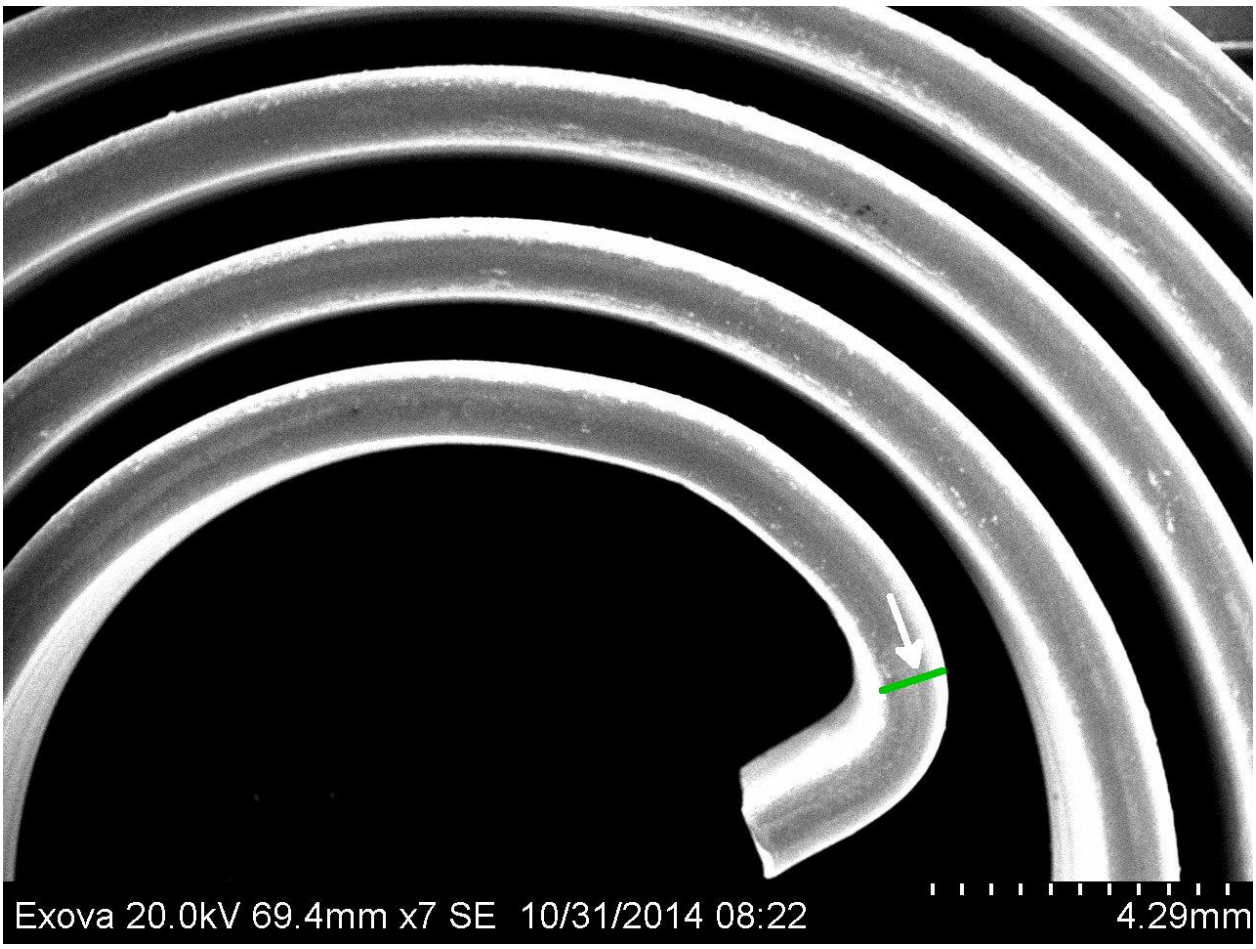


This is an overall view of the right spring that we received. A short green line across the outer turn indicates where we made a cut to remove material for quantitative elemental analysis in our chemistry lab. The section we removed is labeled as “CHEMISTRY”.

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Photograph 3

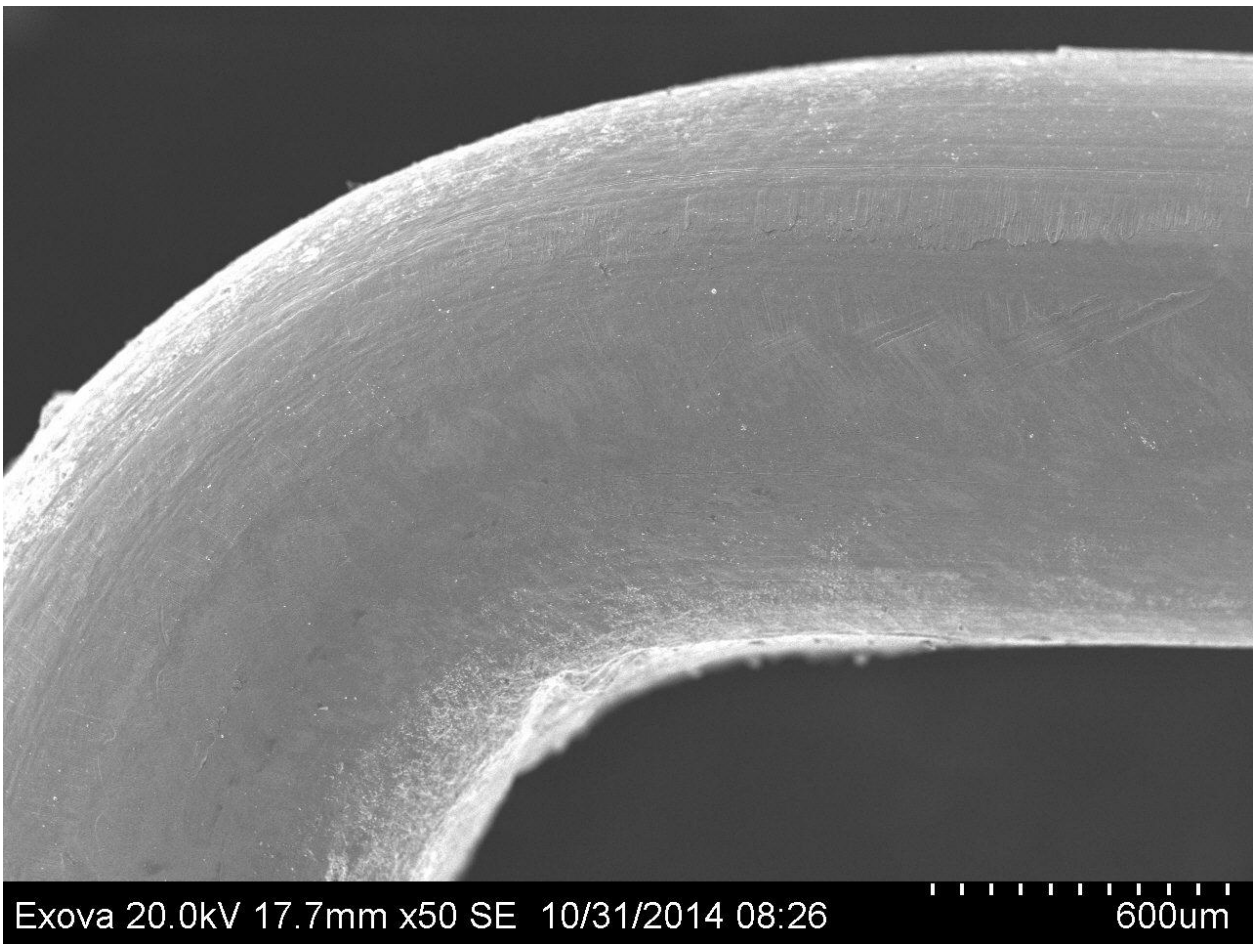


Magnification: 7X
This is a low magnification view that shows the edge surface of several turns for the left spring. We arbitrarily designated the edge shown here as Side 1. The green line indicates our cross-sectioning plane location for the transverse cross-section that we prepared after completing the SEM examination. The white arrow indicates the portion that was mounted.

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Photograph 4

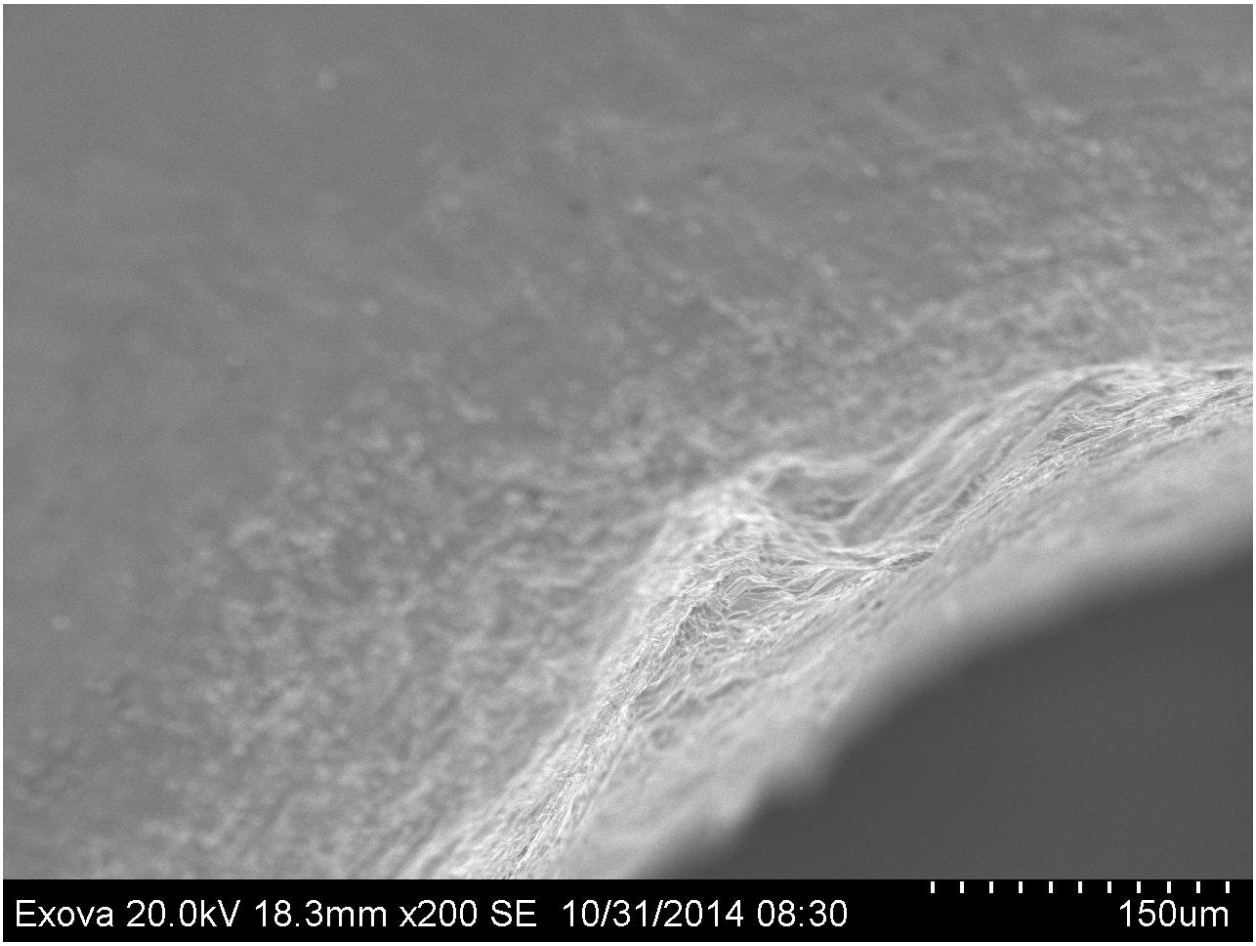


Magnification: 50X
This is a closer view of the first area that we examined on Side 1 of the left spring. Area 1 is at the bend made for the inside hook of the left spring.

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Photograph 5



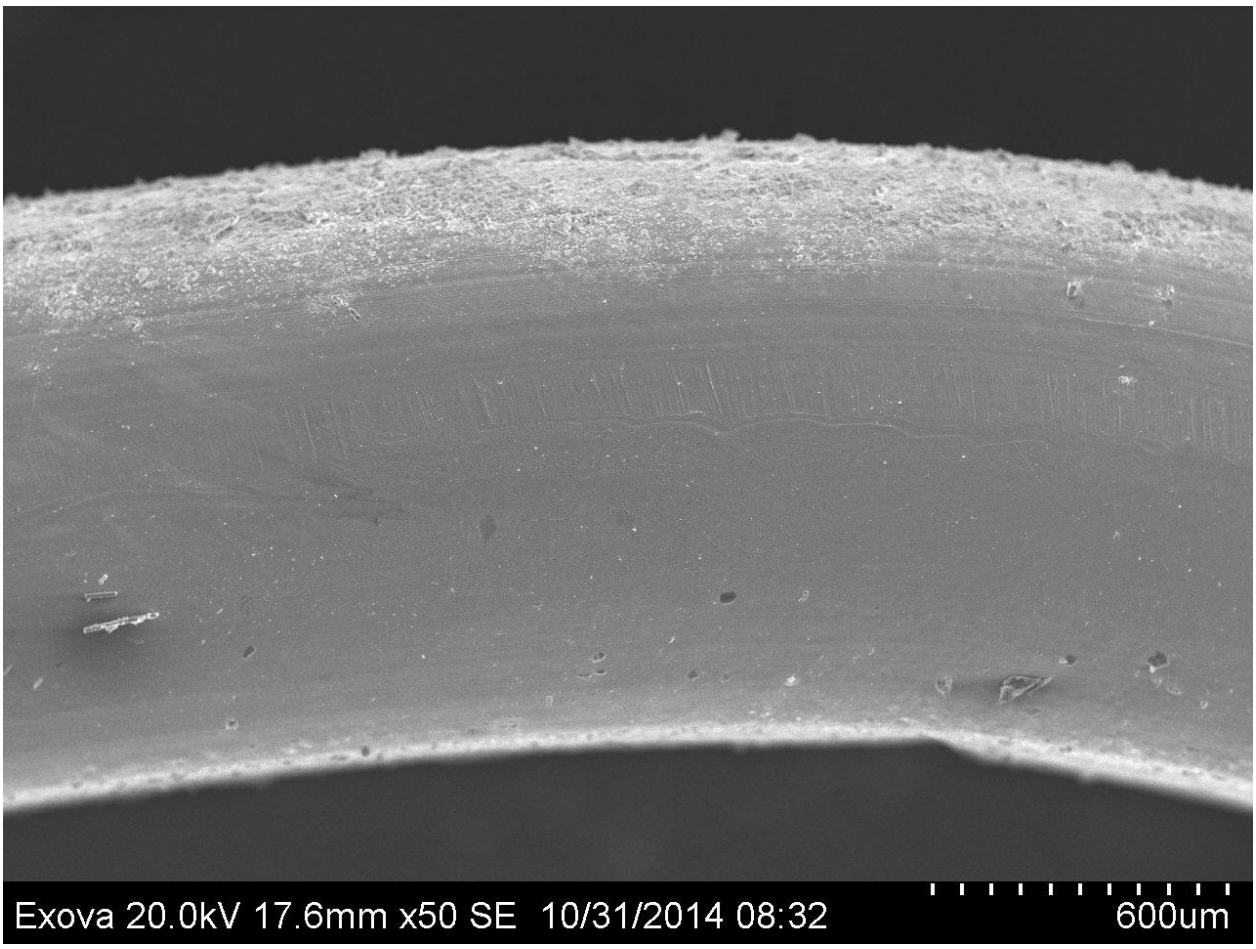
Magnification: 200X

This is an even closer view of the first area that we examined on Side 1 of the left spring. Area 1, which is at the bend made for the inside hook of the left spring, shows a kink in the steel surface at the inside radius of the bend. No cracks or tears are visible.

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Photograph 6

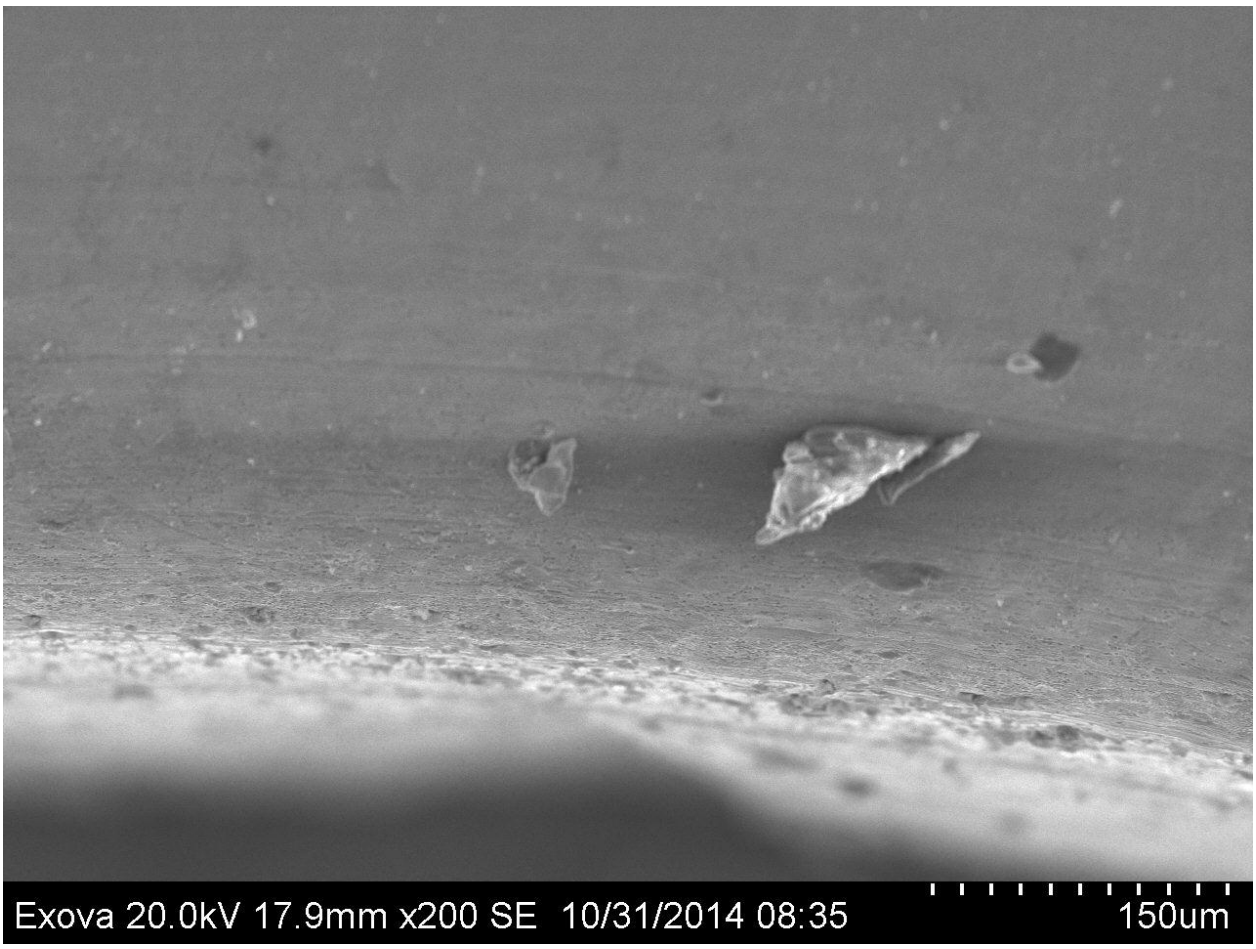


Magnification: 50X
This is a closer view of the second area that we examined on Side 1 of the left spring. Area 2 shows a slight kink in the inside radius surface of the left spring.

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Photograph 7

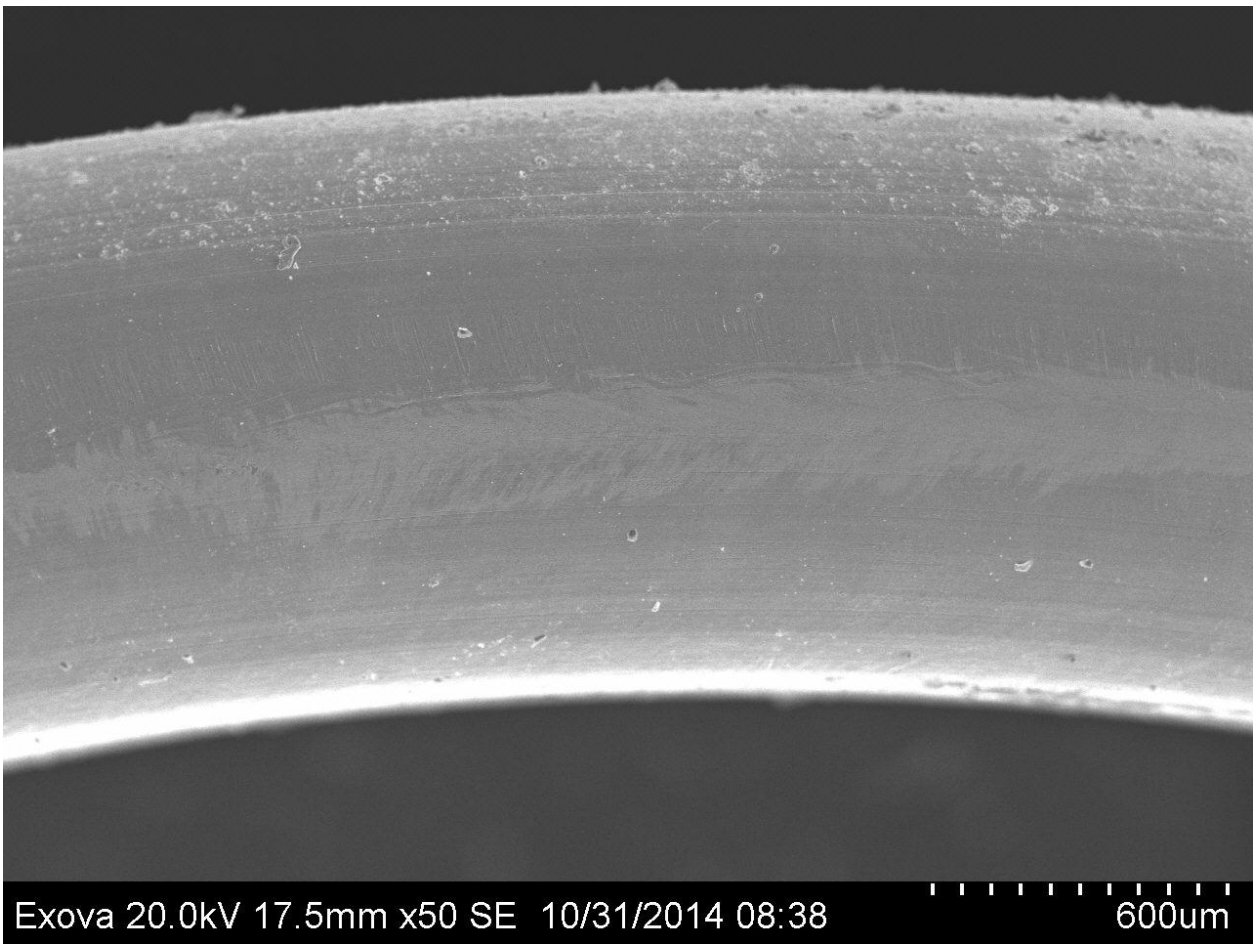


Magnification: 200X
This is an even closer view of the second area that we examined on Side 1 of the left spring. Area2, which further from the inside hook of the left spring, shows a slight kink in the inside radius surface of the steel. No cracks or tears are visible.

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Photograph 8

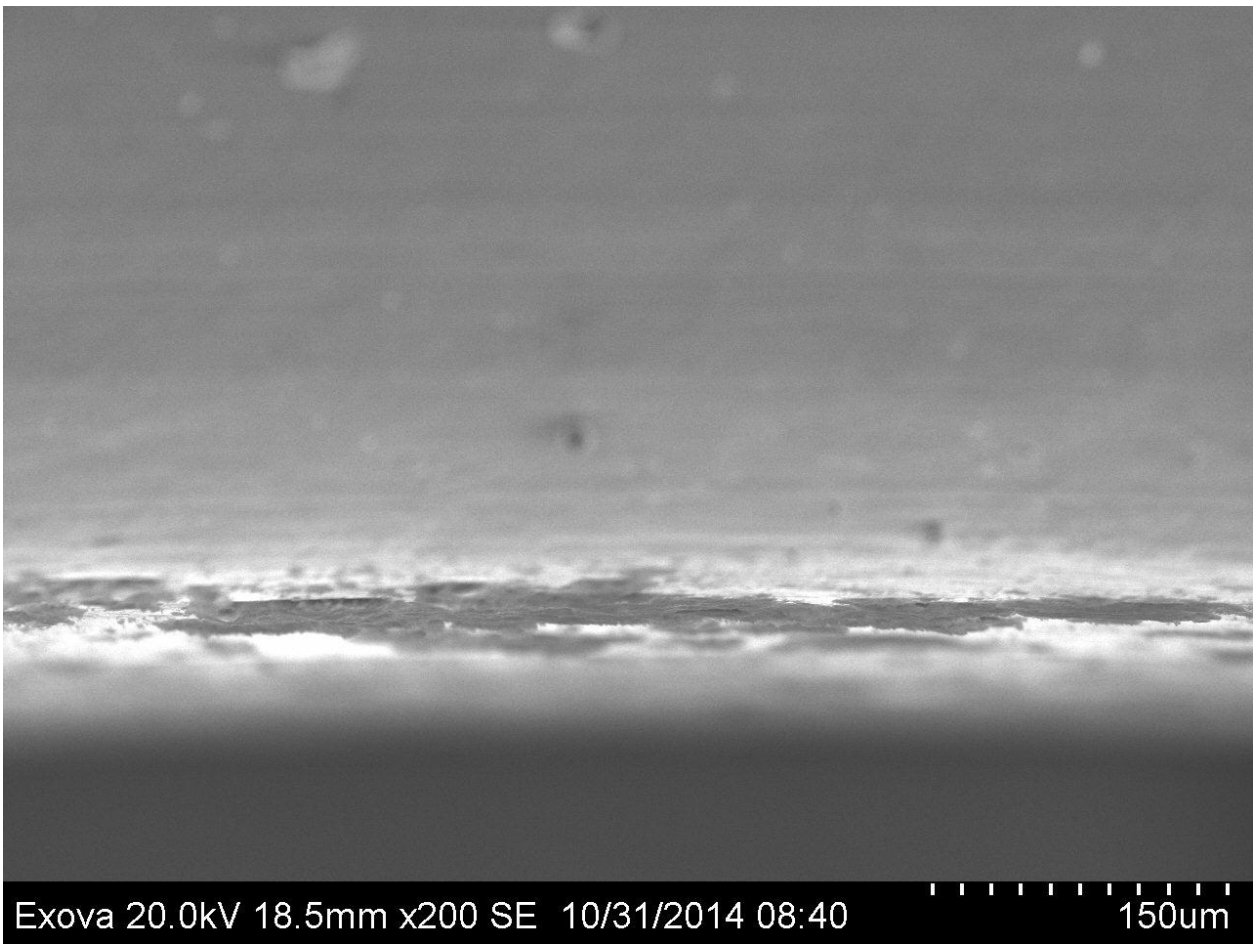


Magnification: 50X
This is a closer view of the third area that we examined on Side 1 of the left spring. Area 3 shows uniform curvature on the inside radius surface of the left spring.

