INSTITUTE of SPRING TECHNOLOGY

Tech-Spring Report 24

The Effect of Stress Relief Temperature on Stainless Steel Spring fatigue Tests

1. Introduction

Report number 21 detailed the results of studies into the effect of stress relief temperatures on Carbon Steel springs. It was concluded that a parallel study for the stress relief temperatures of Stainless steel springs should be done. This report details the results of this work.

2. Spring Design

The spring design used for this study was as follows:-

INSTITUTE OF SPRING TECHNOLOGY Date: 25/09/2009 09:04:39

Spring Type Round Wire Compression

Designed To:	BS 1726-1: 1987	
Tolerance Standard:	BS 1726-1: 2002	

Material

DIN 17224 Aust. Stainless

Youngs Mod (E):	195000	N/mm^2
Rigidity Mod (G):	73000	N/mm^2
Density:	.00000790	Kg/mm^3
Unprestress:	0-40	%
Prestress:	40-59	%
End Type:	Closed and Ground	
Dead Coils:	2.00	
Tip Thickness:	50.00	%
End Fixation:	Fixation not known	

Calculated Data

Solid Length:	22.00	mm
Solid Load:	1983.4	N
Solid Stress:	1747.3	N/mm^2
Stress Factor:	1.41	
Active Coils:	3.50	
Spring Index:	3.93	
Helix Angle:	8.40	Deg
Buckling Possible:	Not Applicable	
Buckling Definite:	Not Applicable	
Spring Pitch:	7.29	mm
Inside Diameter:	11.70	mm
Mean Coil Dia.:	15.70	mm
Wire Length:	273.47	mm
Weight / 100:	2.71	Kg
Natural Freq:	95169	RPM

Design Parameters

Wire Diameter:	4.00	mm	
Outside Diameter:	19.70	mm	
Total Coils:	5.50		
Spring Rate:	172.47	N/mm	(Calculated)
Free Length:	33.50	mm	