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Photograph 9

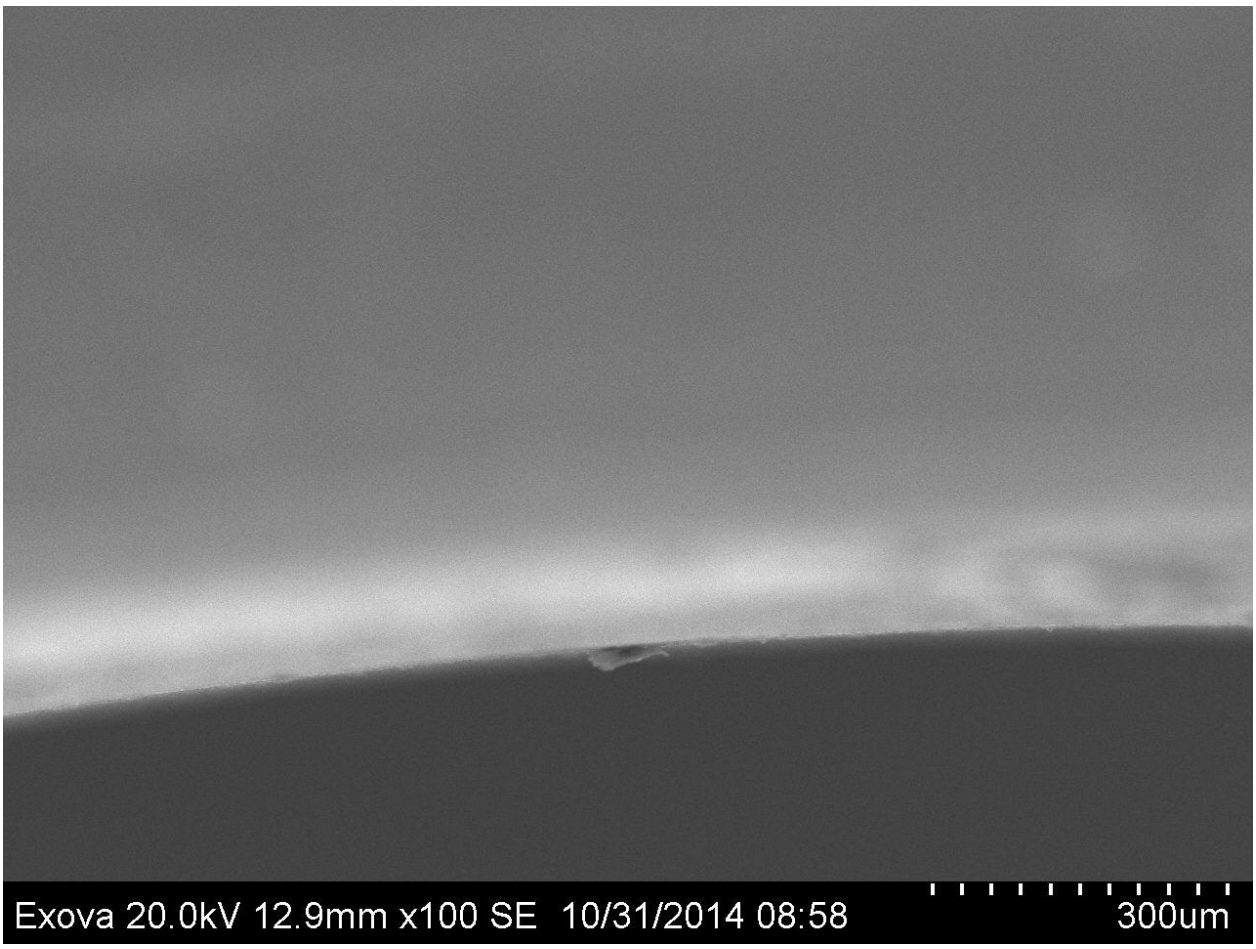


Magnification: 200X
This is an even closer view of the third area that we examined on Side 1 of the left spring. Area 3, which is even further from the inside hook of the left spring, shows uniform curvature. No cracks or tears are visible. We do, however, see dark residue rubbed into the surface.

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Photograph 10

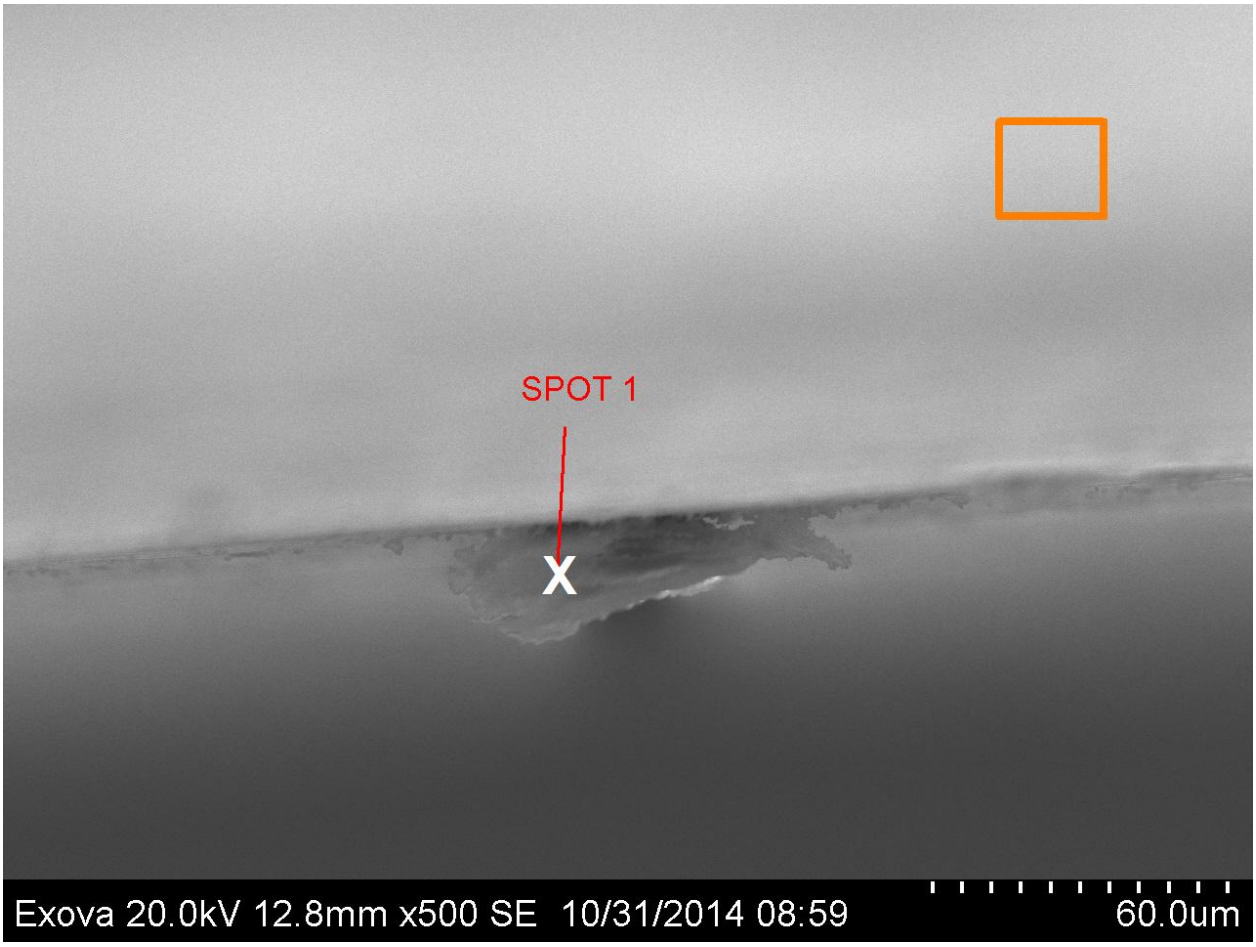


Magnification: 100X
This is a closer view of the fourth area that we examined on Side 1 of the left spring. Area 4 shows uniform curvature on the inside radius surface of the left spring. Some residue is sticking out from the inside surface.

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Photograph 11



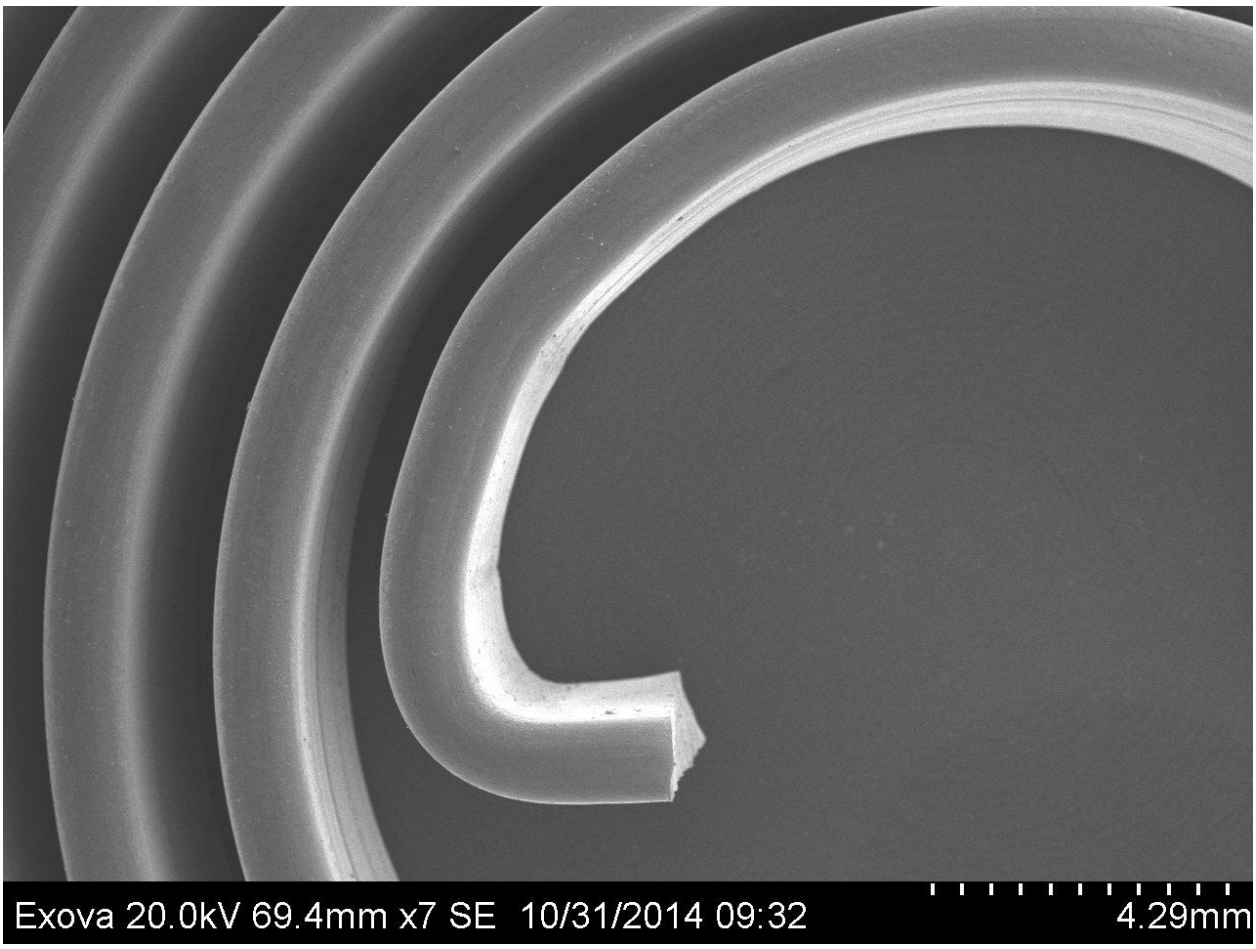
Magnification: 500X

This is an even closer view of the fourth area that we examined on Side 1 of the left spring. Area 4, which is even further from the inside hook of the left spring, shows uniform curvature. No cracks or tears are visible. We do, however, see dark residue sticking out from the surface. We used the EDS system to identify the elements present in the "X" point for the residue and a clean area on the steel surface (the area surrounded by the orange box).

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Photograph 12

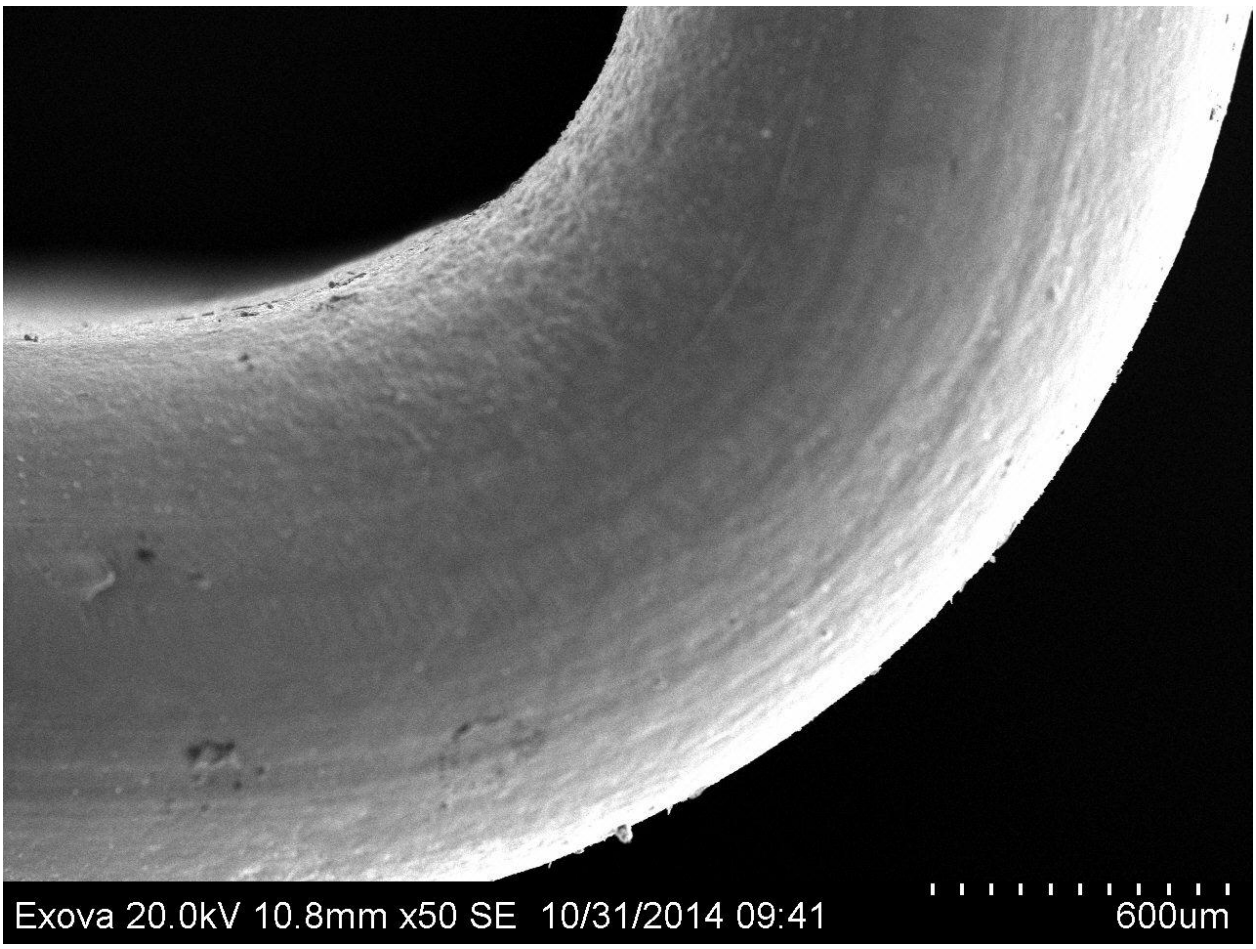


Magnification: 7X
This is a low magnification view that shows the edge surface of several turns for the left spring. We arbitrarily designated the edge shown here as Side 2.

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Photograph 13

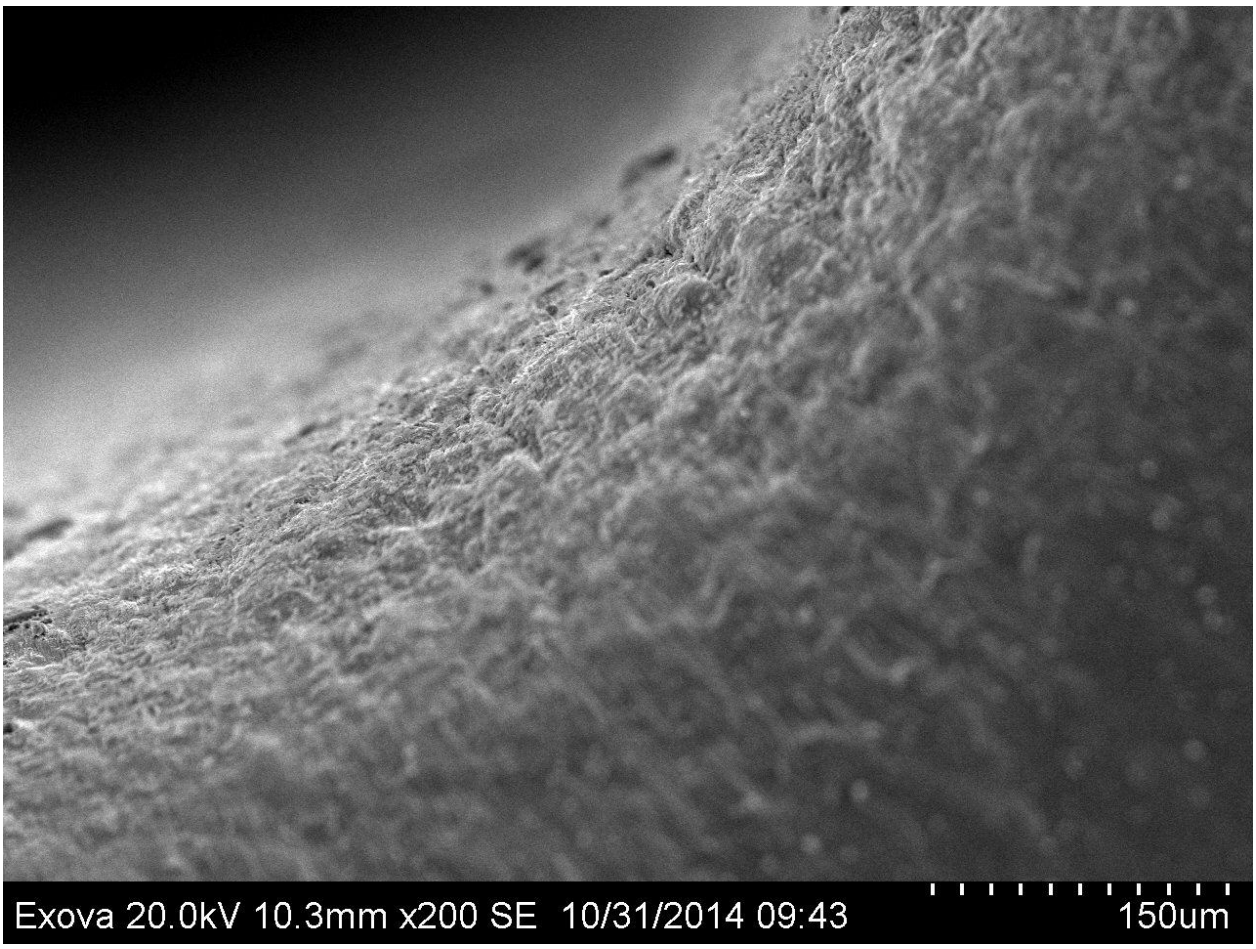


Magnification: 50X
This is a closer view of the first area that we examined on Side 2 of the left spring. Area 1 is at the bend made for the inside hook of the left spring.

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Photograph 14

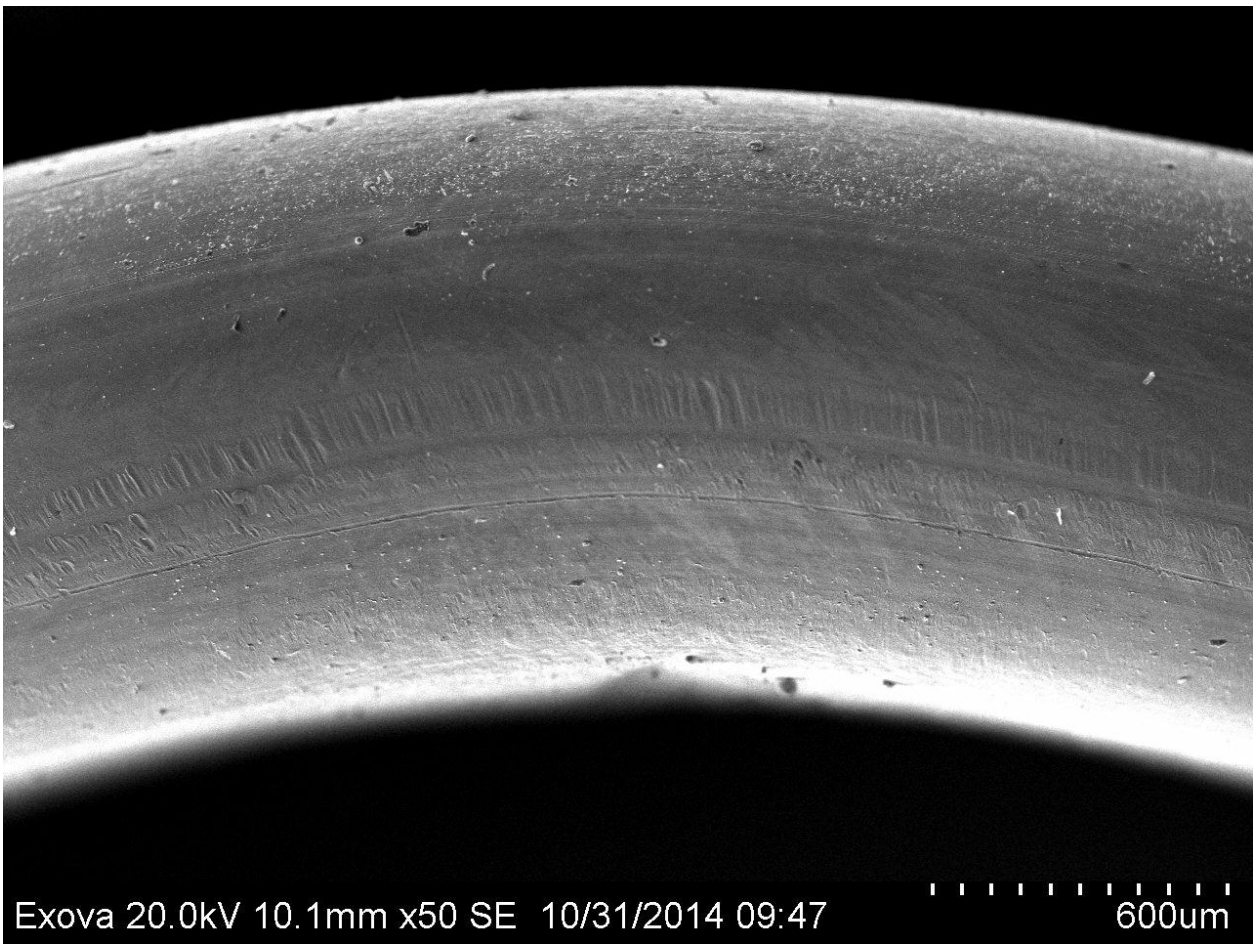


Magnification: 200X
This is an even closer view of the first area that we examined on Side 2 of the left spring. Area 1, which is at the bend made for the inside hook of the left spring, shows a rough steel surface at the inside radius of the bend. No cracks or tears are visible.

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Photograph 15

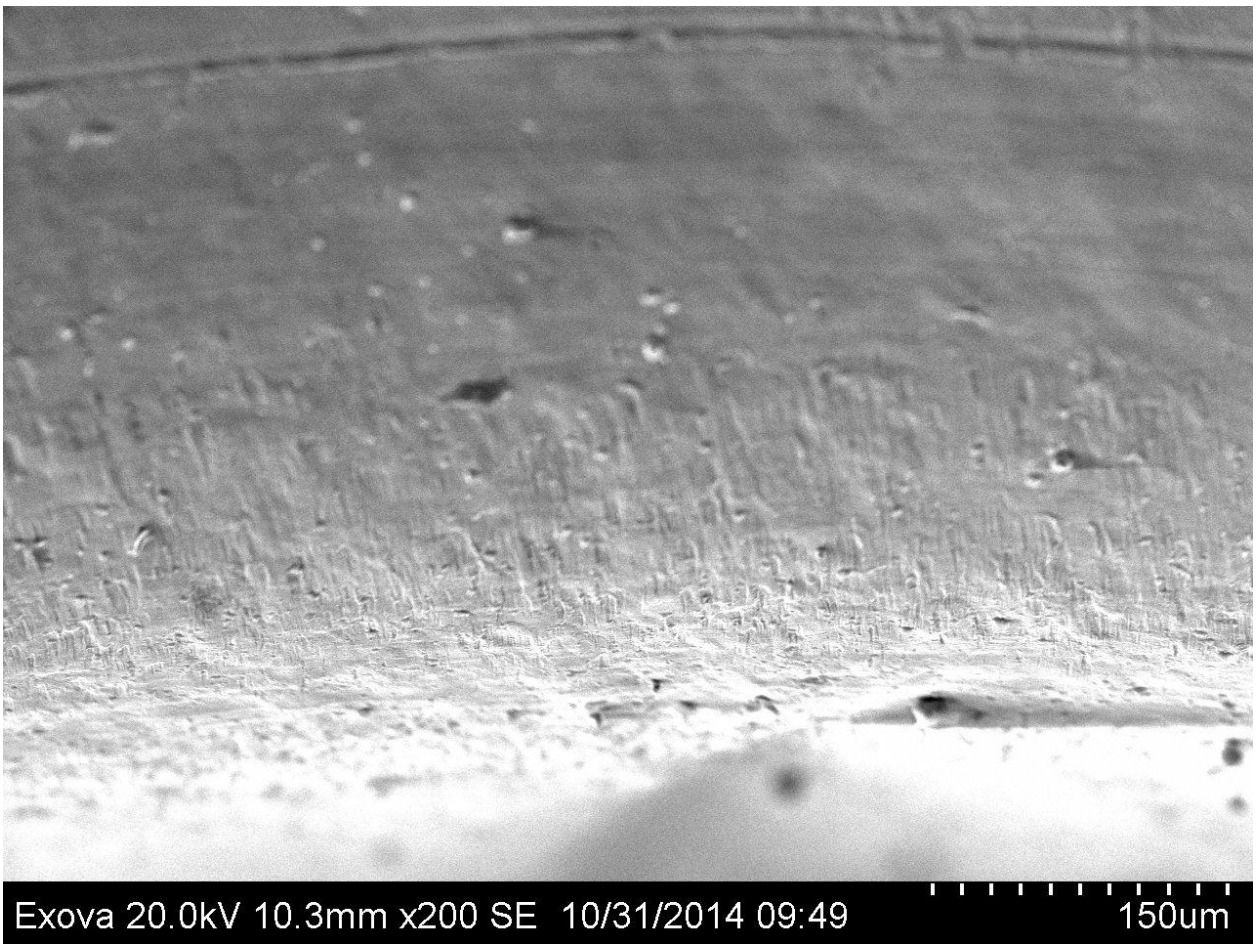


Magnification: 50X
This is a closer view of the second area that we examined on Side 2 of the left spring. Area 2 shows a slight kink in the inside radius surface of the left spring.

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Photograph 16

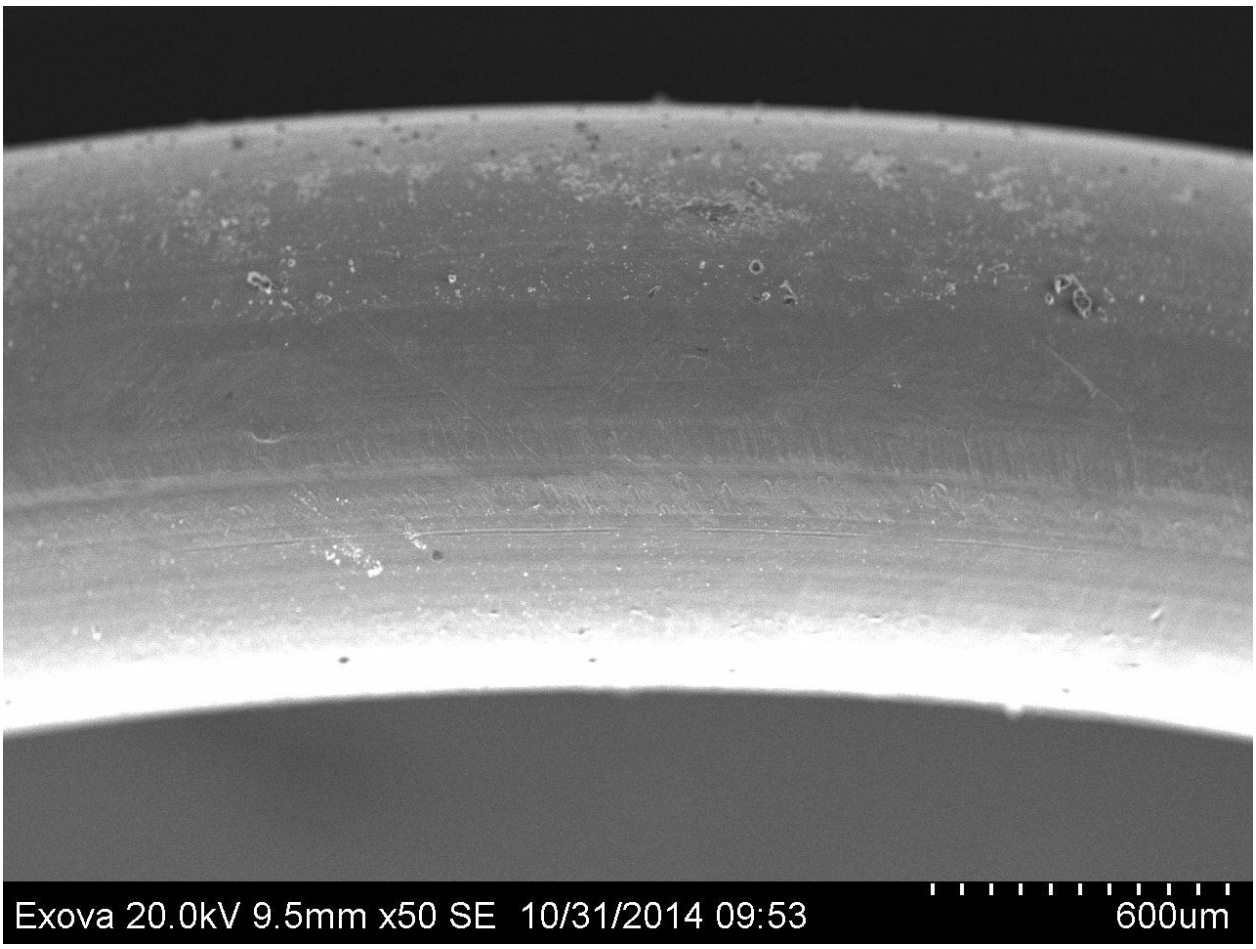


Magnification: 200X
This is an even closer view of the second area that we examined on Side 2 of the left spring. Area 2, which further from the inside hook of the left spring, shows a slight kink in the inside radius surface of the steel. No cracks or tears are visible.

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Photograph 17

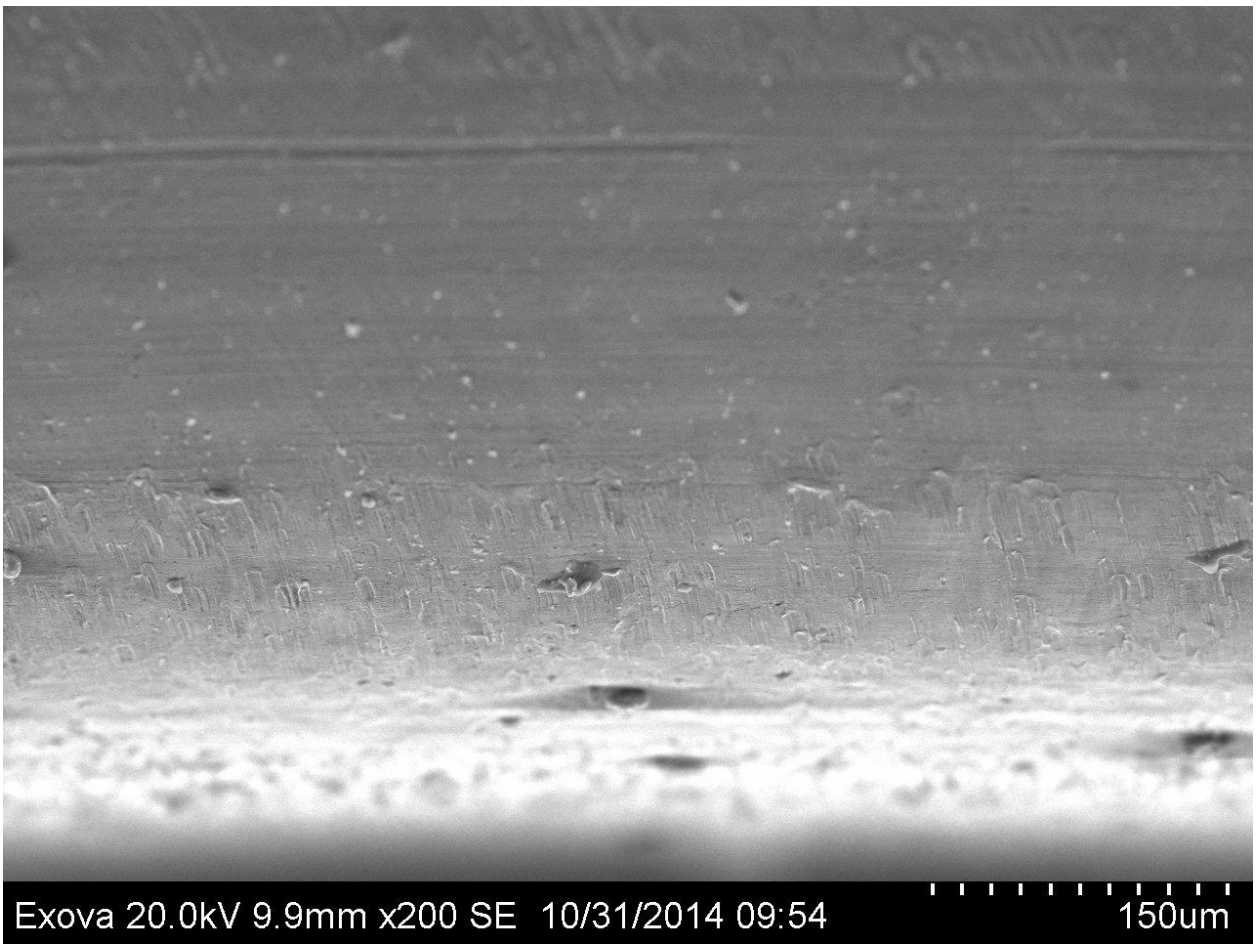


Magnification: 50X
This is a closer view of the third area that we examined on Side 2 of the left spring. Area 3 shows uniform curvature on the inside radius surface of the left spring.

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Photograph 18



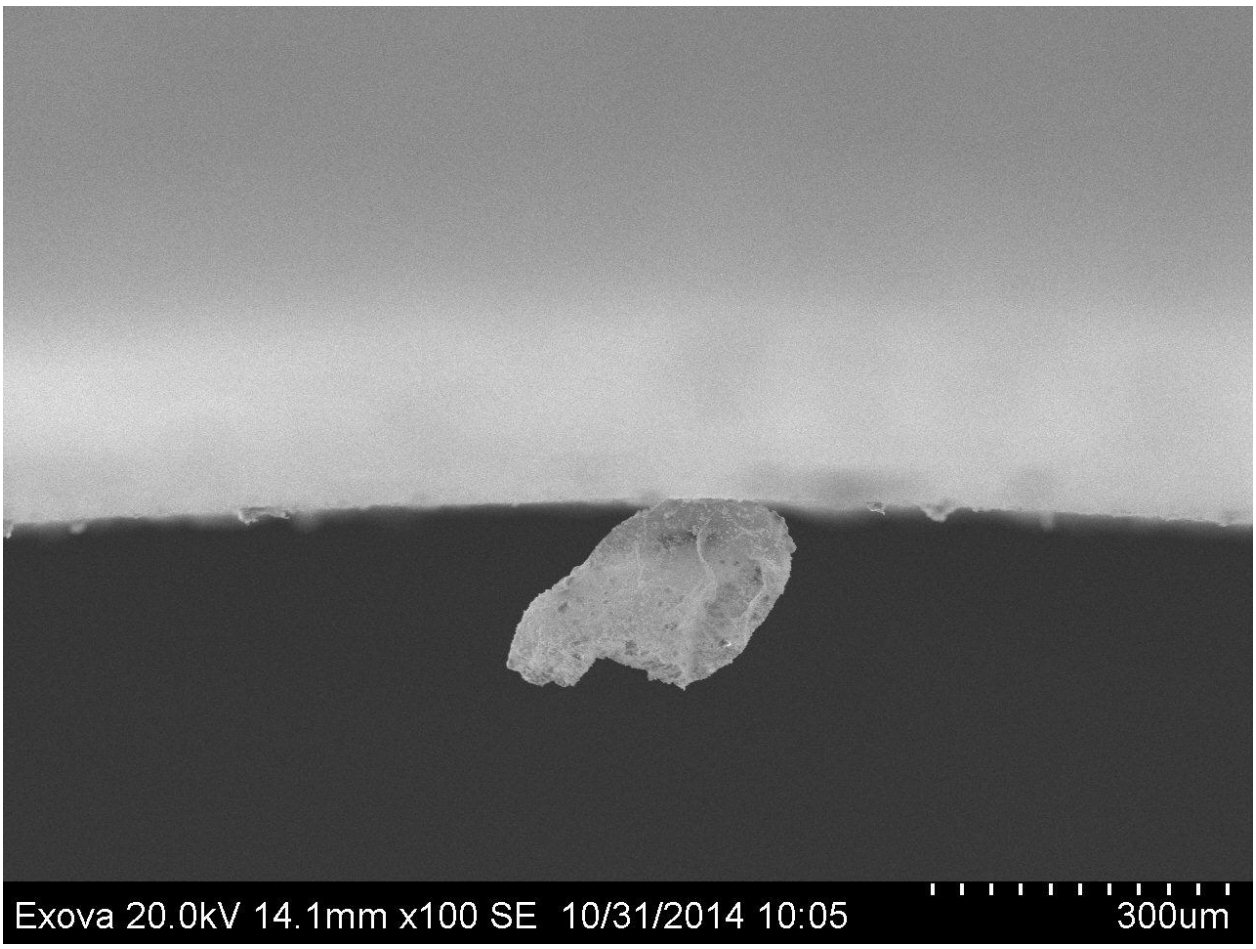
Magnification: 200X

This is an even closer view of the third area that we examined on Side 2 of the left spring. Area 3, which is even further from the inside hook of the left spring, shows uniform curvature. No cracks or tears are visible. We do, however, see fine contamination particles the surface.

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Photograph 19

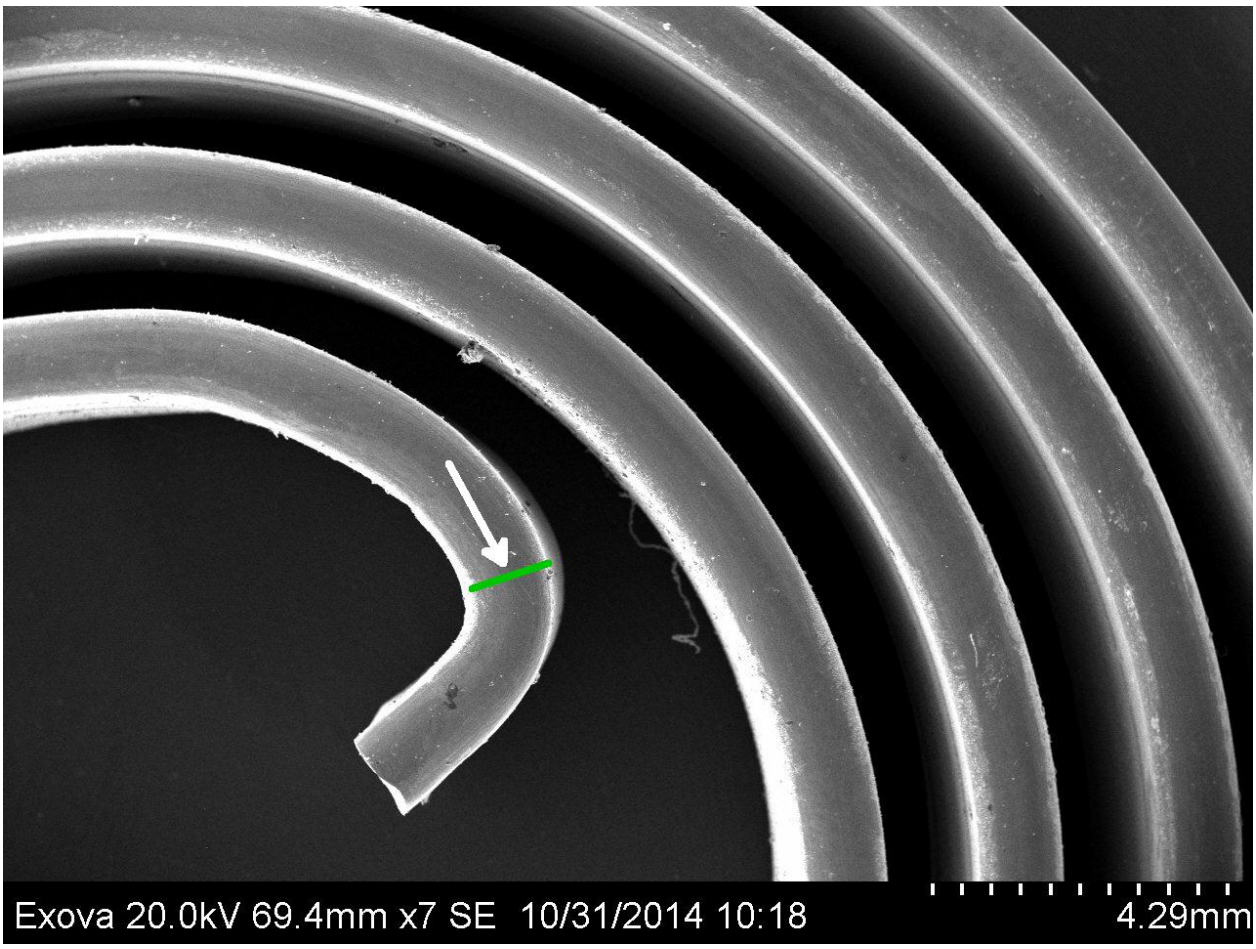


Magnification: 100X
This is a closer view of the fourth area that we examined on Side 2 of the left spring. Area 4 shows uniform curvature on the inside radius surface of the left spring. Some residue is sticking out from the inside surface.

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Photograph 20

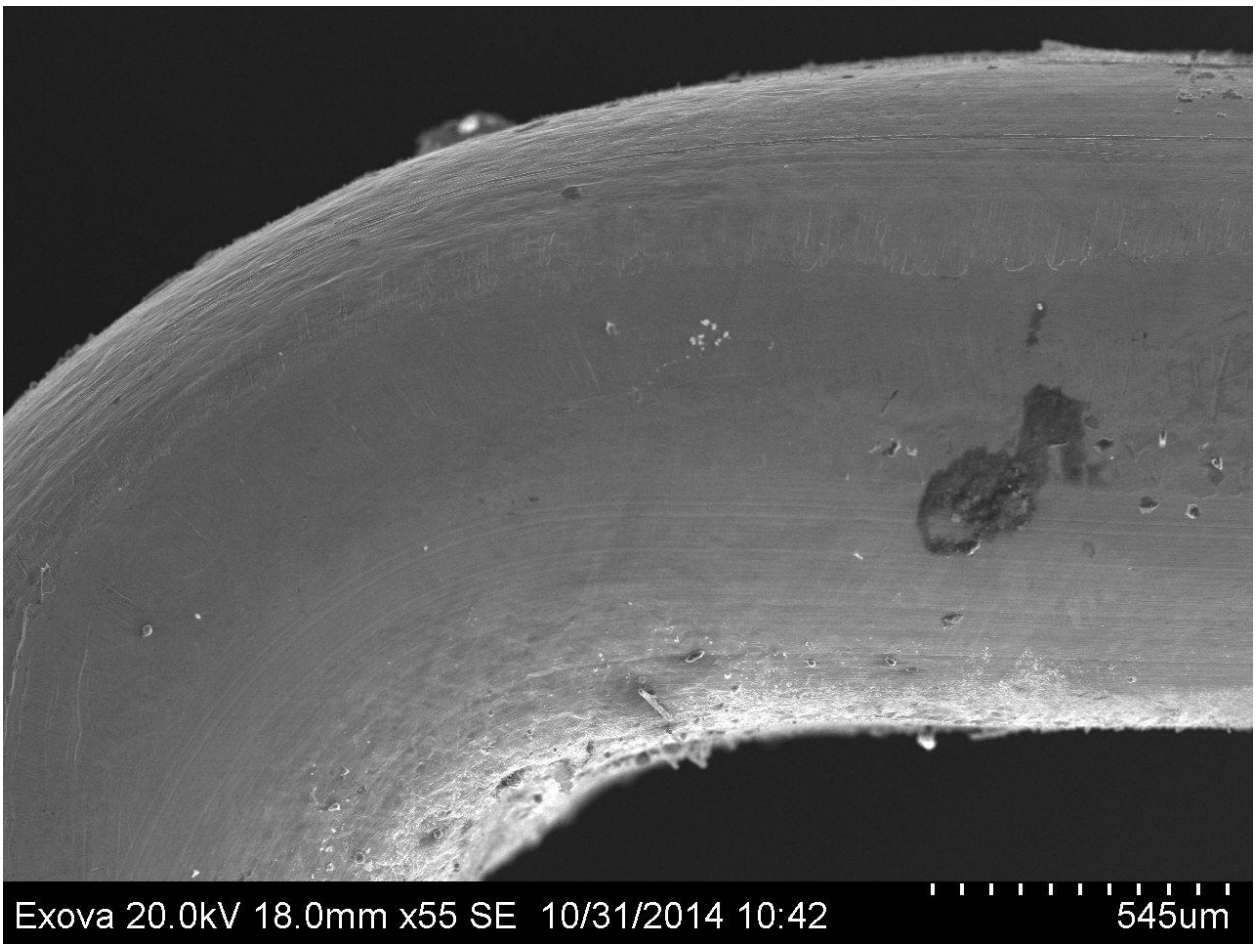


Magnification: 7X
This is a low magnification view that shows the edge surface of several turns for the right spring. We arbitrarily designated the edge shown here as Side 1. The green line indicates our cross-sectioning plane location for the transverse cross-section that we prepared after completing the SEM examination. The white arrow indicates the portion that was mounted.

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Photograph 21

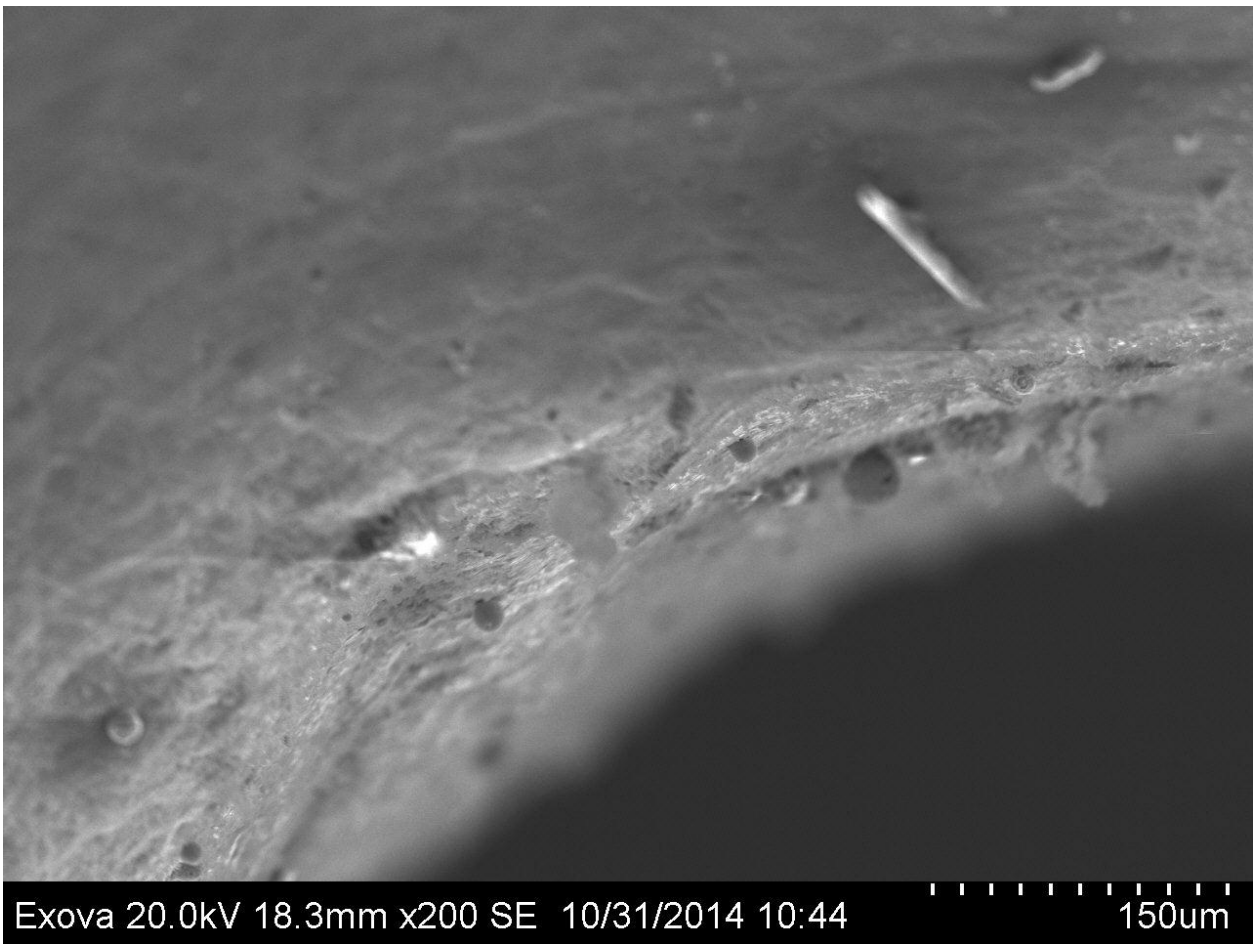


Magnification: 50X
This is a closer view of the first area that we examined on Side 1 of the right spring. Area 1 is at the bend made for the inside hook of the right spring.