Stress Data

	Lower Tensile	% Tensile Solid
CrNi Specified	1500	116 O

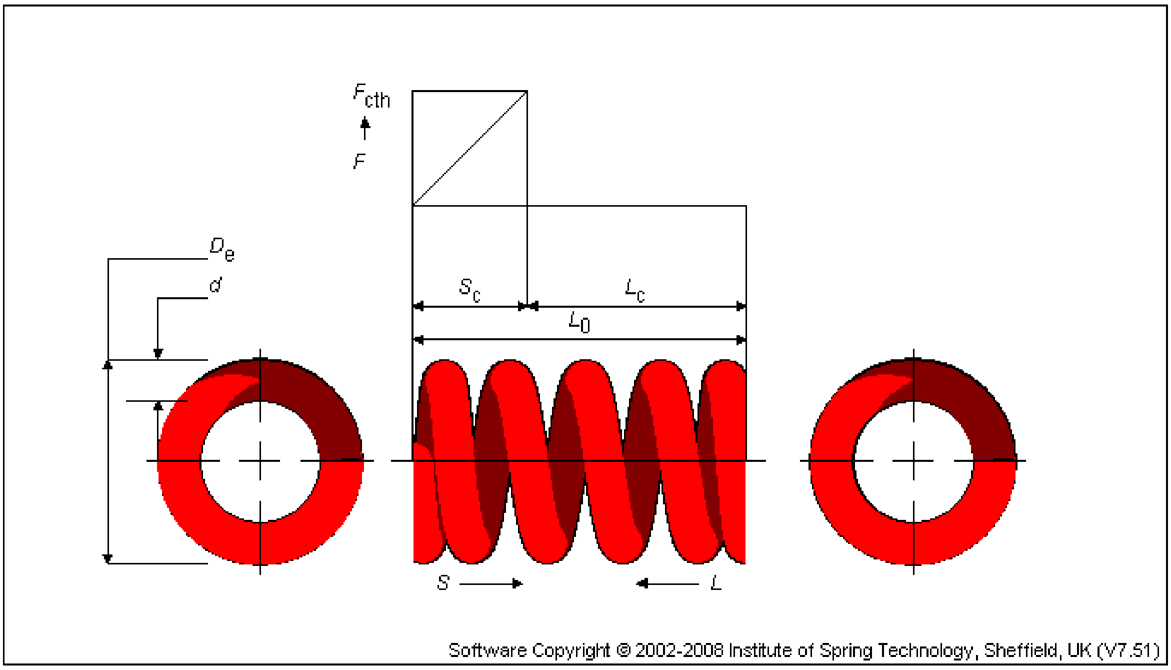
Operating Data

NO DATA

INSTITUTE OF SPRING TECHNOLOGY Date: 25/09/2009 09:08:02

Spring Drawing

	Material:	Right hand helix DIN 17224 Aust. Stainless	
d	Wire Diameter:	4.00	mm
D_e	Outside Diameter:	19.70	mm
n_t	Total Coils:	5.50	
R_s	Spring Rate:	172.47	N/mm
L_0	Free Length:	33.50	mm
L_c	Solid Length	22.00	mm
F_{cth}	Solid Load	1983.4	N



A single batch of springs was produced so that all of the heat treatment variations could be performed upon that batch.

3. **Heat Treatment Program**

The following heat treatment cycles were adopted:-

a) 5 minutes for 250°C after coiling.
b) 15 minutes for 250°C after coiling.
c) 60 minutes for 250°C after coiling.
d) 5 minutes for 350°C after coiling.
e) 15 minutes for 350°C after coiling.
f) 60 minutes for 350°C after coiling.
g) 5 minutes for 450°C after coiling.
h) 15 minutes for 450°C after coiling.
i) 60 minutes for 450°C after coiling.

4. **Fatigue Testing Program**

Spring samples were loaded onto Meyer fatigue test machines, to achieve the different loading stresses as detailed below in table 1:-

Spring data

i	c	0
L_i /[mm]	22	33,5
τ_{ki} / [MPa]	1675,5	0,0
F_i /[N]	1901,9	0,0
τ_k' / [MPa/N]	0,881	

Test 1

i	1	2
L_i /[mm]	31,60	29,30
τ_{ki} / [MPa]	200,0	500,0
F_i /[N]	227,0	567,6
theoretic stroke s_{th} / [mm]		2,30
measured stroke s_m / [mm]		2,45
alternating stress τ_{kh} / [MPa]		300,0
mean stress τ_{km} / [MPa]		350,0
all springs passed 20 mio cycles		

Test 2

i	1	2
L_i /[mm]	31,50	28,70
τ_{ki} / [MPa]	200,0	570,0
F_i /[N]	227,0	647,0
theoretic stroke s_{th} / [mm]		2,80
measured stroke s_m / [mm]		2,80
alternating stress τ_{kh} / [MPa]		370,0
mean stress τ_{km} / [MPa]		385,0
bout half of the springs failed up to 5 mio cycle		

Test 3

i	1	2
L_i /[mm]	31,40	27,60
τ_{ki} / [MPa]	220,0	720,0
F_i /[N]	249,7	817,3
theoretic stroke s_{th} / [mm]		3,80
measured stroke s_m / [mm]		3,60
alternating stress τ_{kh} / [MPa]		500,0
mean stress τ_{km} / [MPa]		470,0
all springs failed after 0,3 mio cycles		

Table 1

The fatigue test results obtained for each of the three nominal test parameters are detailed in figures 1, 2, and 3

Results of the durability test

series	300 MPa	pieces	54	start	2009-05-04
Meyer machine number	3	loading cycles	2,0E+7	end	2009-05-14
τkh'	0,881				

row	spring number	τkh [MPa]	loading cycles to failure [Mio]		passed springs
250° 5 min	1	280,4			20
	2	280,4			20
	3	280,4			20
	4	280,4			20
	5	280,4			20
	6	280,4			20
250° 15 min	1	297,8			20
	2	297,8			20
	3	297,8			20
	4	297,8			20
	5	297,8			20
	6	297,8			20
250° 60 min	1	279,6			20
	2	279,6			20
	3	279,6			20
	4	279,6			20
	5	279,6			20
	6	279,6			20
350° 5 min	1	293,1			20
	2	293,1			20
	3	293,1			20
	4	293,1			20
	5	293,1			20
	6	293,1			20
350° 15 min	1	307,3			20
	2	307,3			20
	3	307,3			20
	4	307,3			20
	5	307,3			20
	6	307,3			20
350° 60 min	1	302,2			20
	2	302,2			20
	3	302,2			20
	4	302,2			20
	5	302,2			20
	6	302,2			20
450° 5 min	1	306,7			20
	2	306,7			20
	3	306,7			20
	4	306,7			20
	5	306,7			20
	6	306,7			20
450° 15 min	1	303,6			20
	2	303,6			20
	3	303,6			20
	4	303,6			20
	5	303,6			20
	6	303,6			20
450° 60 min	1	307,9			20
	2	307,9			20
	3	307,9			20
	4	307,9			20
	5	307,9			20
	6	307,9			20