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Photograph 22

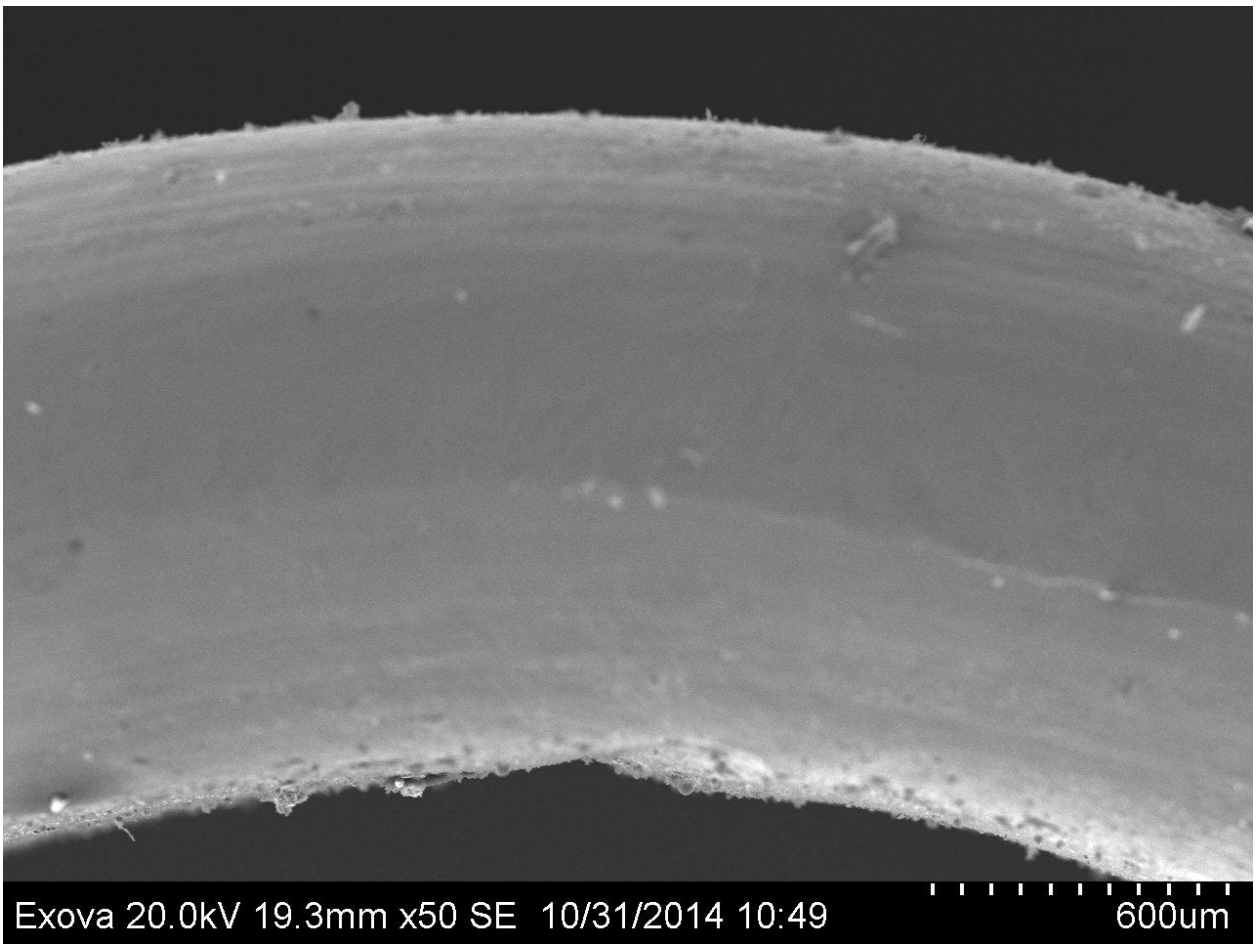


Magnification: 200X
This is an even closer view of the first area that we examined on Side 1 of the right spring. Area 1, which is at the bend made for the inside hook of the right spring, shows a kink in the steel surface at the inside radius of the bend. No cracks or tears are visible.

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Photograph 23

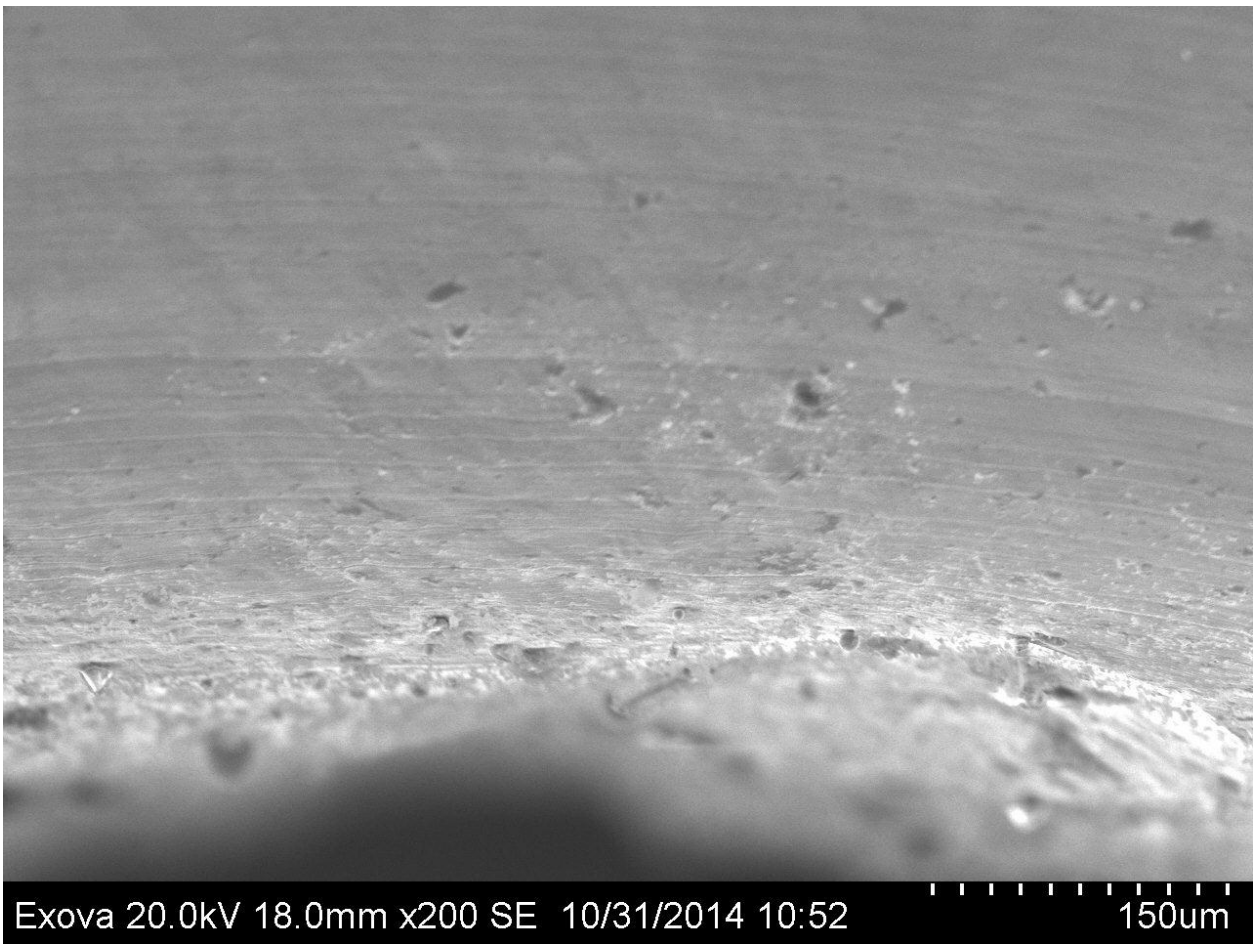


Magnification: 50X
This is a closer view of the second area that we examined on Side 1 of the right spring. Area 2 shows a slight kink in the inside radius surface of the right spring.

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Photograph 24

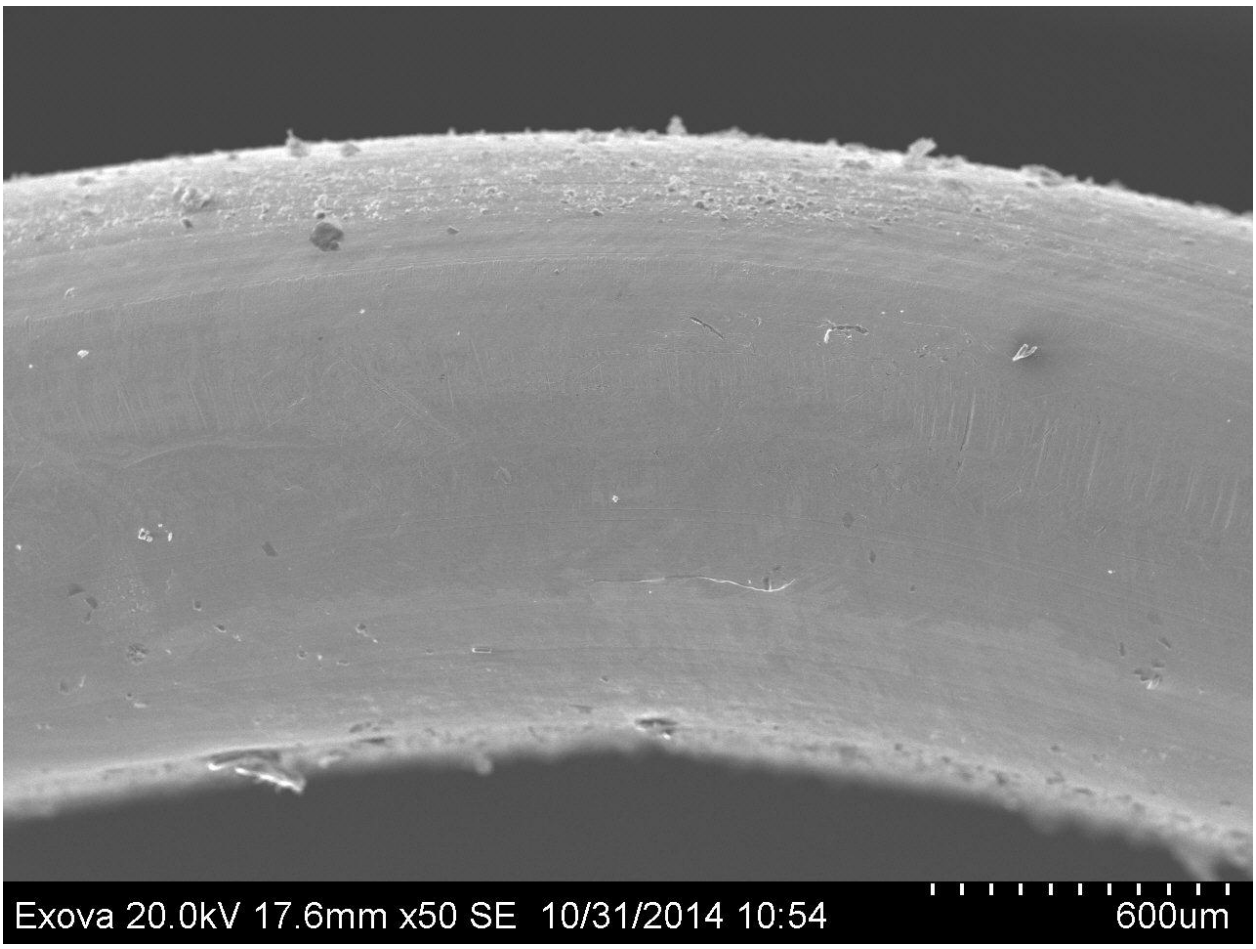


Magnification: 200X
This is an even closer view of the second area that we examined on Side 1 of the right spring. Area 2, which further from the inside hook of the right spring, shows a slight kink in the inside radius surface of the steel. No cracks or tears are visible.

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Photograph 25

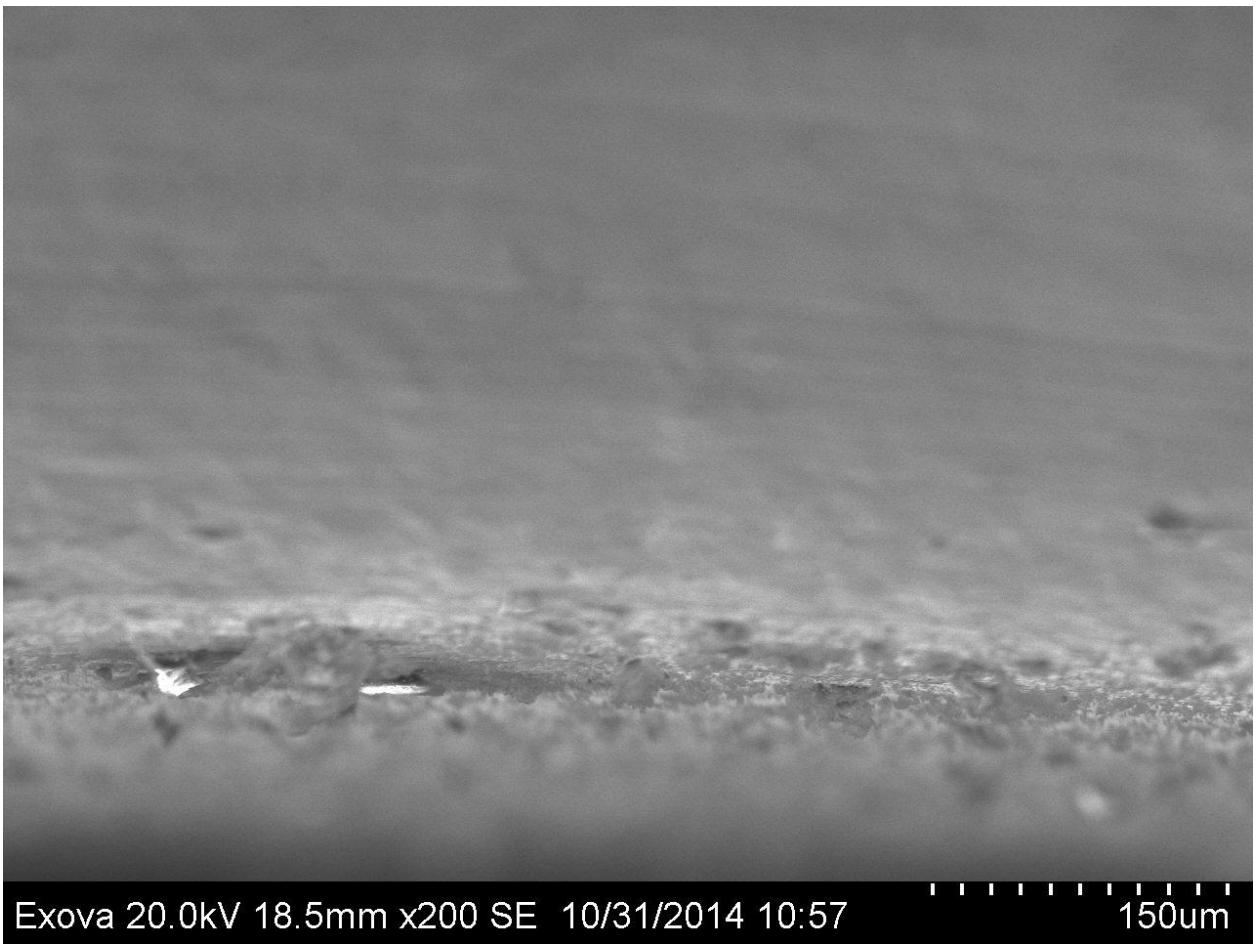


Magnification: 50X
This is a closer view of the third area that we examined on Side 1 of the right spring. Area 3 shows uniform curvature on the inside radius surface of the right spring.

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Photograph 26

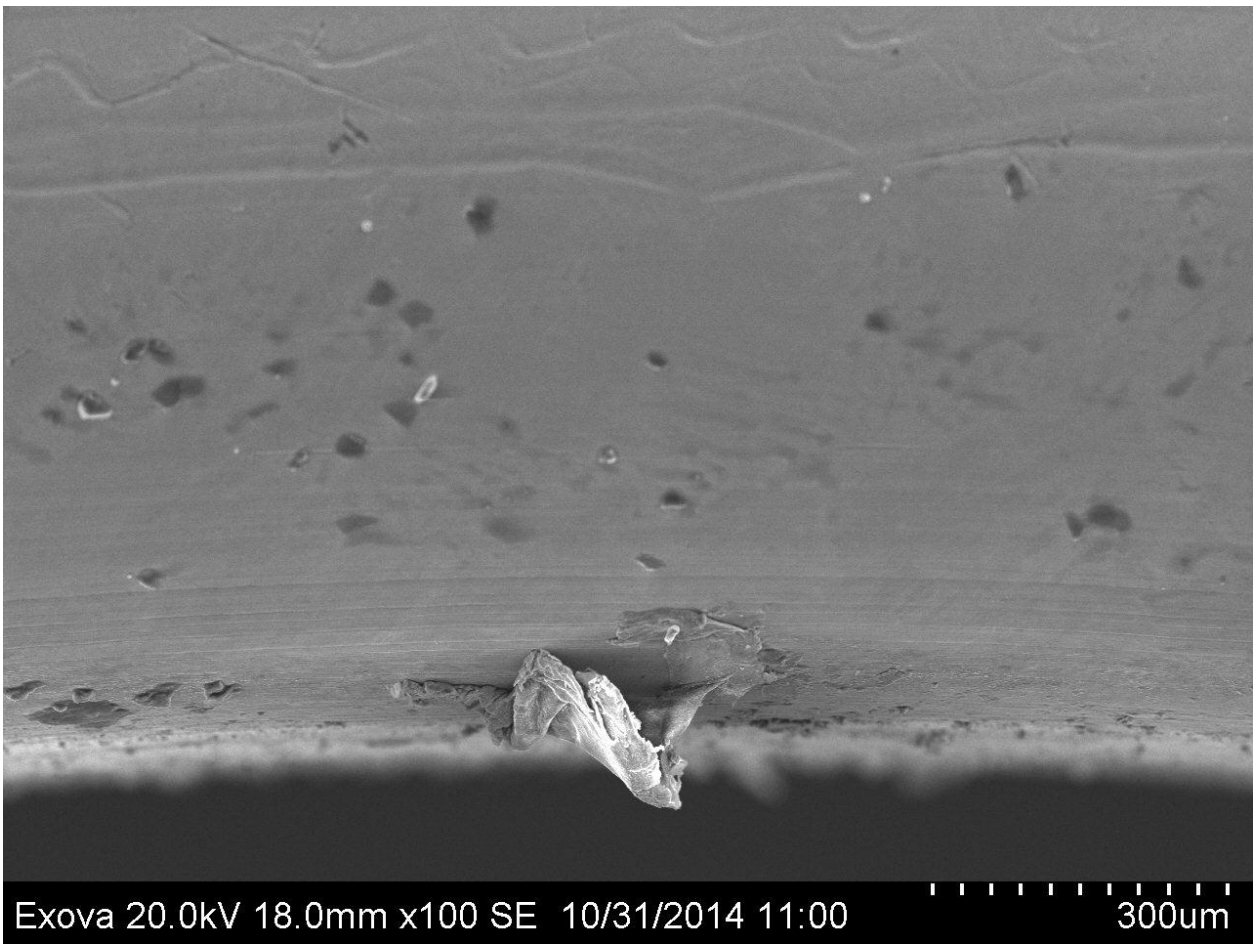


Magnification: 200X
This is an even closer view of the third area that we examined on Side 1 of the right spring. Area 3, which is even further from the inside hook of the right spring, shows uniform curvature. No cracks or tears are visible.

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Photograph 27

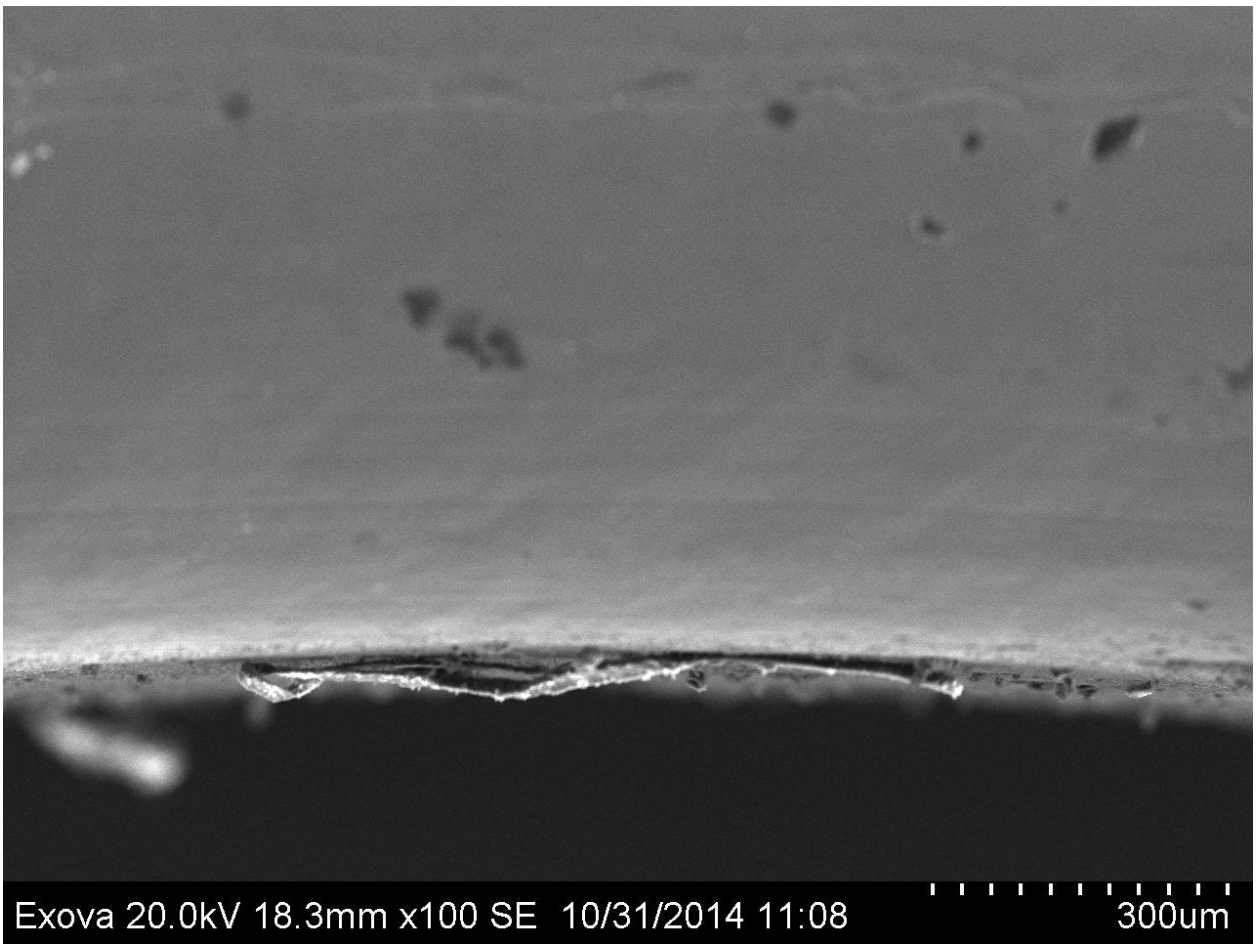


Magnification: 100X
This is a closer view of the fourth area that we examined on Side 1 of the right spring. Area 4 shows uniform curvature on the inside radius surface of the right spring. Some residue is present on the inside surface.

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Photograph 28

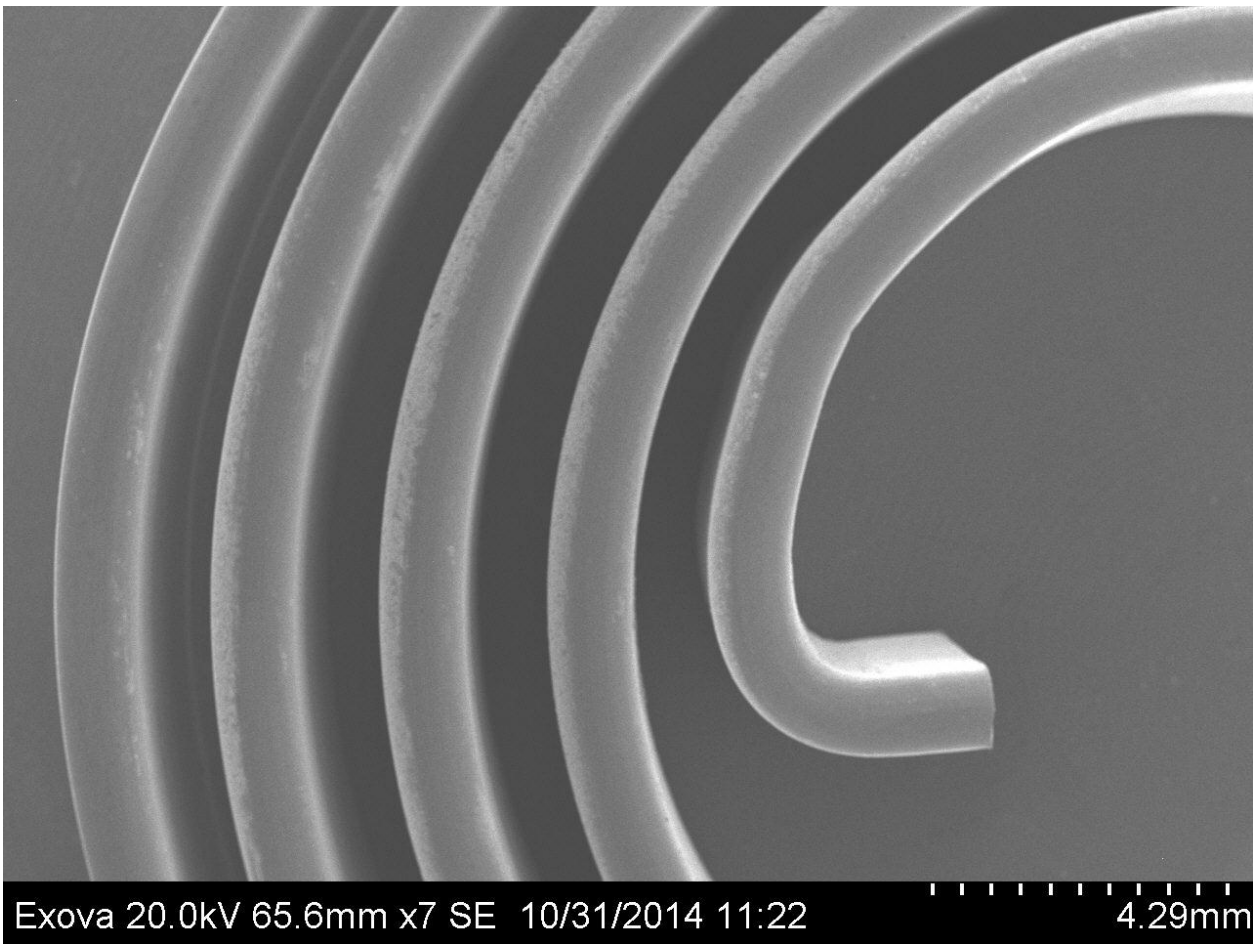


Magnification: 100X
This is a closer view of the fifth area that we examined on Side 1 of the right spring. Area 5 shows uniform curvature on the inside radius surface of the right spring. Some residue is present on the inside surface.