Figure 1, 300 MPa loading

INSTITUTE of SPRING TECHNOLOGY

Results of the durability test

series	370 MPa	pieces	54	start	2009-05-13
Meyer machine number	2	loading cycles	5,0E+6	end	2009-05-15
				τkh'	0,881

row	spring number	τkh [MPa]	loading cycles to failure [Mio]			passed springs
250° 5 min	1	335,8				5
	2	335,8				5
	3	335,8	1,55	2,00	1,78	
	4	335,8	3,23	3,45	3,34	
	5	335,8				5
	6	335,8	2,50	2,63	2,57	
250° 15 min	1	370,7				5
	2	370,7				5
	3	370,7				5
	4	370,7	3,62	4,00	3,81	
	5	370,7	2,63	2,79	2,71	
	6	370,7				5
250° 60 min	1	368,3				5
	2	368,3	2,63	2,79	2,71	
	3	368,3				5
	4	368,3	0,61	1,00	0,81	
	5	368,3	3,14	3,23	3,19	
	6	368,3				5
350° 5 min	1	354,9				5
	2	354,9				5
	3	354,9				5
	4	354,9	2,00	2,26	2,13	
	5	354,9				5
	6	354,9				5
350° 15 min	1	368,8				5
	2	368,8				5
	3	368,8	3,14	3,23	3,19	
	4	368,8	3,62	4,00	3,75	
	5	368,8				5
	6	368,8	3,62	4,00	3,87	
350° 60 min	1	366,9				5
	2	366,9				5
	3	366,9	2,81	3,00	2,91	
	4	366,9				5
	5	366,9	2,79	2,81	2,80	
	6	366,9	2,50	2,63	2,57	
450° 5 min	1	368,7	1,08	1,22	1,15	
	2	368,7	3,62	4,00	3,81	
	3	368,7				5
	4	368,7	3,09	3,14	3,12	
	5	368,7				5
	6	368,7				5
450° 15 min	1	368,6				5
	2	368,6				5
	3	368,6				5
	4	368,6	1,08	1,22	1,15	
	5	368,6	2,63	2,79	2,71	
	6	368,6				5
450° 60 min	1	372,1				5
	2	372,1				5
	3	372,1				5
	4	372,1	0,61	1,00	0,81	
	5	372,1				5
	6	372,1				5

Figure 2, 370 MPa Loading

INSTITUTE of SPRING TECHNOLOGY

Results of the durability test

series	500 MPa	pieces	54	start	2009-05-13
Meyer machine number	5	loading cycles	3,0E+5	end	2009-05-15
τkh'	0,881				

row	spring number	τkh [MPa]	loading cycles to failure [Mio]			passed springs
250° 5 min	1	440,2	0,05	0,19	0,08	
	2	440,2	0,05	0,19	0,11	
	3	440,2	0,29	0,29	0,29	
	4	440,2	0,05	0,19	0,13	
	5	440,2	0,05	0,19	0,16	
	6	440,2	0,19	0,21	0,20	
250° 15 min	1	501,4	0,24	0,24	0,24	
	2	501,4	0,05	0,19	0,08	
	3	501,4	0,05	0,19	0,11	
	4	501,4	0,25	0,25	0,25	
	5	501,4	0,05	0,19	0,13	
	6	501,4	0,05	0,19	0,16	
250° 60 min	1	490,9	0,05	0,19	0,07	
	2	490,9	0,05	0,19	0,09	
	3	490,9	0,05	0,19	0,11	
	4	490,9	0,05	0,19	0,13	
	5	490,9	0,05	0,19	0,15	
	6	490,9	0,05	0,19	0,17	
350° 5 min	1	468,2	0,27	0,27	0,27	
	2	468,2	0,24	0,24	0,24	
	3	468,2	0,19	0,21	0,20	
	4	468,2	0,05	0,19	0,09	
	5	468,2	0,05	0,19	0,12	
	6	468,2	0,05	0,19	0,16	
350° 15 min	1	488,0	0,26	0,26	0,26	
	2	488,0	0,05	0,19	0,08	
	3	488,0	0,05	0,19	0,11	
	4	488,0	0,36	0,38	0,37	
	5	488,0	0,05	0,19	0,13	
	6	488,0	0,05	0,19	0,16	
350° 60 min	1	498,6	0,05	0,19	0,07	
	2	498,6	0,05	0,19	0,09	
	3	498,6	0,05	0,19	0,11	
	4	498,6	0,05	0,19	0,13	
	5	498,6	0,05	0,19	0,15	
	6	498,6	0,05	0,19	0,17	
450° 5 min	1	492,6	0,05	0,19	0,08	
	2	492,6	0,25	0,25	0,25	
	3	492,6	0,05	0,19	0,11	
	4	492,6	0,05	0,19	0,13	
	5	492,6	0,05	0,19	0,16	
	6	492,6	0,19	0,21	0,20	
450° 15 min	1	493,8	0,05	0,19	0,07	
	2	493,8	0,05	0,19	0,10	
	3	493,8	0,19	0,21	0,20	
	4	493,8	0,05	0,19	0,12	
	5	493,8	0,05	0,19	0,14	
	6	493,8	0,05	0,19	0,17	
450° 60 min	1	496,7	0,05	0,19	0,07	
	2	496,7	0,05	0,19	0,09	
	3	496,7	0,05	0,19	0,11	
	4	496,7	0,05	0,19	0,13	
	5	496,7	0,05	0,19	0,15	
	6	496,7	0,05	0,19	0,17	

Figure 3, 500 MPa Loading

5. Fatigue Test Results Analysis by Innotech

tempering conditions (series)		lifetime	alternating stress
temperature / [°C]	time / [min]	$N_{A=50\%}$ / 10^6	[MPa]
250	5	0,15	440,20
	15	0,15	501,40
	60	0,11	490,90
350	5	0,17	468,20
	15	0,16	488,00
	60	0,11	498,60
450	5	0,14	492,60
	15	0,13	493,80
	60	0,11	496,70

Table 2

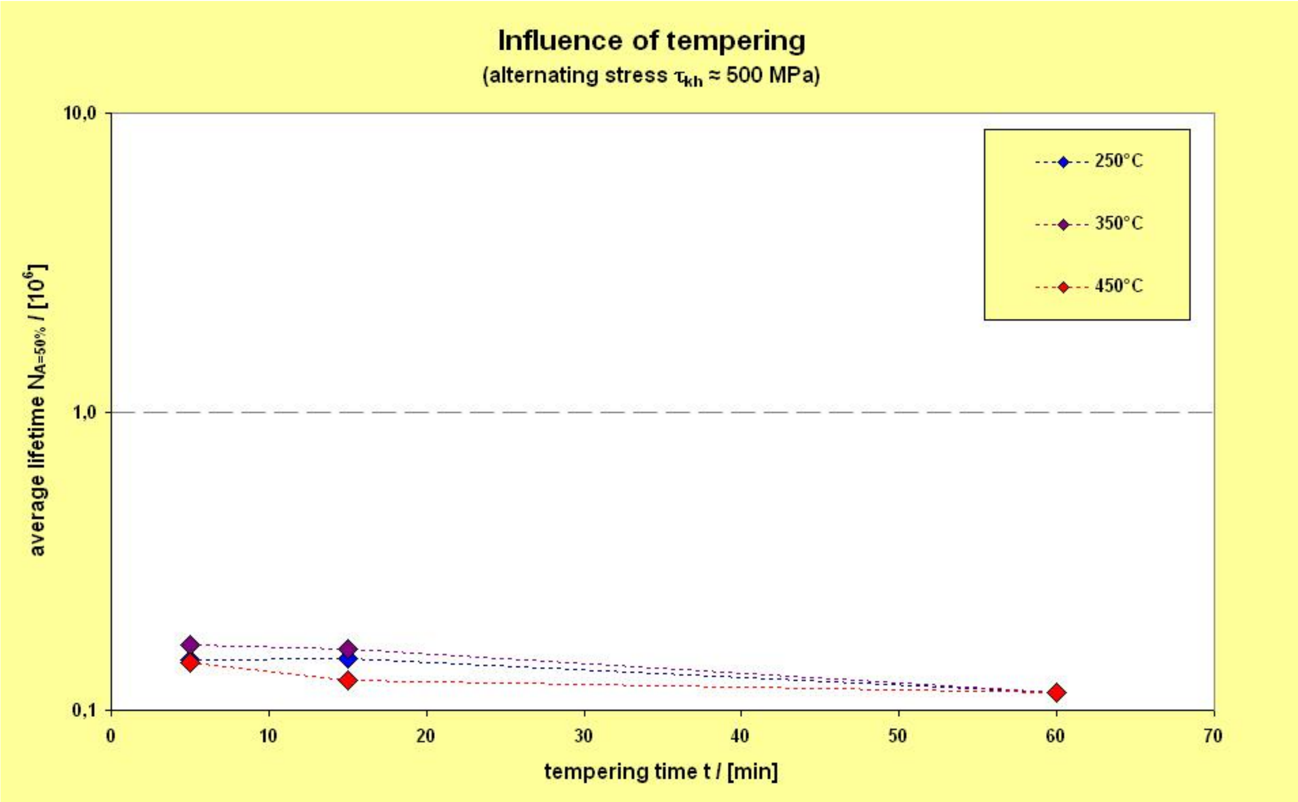


Figure 4

6. **Fatigue Test Results Analysis by IST**

As all of the tests at a stress level of 300 MPa passed 20 million cycles without failure irrespective to tempering temperature no meaningful analysis is possible on this data.

When testing at a stress level of 500Mpa there is a subtle suggestion from the results that 15 minutes at temperature gives slightly higher fatigue lives than 5 minutes heat treatment. 60 minutes heat treatment gives inferior fatigue lives to 15 minutes and 5 minutes. The overall spread in fatigue lives was however very small (from 0.07 to 0.27 million cycles) reducing the value of this indication significantly.

IST have therefore concentrated analysis on the first fatigue failure for each time / temperature combination at 370MPa set of data, with the following results:-