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Photograph 29

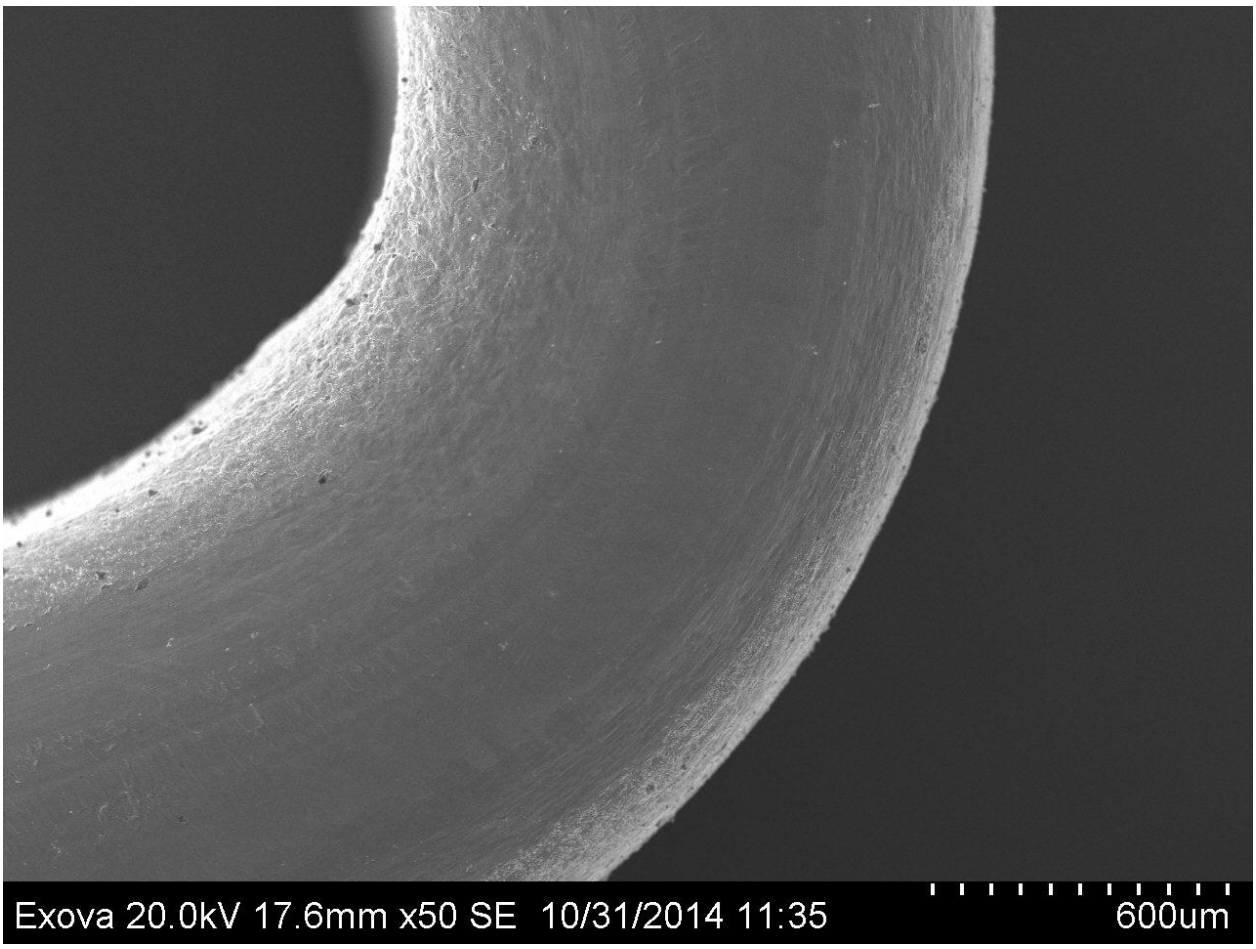


Magnification: 7X
This is a low magnification view that shows the edge surface of several turns for the right spring. We arbitrarily designated the edge shown here as Side 2.

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Photograph 30

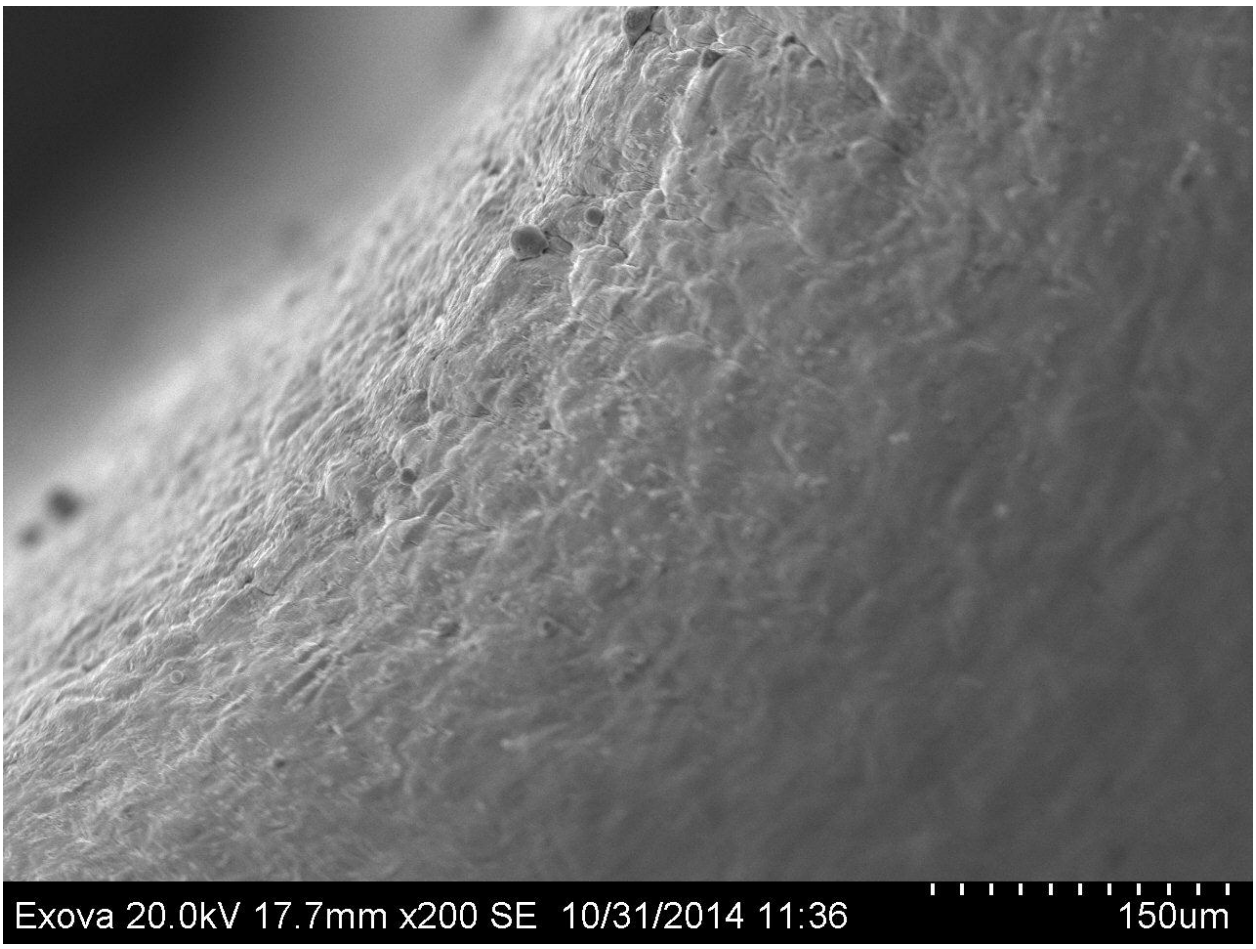


Magnification: 50X
This is a closer view of the first area that we examined on Side 2 of the right spring. Area 1 is at the bend made for the inside hook of the right spring.

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Photograph 31

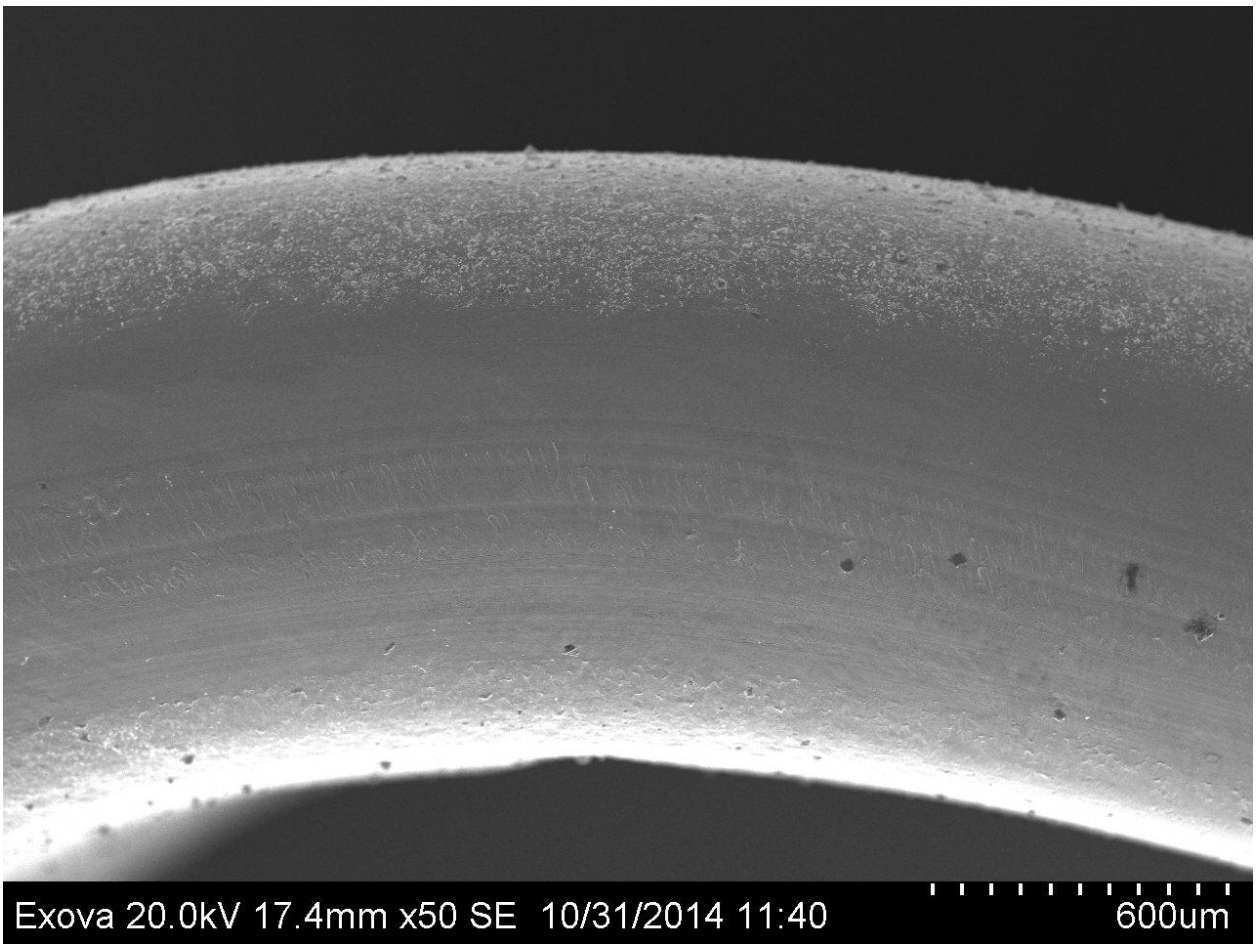


Magnification: 200X
This is an even closer view of the first area that we examined on Side 2 of the right spring. Area 1, which is at the bend made for the inside hook of the right spring, shows a rough steel surface at the inside radius of the bend. No cracks or tears are visible.

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Photograph 32

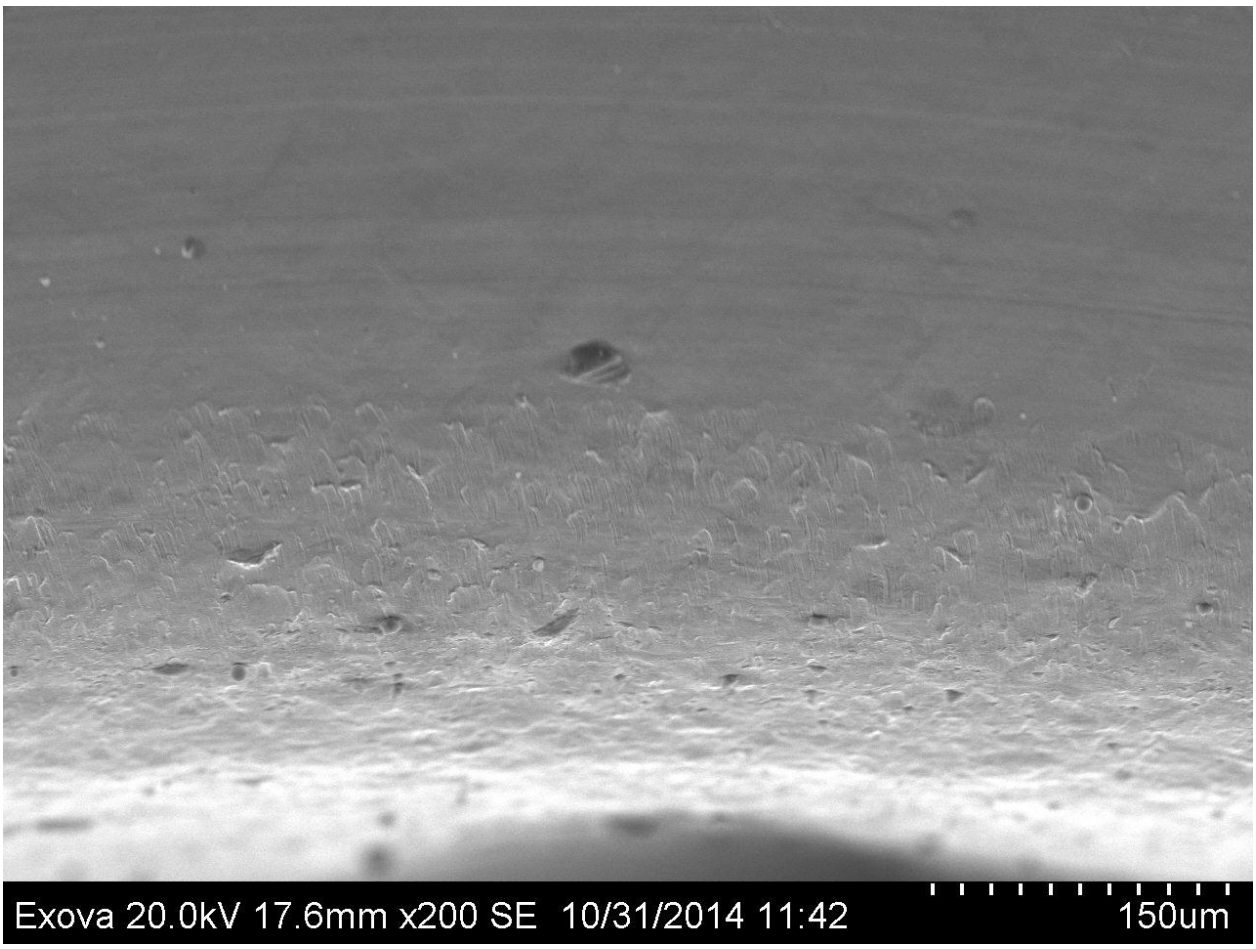


Magnification: 50X
This is a closer view of the second area that we examined on Side 2 of the right spring. Area 2 shows a slight kink in the inside radius surface of the right spring.

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Photograph 33

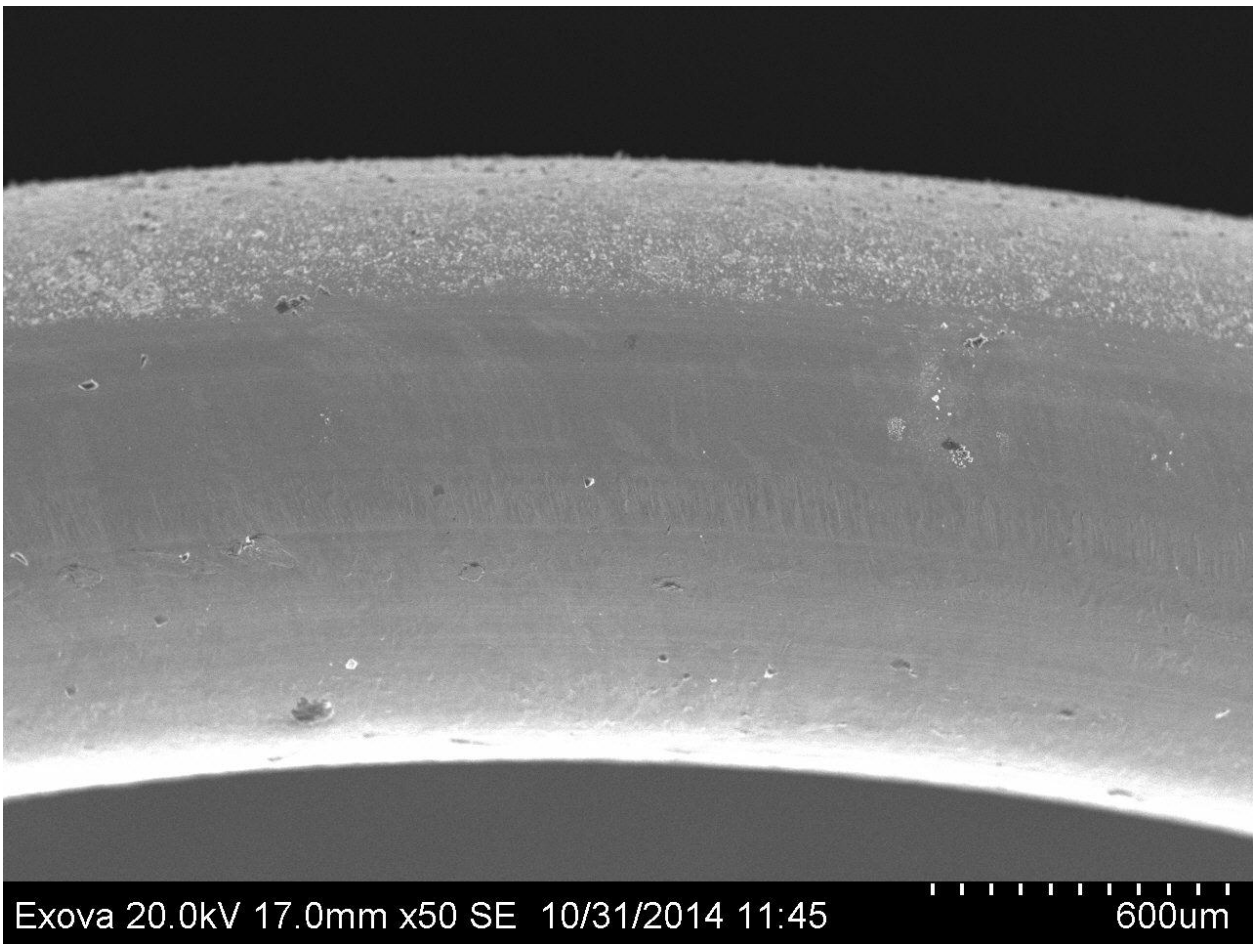


Magnification: 200X
This is an even closer view of the second area that we examined on Side 2 of the right spring. Area 2, which further from the inside hook of the right spring, shows a slight kink in the inside radius surface of the steel. No cracks or tears are visible.

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Photograph 34

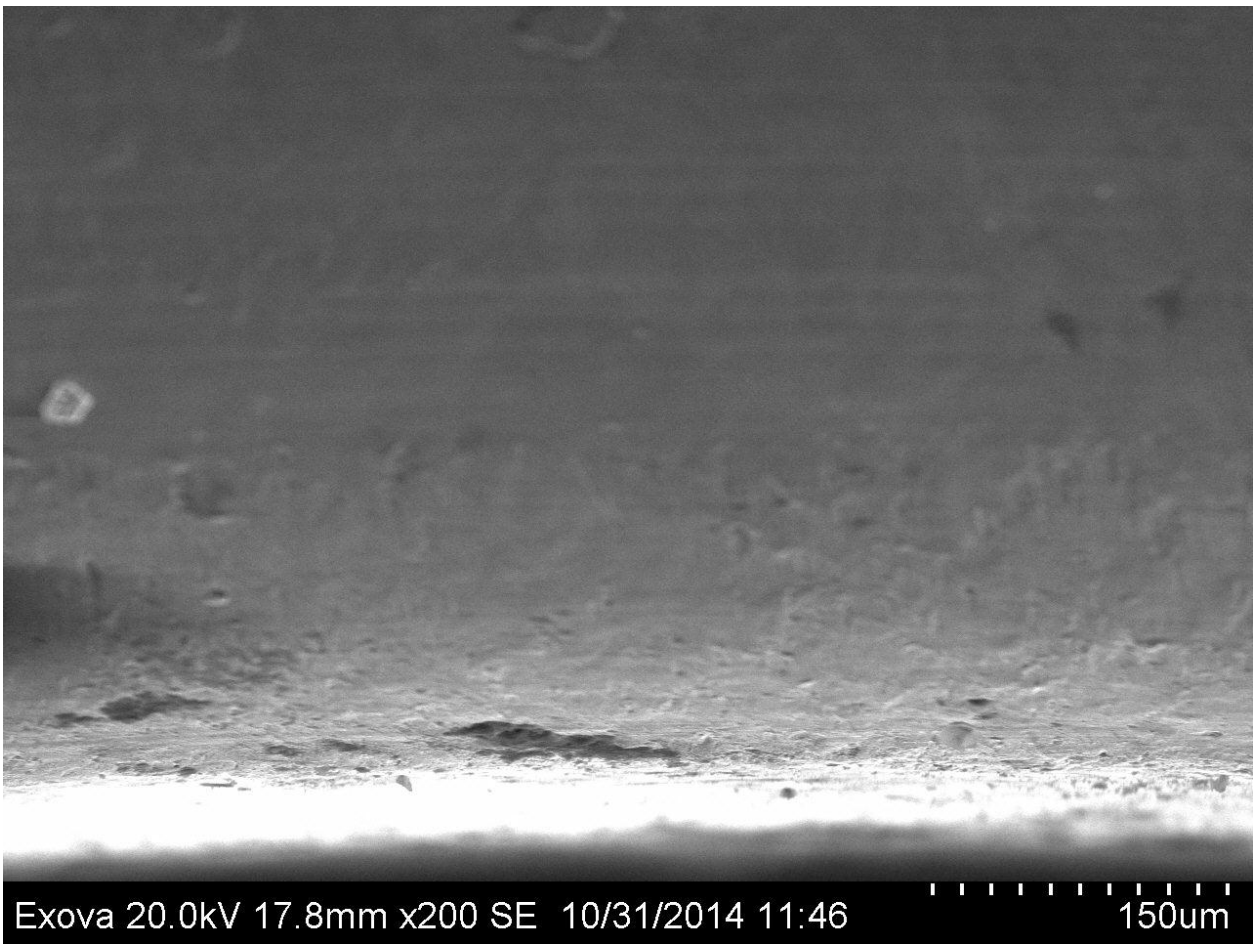


Magnification: 50X
This is a closer view of the third area that we examined on Side 2 of the right spring. Area 3 shows uniform curvature on the inside radius surface of the right spring.

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Photograph 35

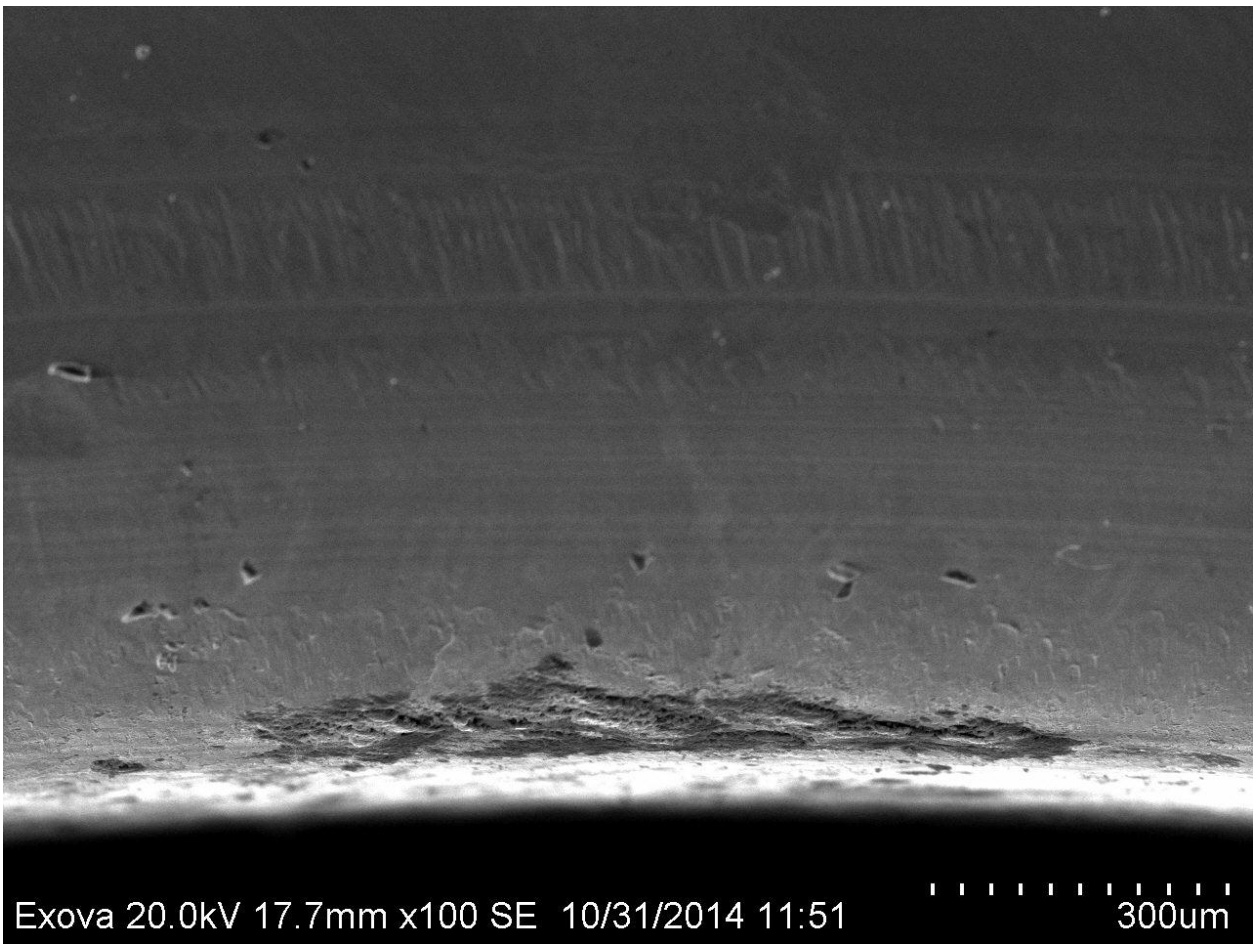


Magnification: 200X
This is an even closer view of the third area that we examined on Side 2 of the right spring. Area 3, which is even further from the inside hook of the right spring, shows uniform curvature. No cracks or tears are visible. We do, however, see contamination on the surface.

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Photograph 36

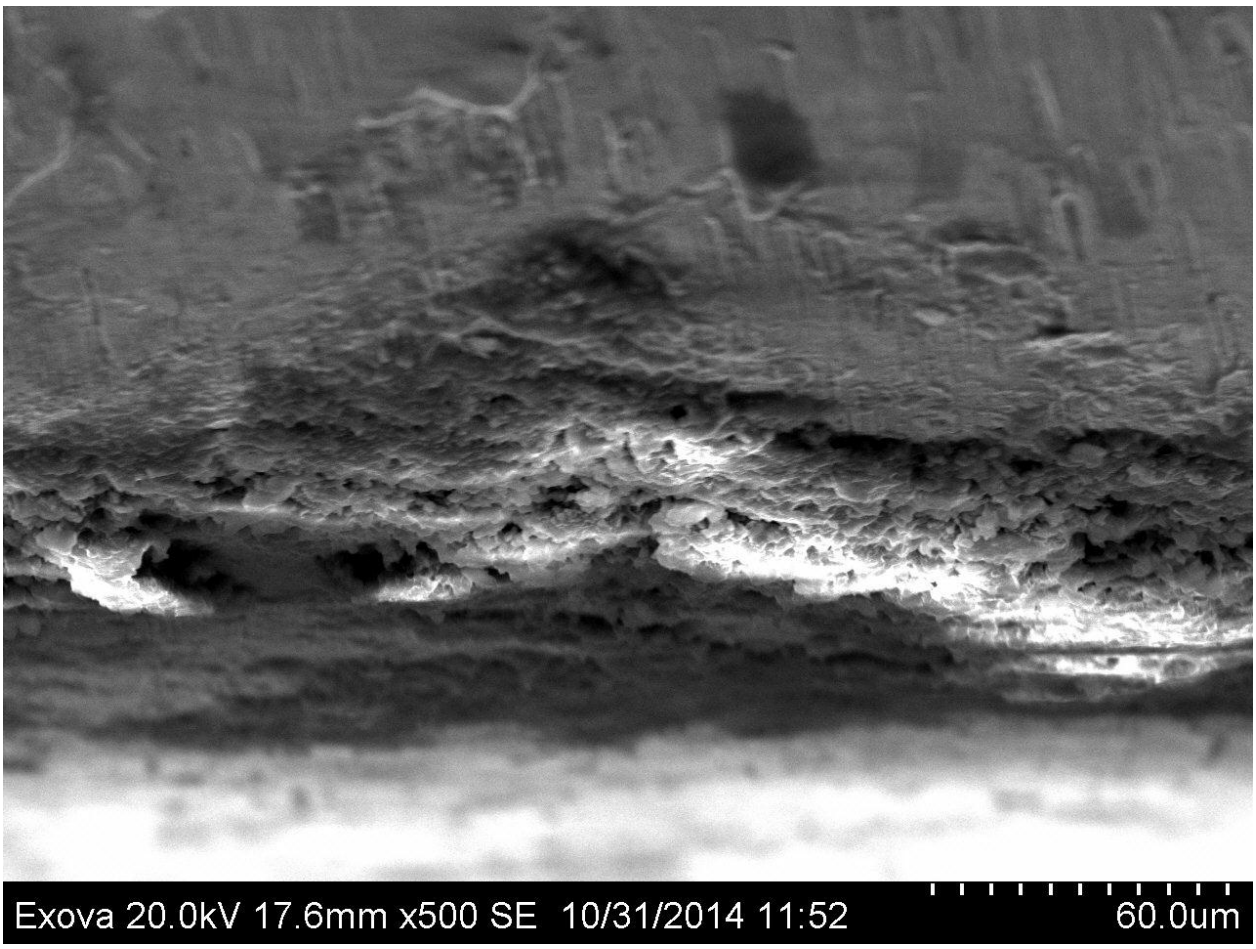


Magnification: 100X
This is a closer view of the fourth area that we examined on Side 2 of the right spring. Area 4 shows uniform curvature on the inside radius surface of the right spring. Some residue is present on the inside surface.

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Photograph 37

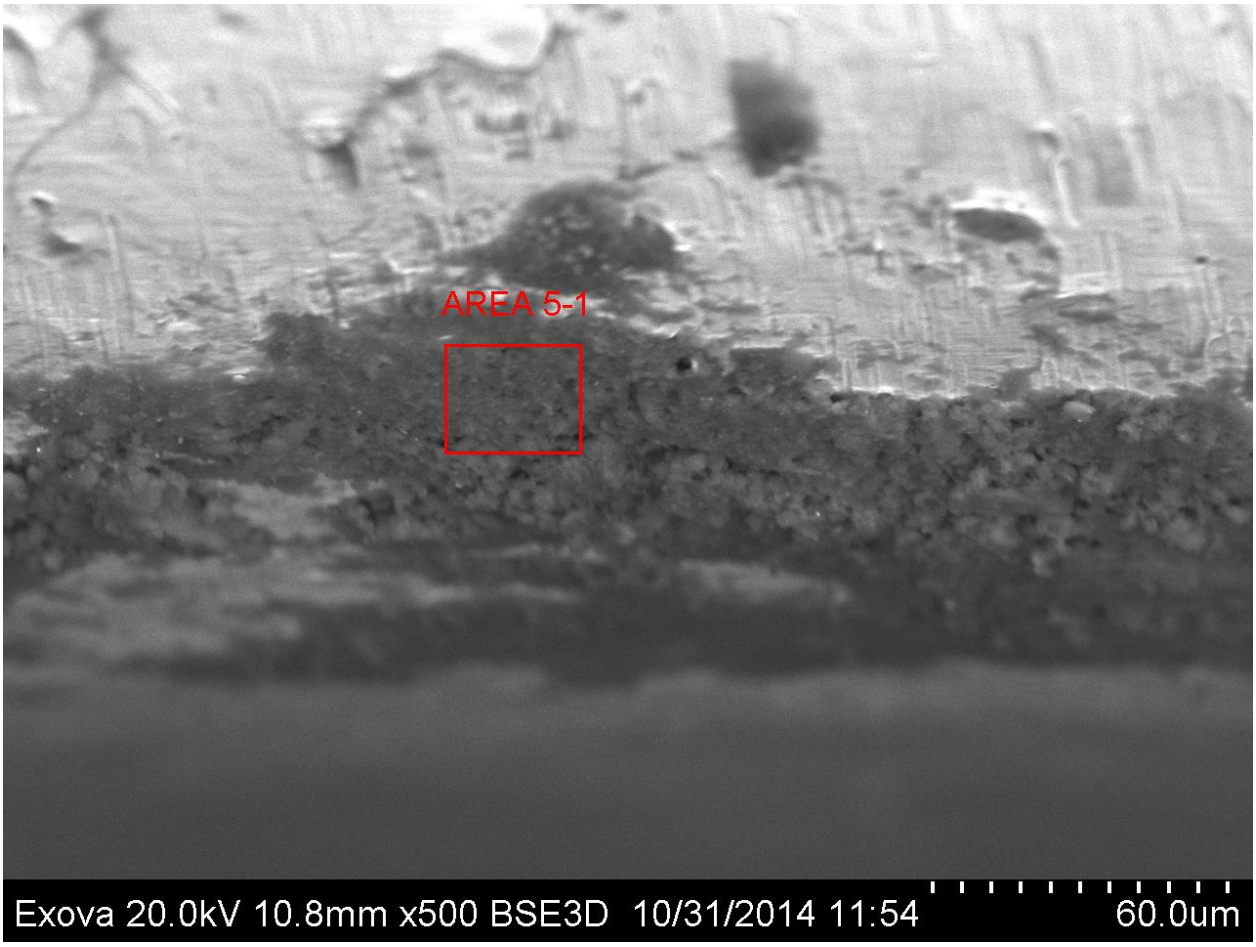


Magnification: 500X
This is an even closer view of the fourth area that we examined on Side 2 of the right spring. Area 4, which is even further from the inside hook of the right spring, shows uniform curvature. No cracks or tears are visible. We do, however, see contamination on the surface.

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Photograph 38



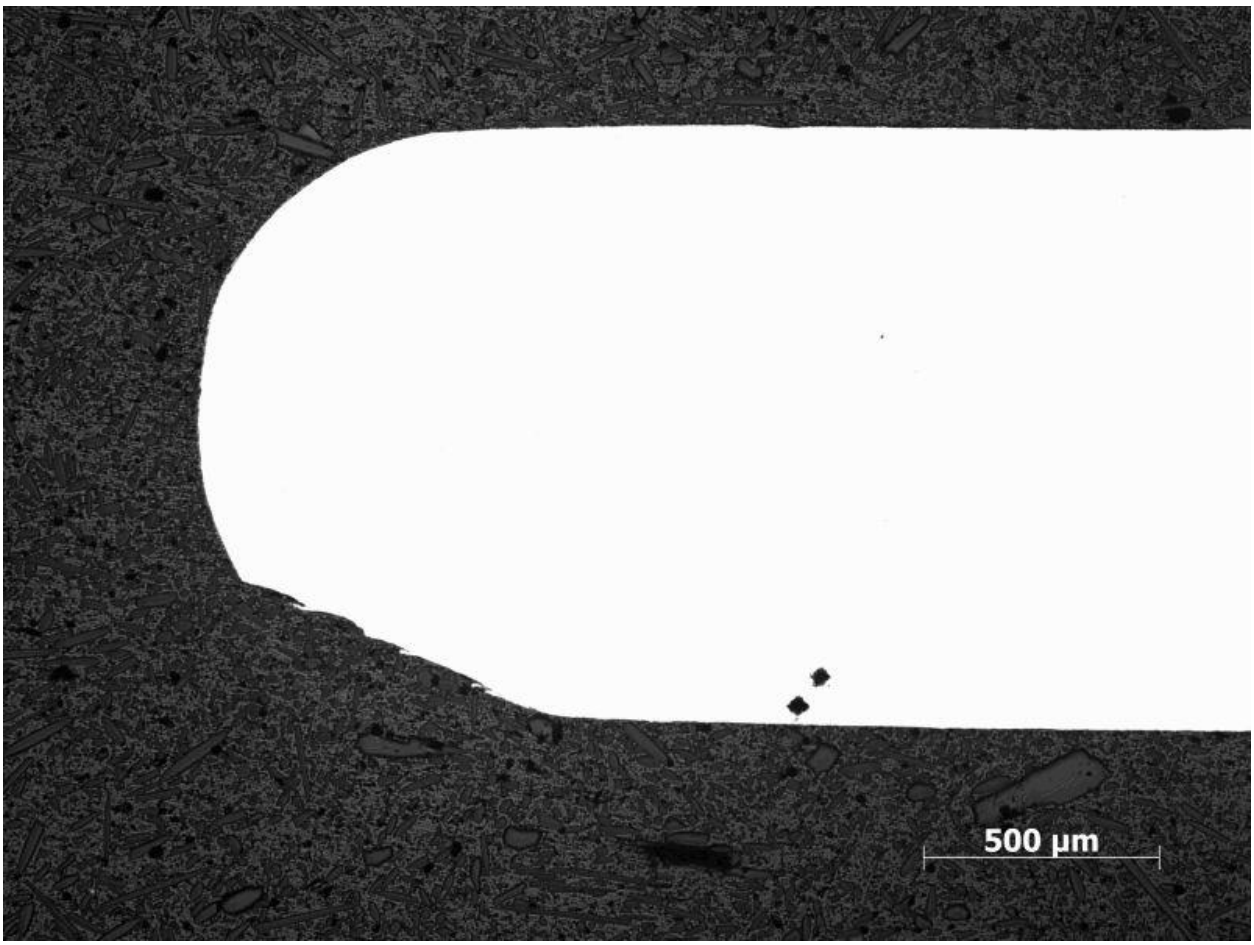
Magnification: 500X

This is an even closer view of the fifth area that we examined on Side 2 of the right spring. Area 5, which is even further from the inside hook of the right spring, shows uniform curvature. No cracks or tears are visible. We do, however, see contamination on the surface. We used the EDS system to identify the elements present in area surrounded by the red box.

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Photograph 39

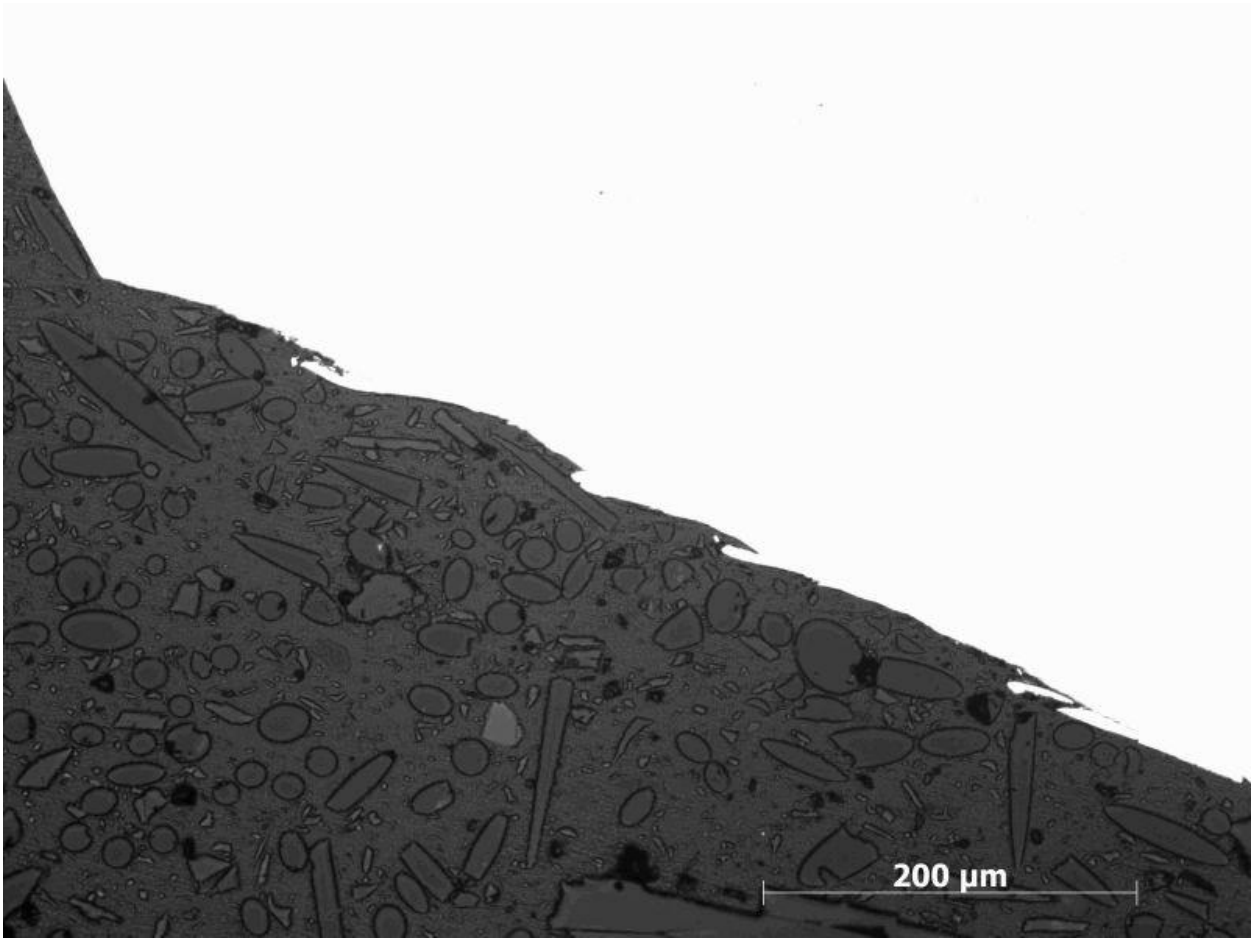


Magnification: 50X As-Polished
This is a low magnification view of the cross-section of the edge on one side of the strip used to make the left spring. We arbitrarily designated this edge as corner A. The lower portion of corner A does not have a fully radiused profile.

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Photograph 40



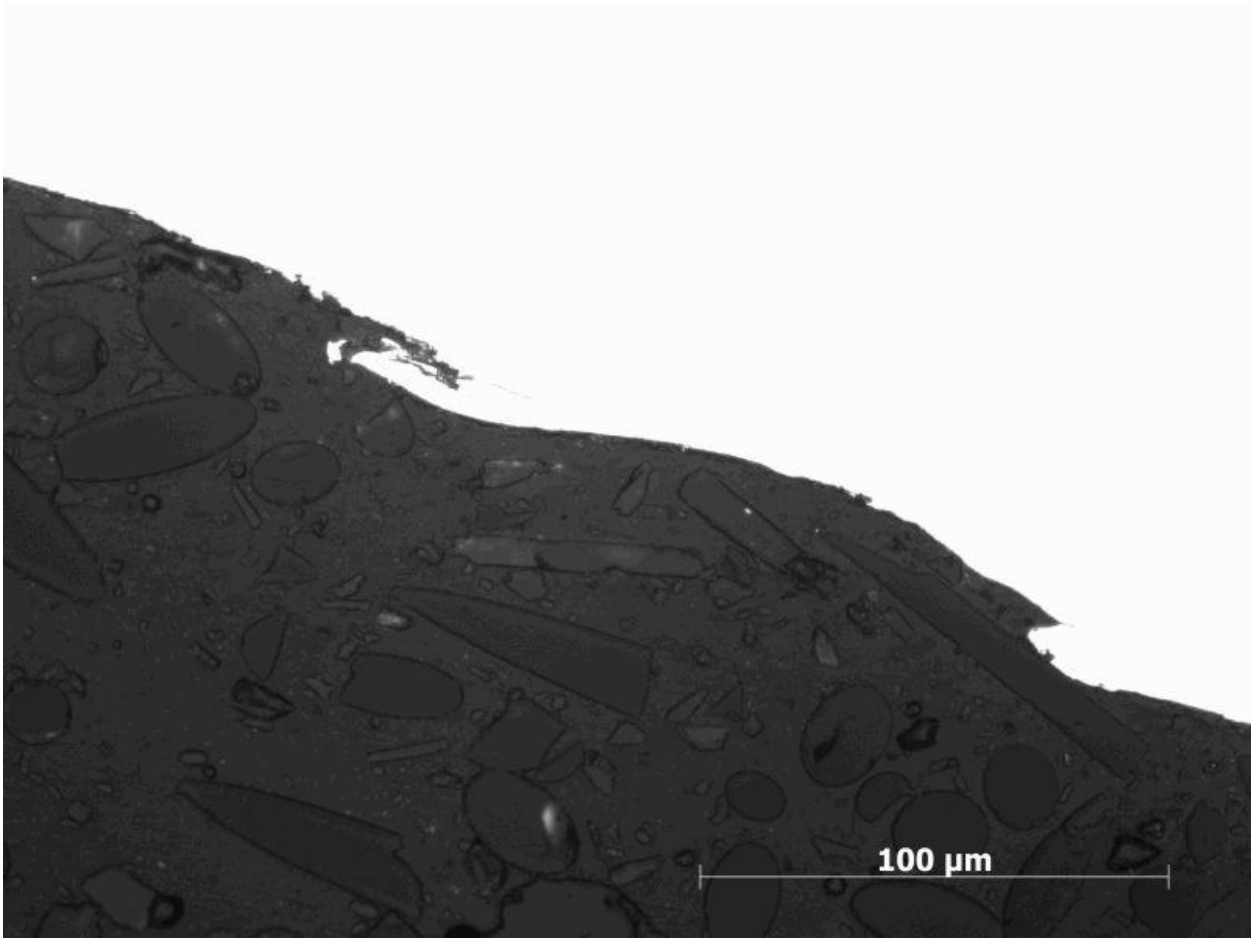
Magnification: 200X As-Polished

This is a closer view of the lower portion of corner A of the cross-section for the strip used to make the left spring. This area does not show a full radius profile as expected for a fully polished strip edge. Material appears to have chipped out.

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Photograph 41



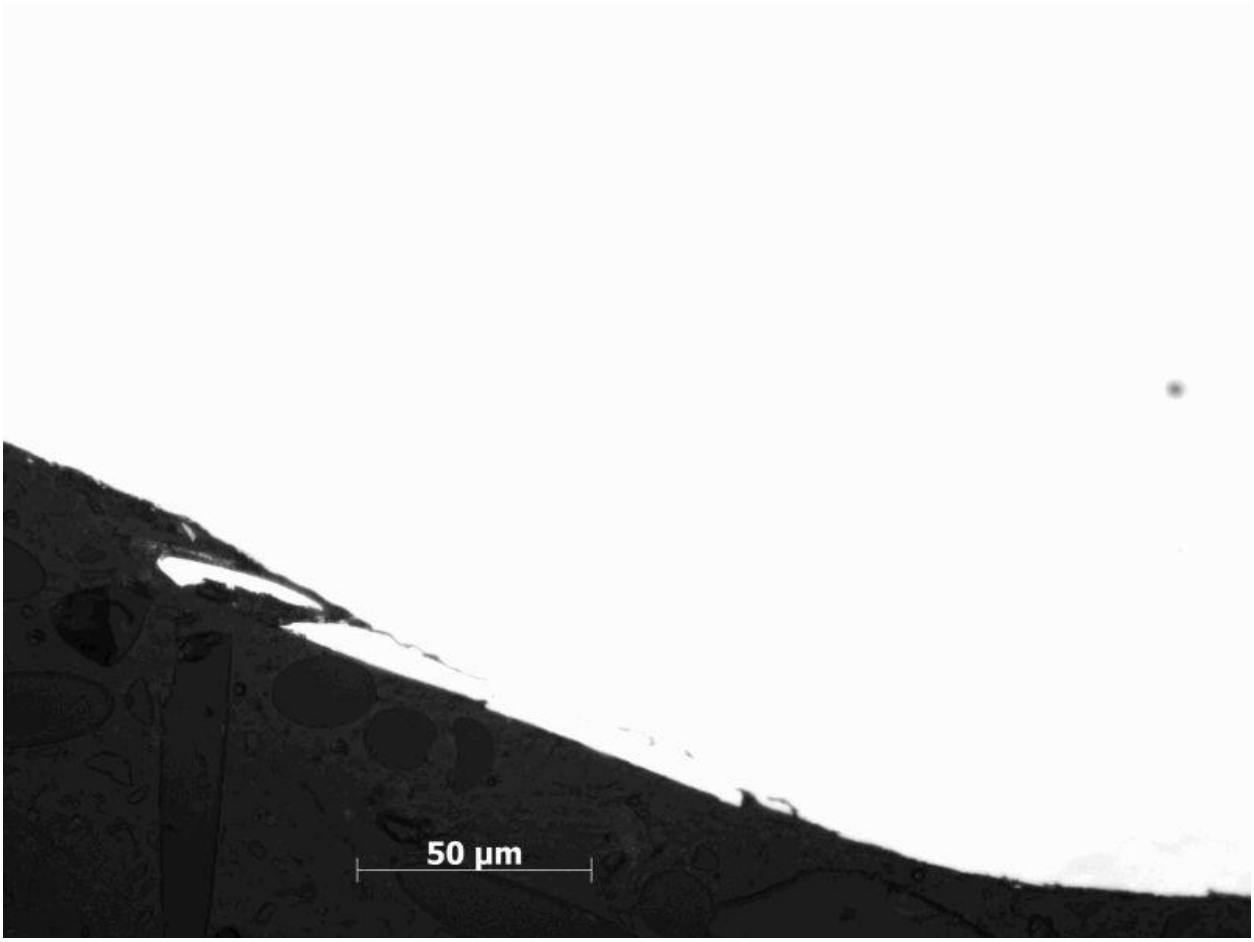
Magnification: 500X As-Polished

This is a high magnification view of a part of the lower portion of corner A of the cross-section for the strip used to make the left spring. This area does not show a full radius profile as expected for a fully polished strip edge. Material appears to have chipped out.

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Photograph 42



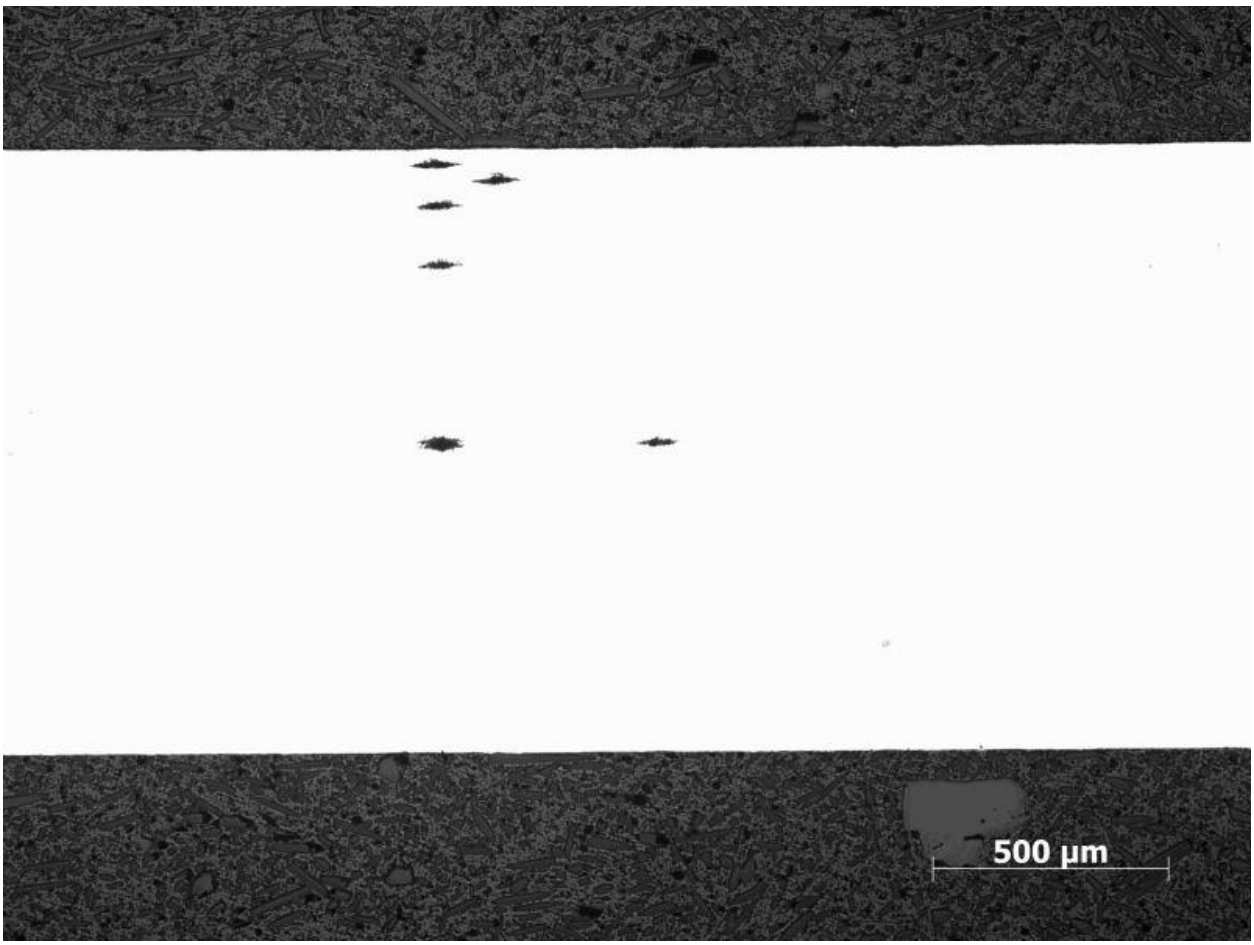
Magnification: 500X As-Polished

This is a high magnification view of another part of the lower portion of corner A of the cross-section for the strip used to make the left spring. This area does not show a full radius profile as expected for a fully polished strip edge. Material appears to have chipped out.

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Photograph 43

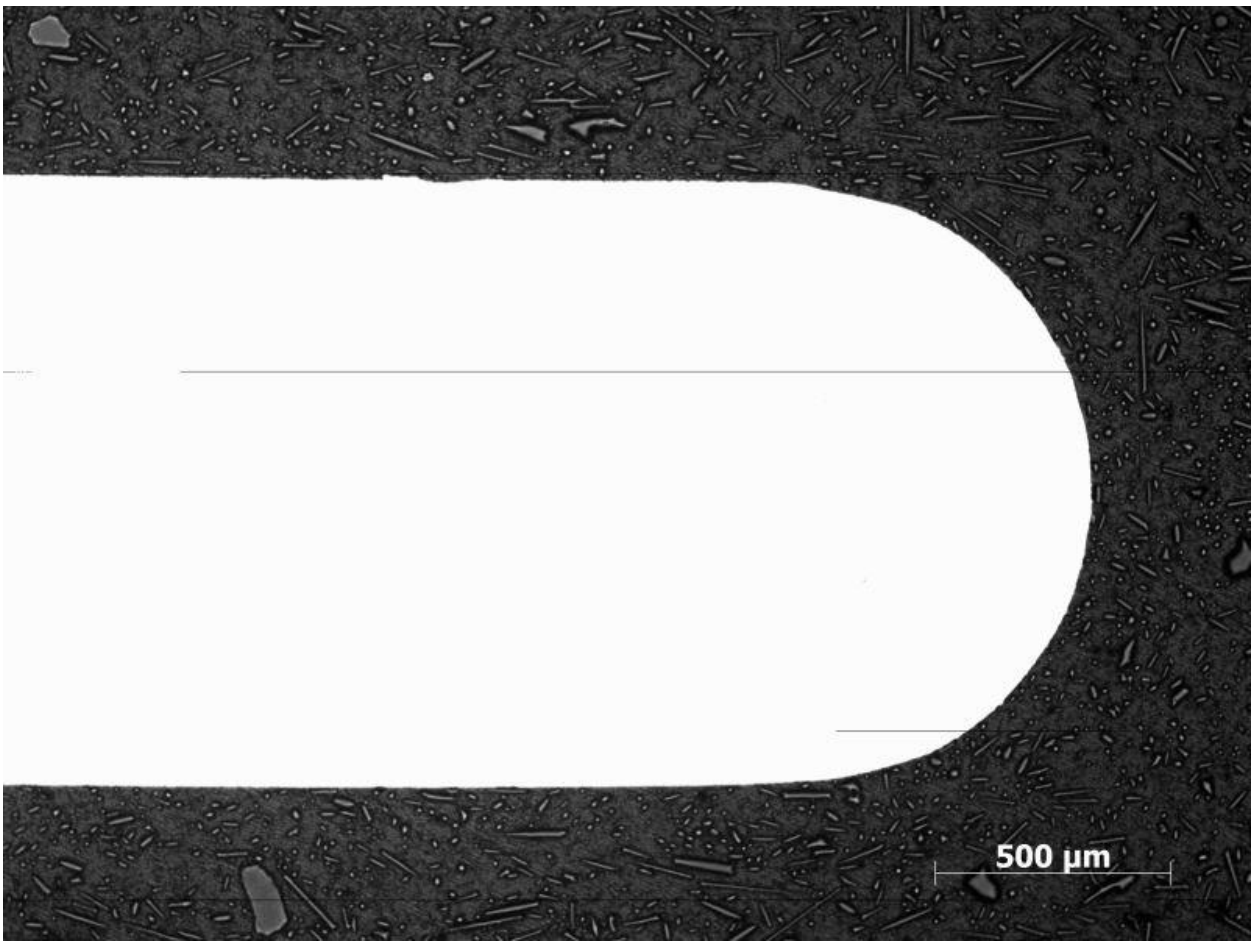


Magnification: 50X As-Polished
This is a low magnification view of the cross-section of the center of the strip used to make the left spring. One can se the elongated indentations produced during subsequent Knoop micro-indentation hardness testing.

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These results pertain only to the item(s) tested as sampled by the client otherwise indicated.
Testing has been conducted to specification revision levels as described in the laboratory's document control procedure.
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Photograph 44

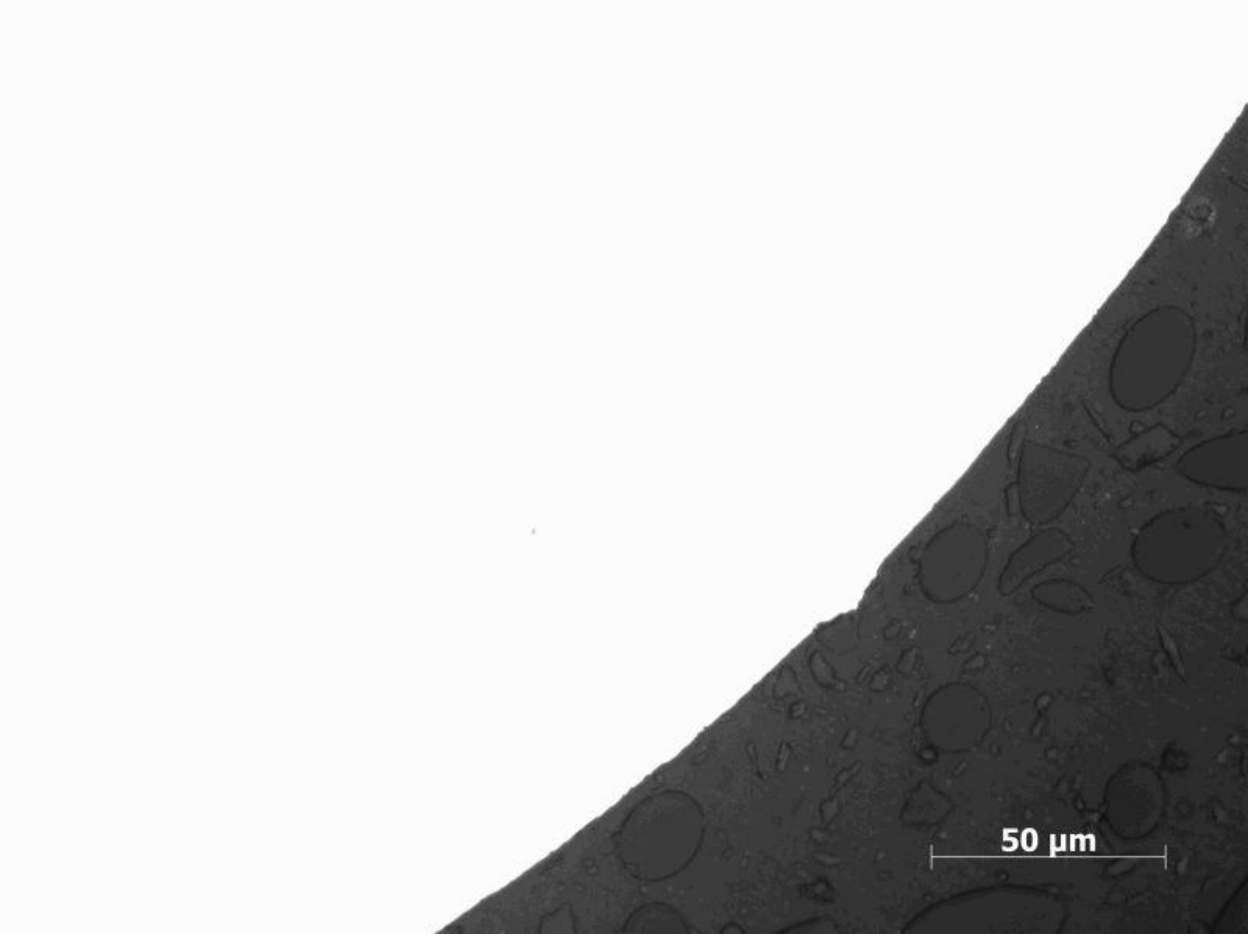


Magnification: 50X As-Polished
This is a low magnification view of the cross-section of the edge on the other side of the strip used to make the left spring. We arbitrarily designated this edge as corner B. Corner B essentially shows a fully radiused profile.

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Photograph 45



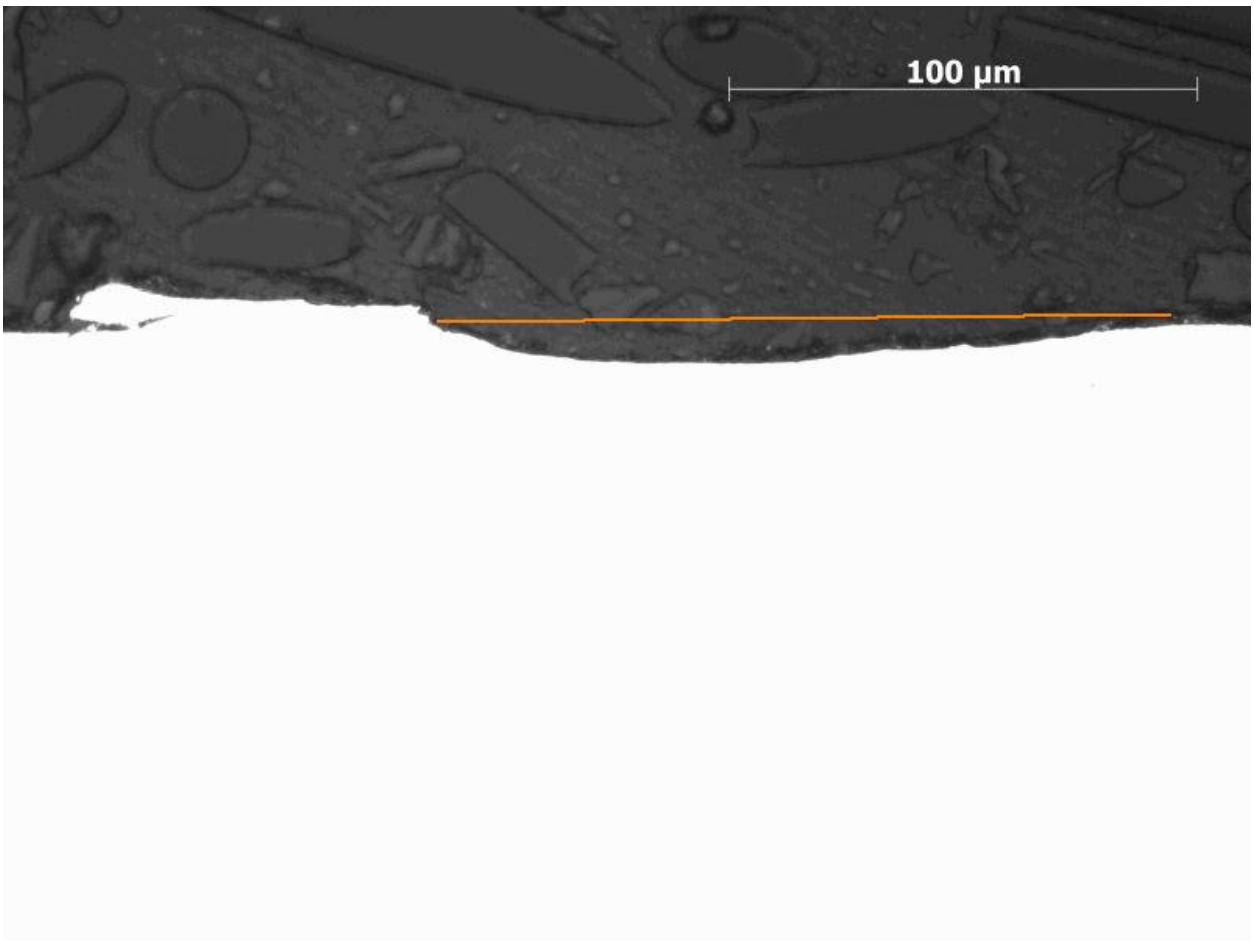
Magnification: 500X As-Polished

This is a high magnification view of a part of the lower portion of corner B of the cross-section for the strip used to make the left spring. This area does show a full radius profile as expected for a fully polished strip edge, with a slight bump in the surface.

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Photograph 46



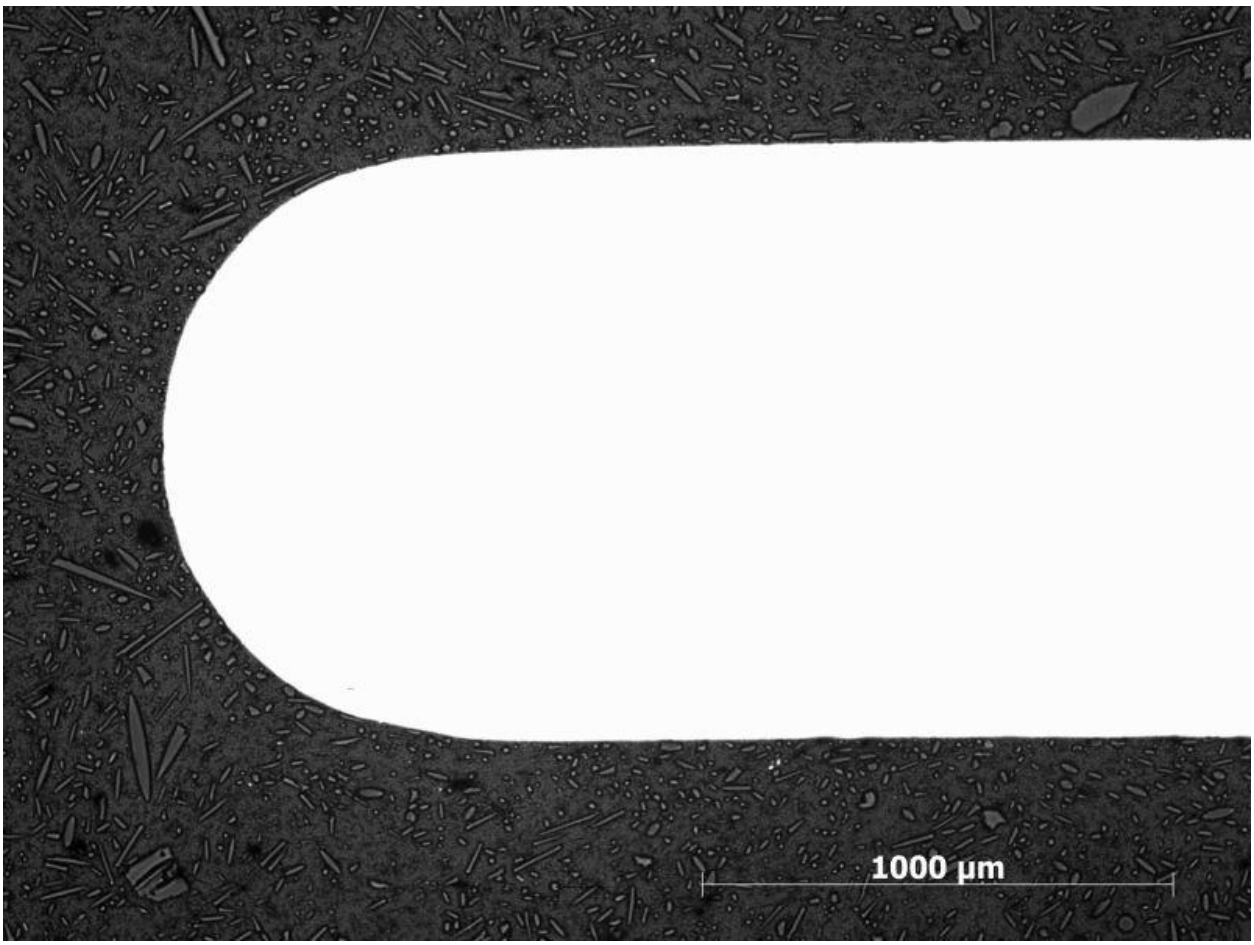
Magnification: 500X As-Polished

This is a high magnification view of the upper portion of corner B of the cross-section for the strip used to make the left spring. This area is just past the full radius profile. The orange line is provided to show that the surface is slightly dished out in one area while a bump is seen on the left side.

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Photograph 47



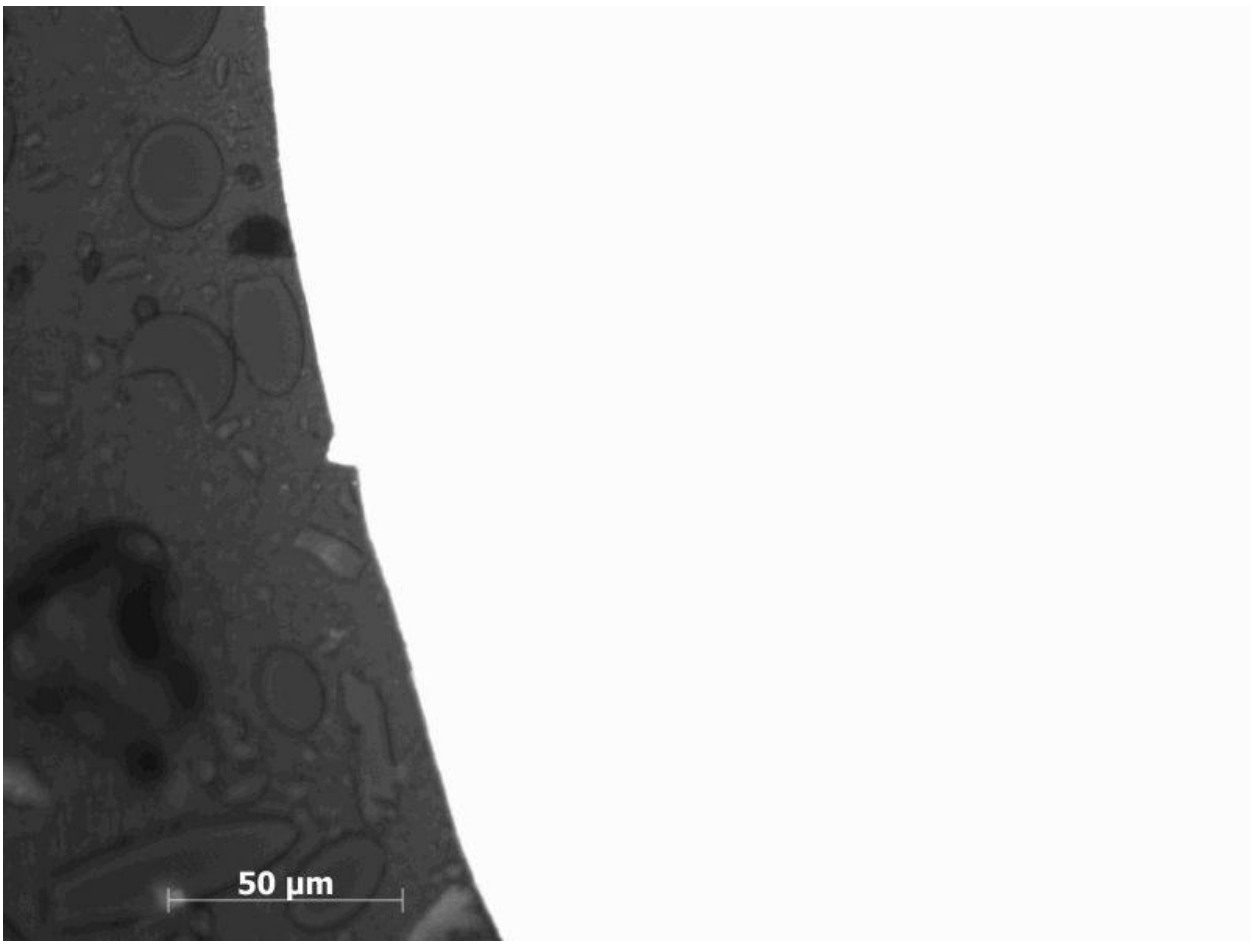
Magnification: 50X As-Polished

This is a low magnification view of the cross-section of the edge on one side of the strip used to make the right spring. We arbitrarily designated this edge as corner A. The lower portion of corner A does not have a fully radiused profile.

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Photograph 48



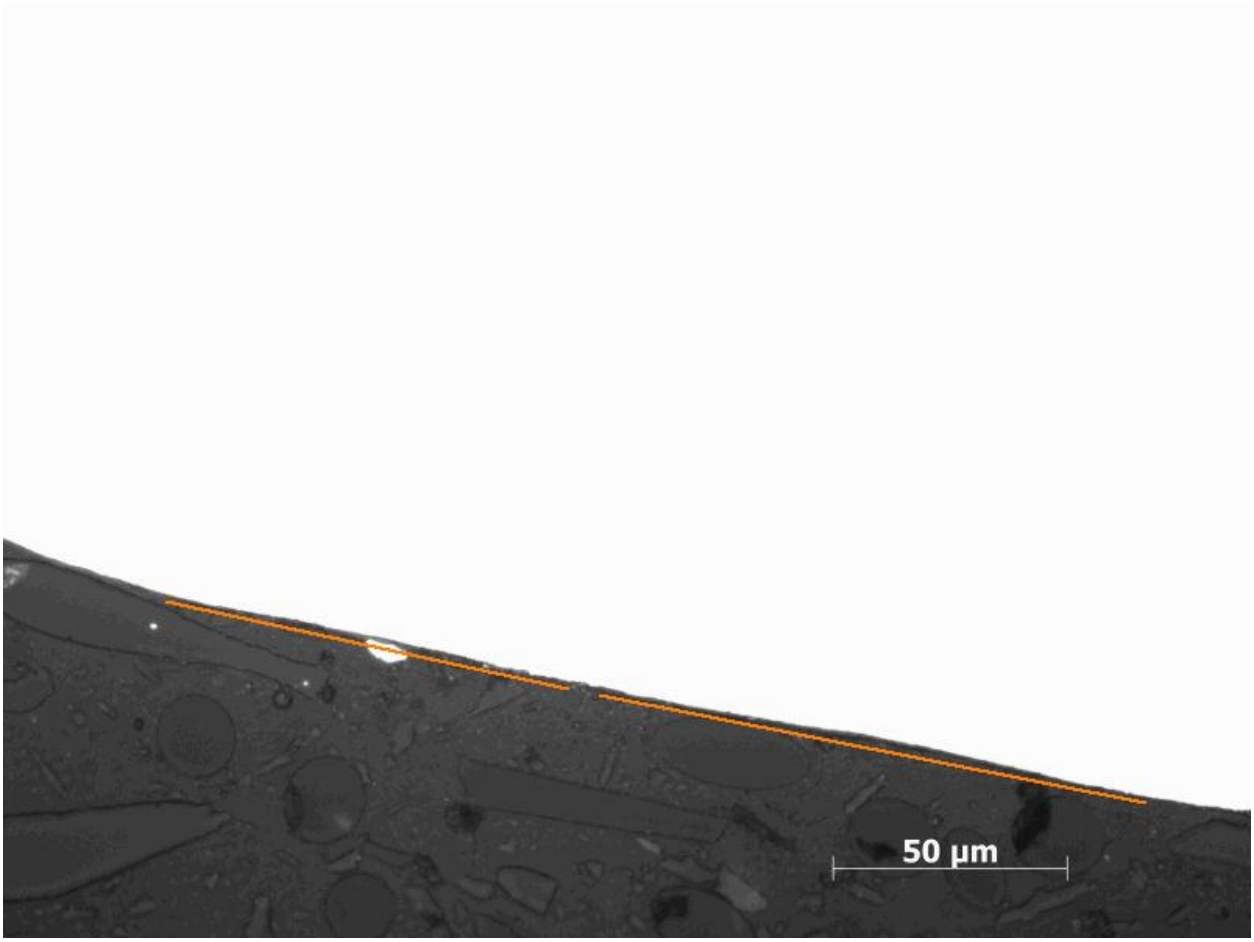
Magnification: 500X As-Polished

This is a high magnification view of a part of the lower portion of corner A of the cross-section for the strip used to make the right spring. This area does show a full radius profile as expected for a fully polished strip edge, with a slight bump in the surface.

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Photograph 49



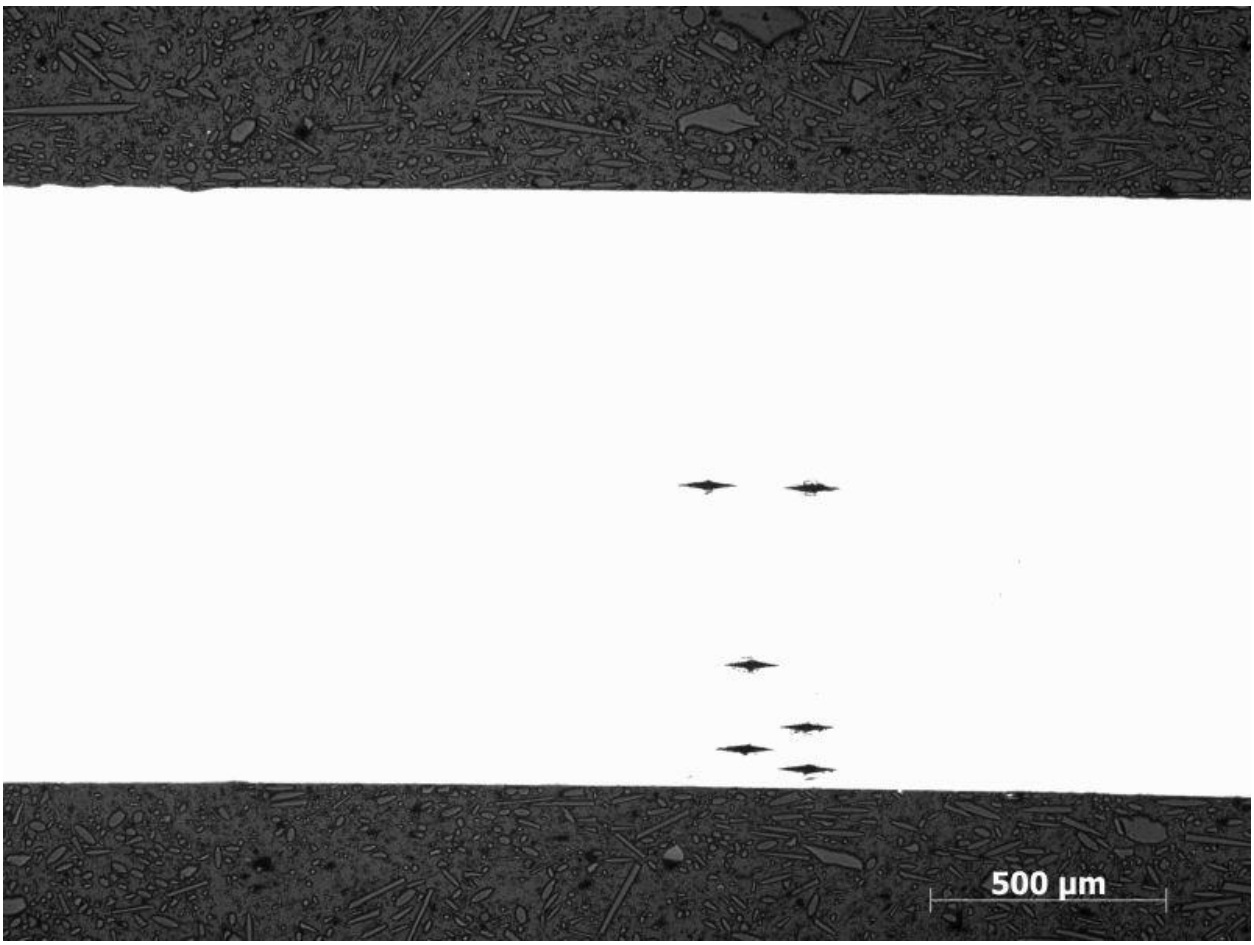
Magnification: 500X As-Polished

This is a high magnification view of the lower portion of corner B of the cross-section for the strip used to make the right spring. The orange line is provided to show that the surface is slightly dished out in one area.

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Photograph 50



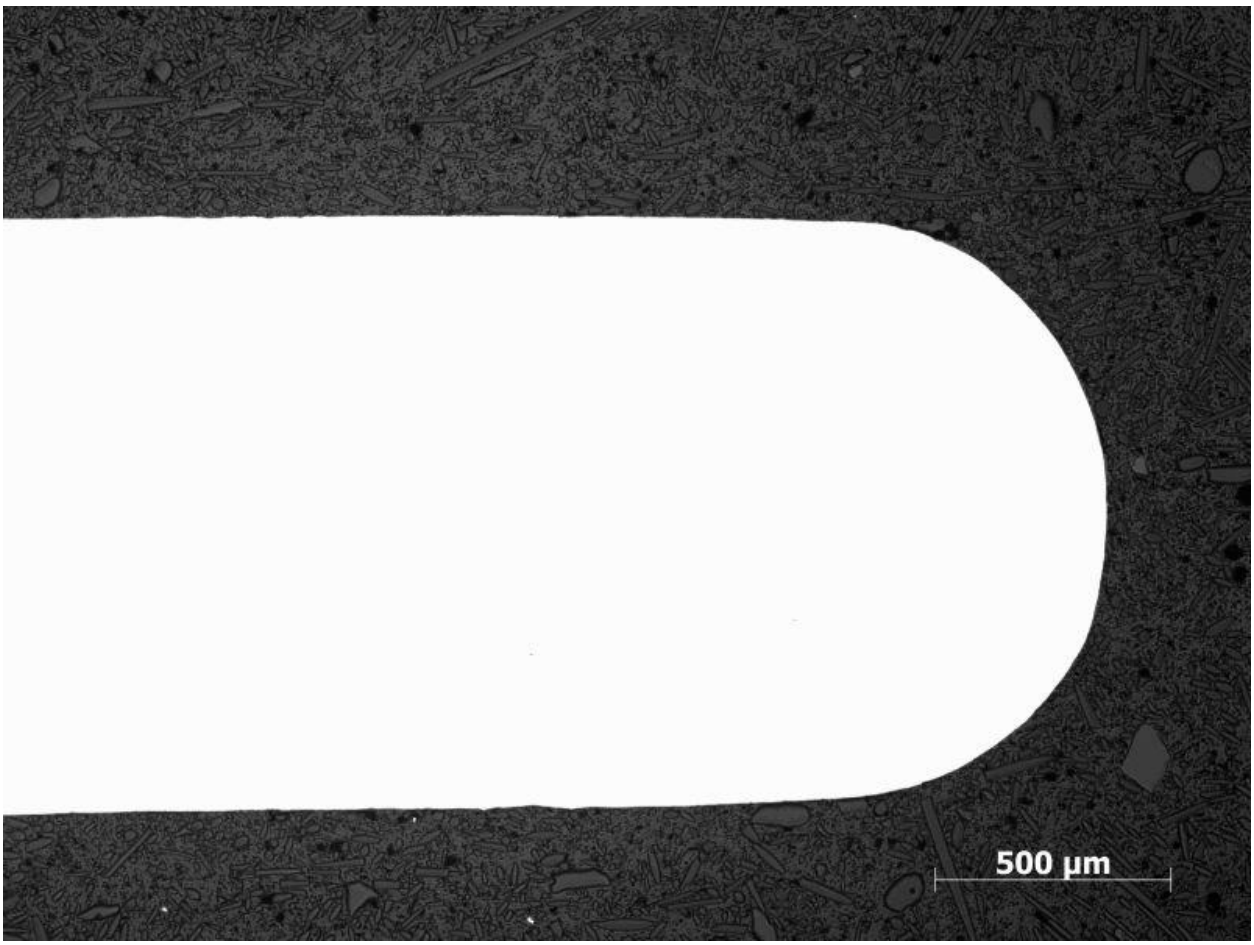
Magnification: 50X As-Polished

This is a low magnification view of the cross-section of the center of the strip used to make the left spring. One can see the elongated indentations produced during subsequent Knoop micro-indentation hardness testing.

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Photograph 51



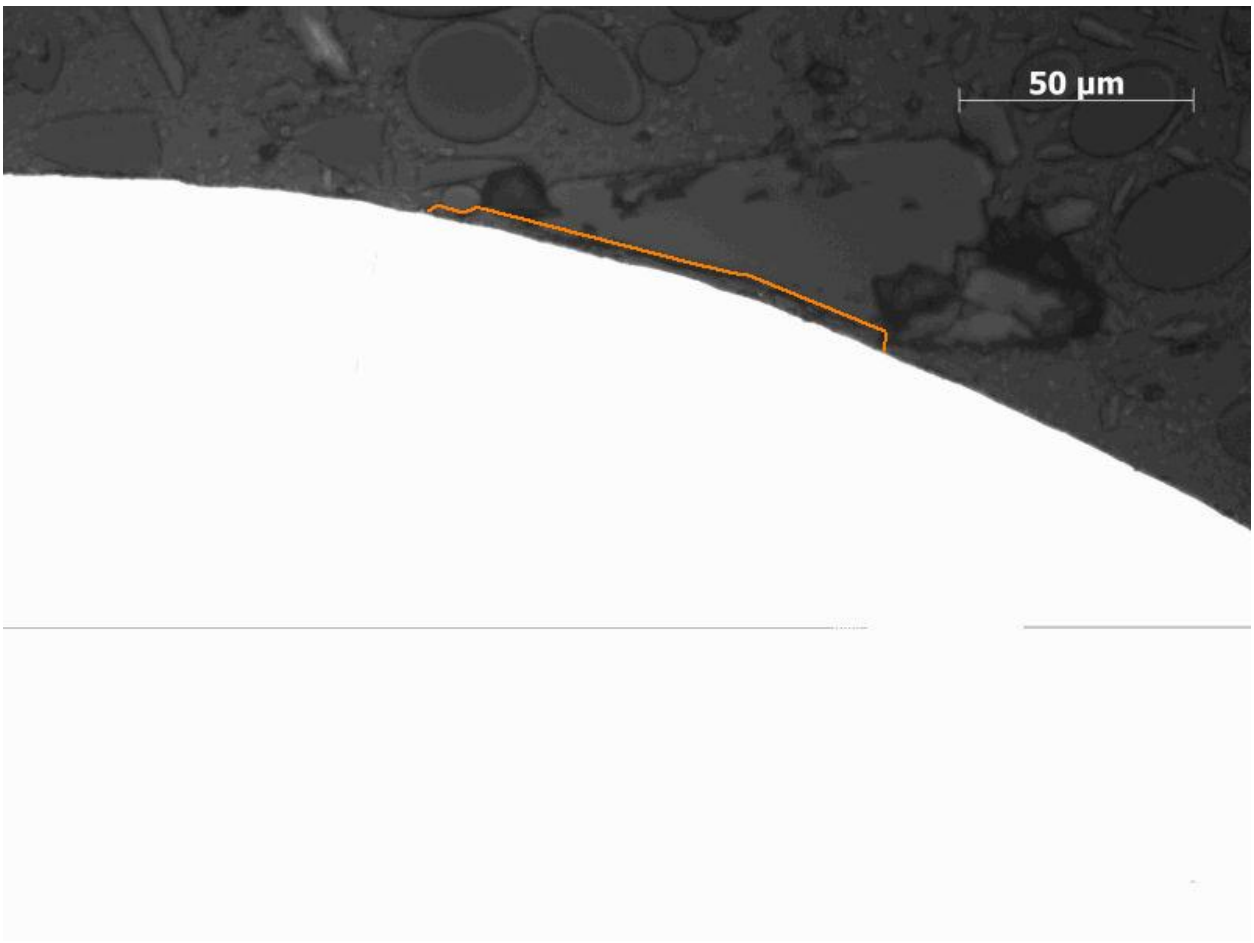
Magnification: 50X As-Polished

This is a low magnification view of the cross-section of the edge on the other side of the strip used to make the right spring. We arbitrarily designated this edge as corner B. Corner B essentially shows a fully radiused profile.

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Photograph 52



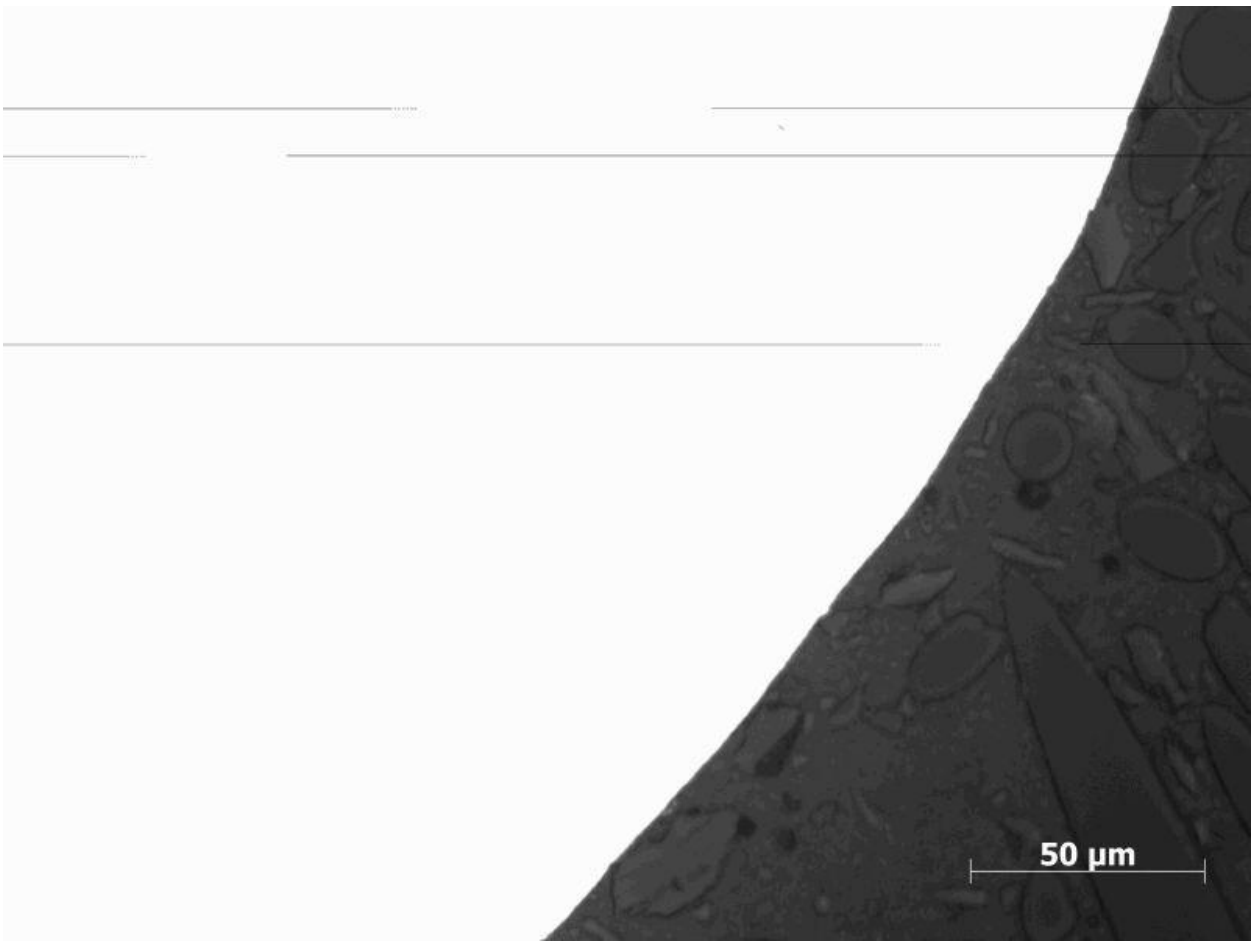
Magnification: 500X As-Polished

This is a high magnification view of a part of the upper portion of corner B of the cross-section for the strip used to make the right spring. This area does show a full radius profile as expected for a fully polished strip edge, with a slight bump of deposits on the surface as outlined by orange lines.

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Photograph 53



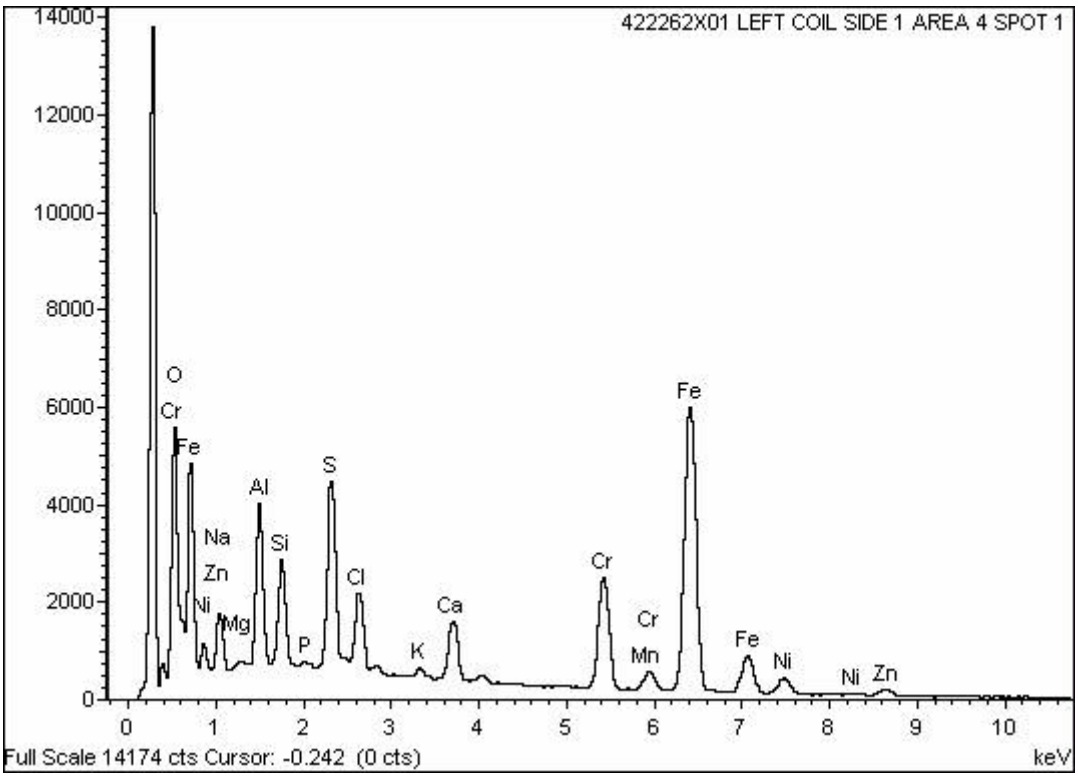
Magnification: 500X As-Polished

This is a high magnification view of the lower portion of corner B of the cross-section for the strip used to make the left spring. This area does show a full radius profile as expected for a fully polished strip edge.

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Figure 1

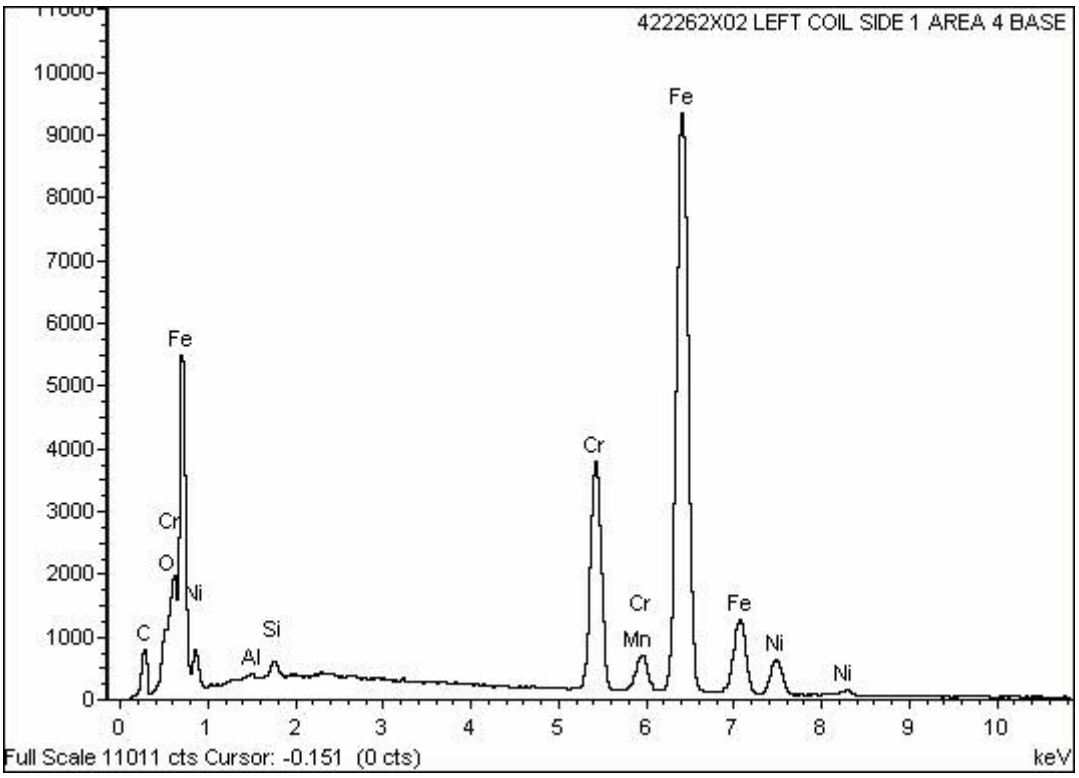


This is the EDS spectrum that we recorded for point location “X” in the residue on the ID surface in Photograph 11. The main elements detected were carbon (C), oxygen (O), aluminum (Al), silicon (Si), sulfur (S), chromium (Cr) and iron (Fe). Lesser amounts of nickel (Ni), zinc (Zn), sodium (Na), magnesium (Mg), phosphorus (P), chlorine (Cl), potassium (K), calcium (Ca) and manganese (Mn) were also present.

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Figure 2

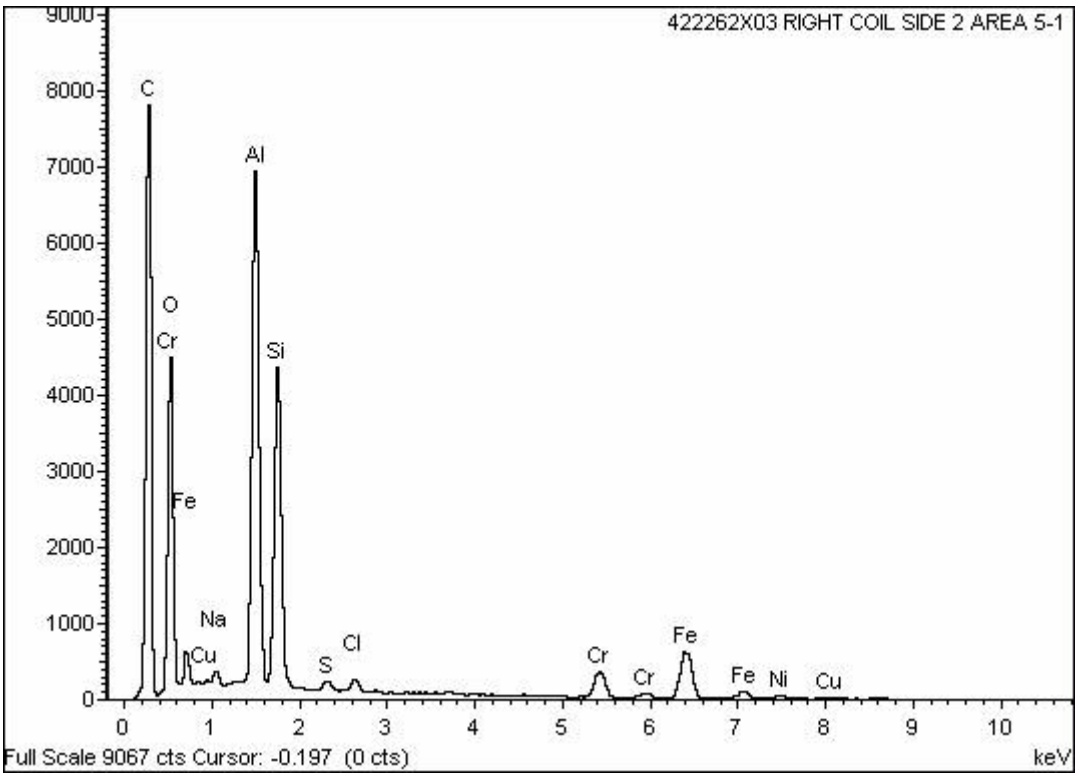


This is the EDS spectrum that we recorded for the area surrounded by the orange box in Photograph 11. The main elements detected were chromium (Cr) and iron (Fe). Lesser amounts of carbon (C), oxygen (O), aluminum (Al), silicon (Si), manganese (Mn) and nickel (Ni) were also present.

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Figure 3



This is the EDS spectrum that we recorded for the area surrounded by the red box in Photograph 38. The main elements detected were carbon (C), oxygen (O), aluminum (Al) and silicon (Si). Lesser amounts of iron (Fe), copper (Cu), sodium (Na), sulfur, chlorine (Cl), chromium (Cr), manganese (Mn) and nickel (Ni) were also present.

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