Temperature (°C)	Time (minutes)	Lifetime
250	5	1.76
250	15	2.71
250	60	0.81
350	5	2.13
350	15	3.19
350	60	2.57
450	5	1.15
450	15	1.15
450	60	0.81

Figure 5

This data is represented in figure 6 as graphs of fatigue lives against heat treatment times:-

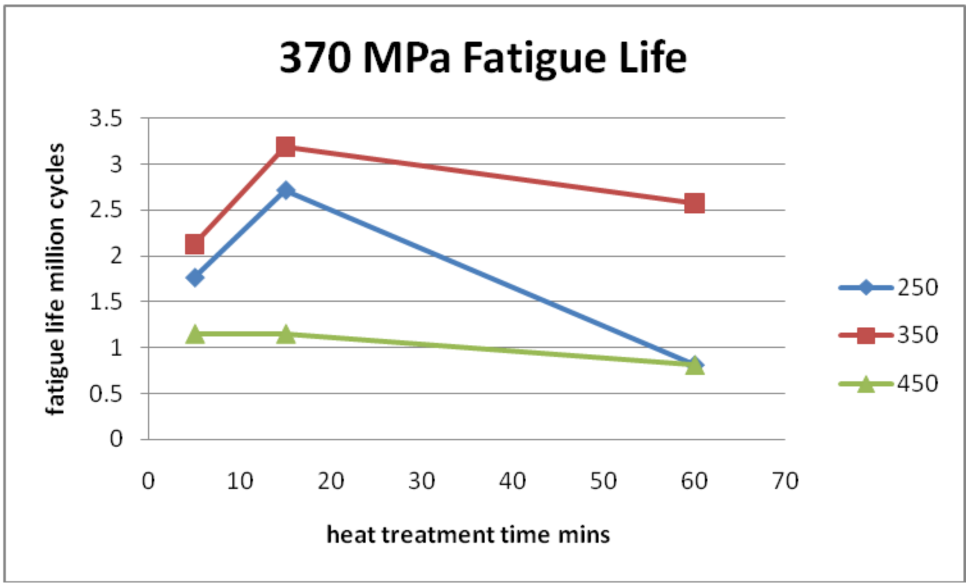


Figure 6

Heat treatment at 450° C gave the worst fatigue lives. Heat treatment at 250° C for either 5 or 15 minutes gave significant improvements over 450° C treatment. When this heat treatment was extended to one hour there was absolutely no difference between 250 and

450° C heat treatments in terms of fatigue lives. 350°C heat treatments gave superior fatigue lives at all treatment times to either 250 or 450° C.

7. Metallography of Failed Springs

All fracture surfaces were examined for evidence of defects. No trace of any material or manufacturing defects were identified that could have lead to premature failure of any of the springs. In all cases failure was caused by overload.

A typical fatigue failure from these springs is illustrated in figure 7 (actually from the 350°C / 15 minute sample) below:-

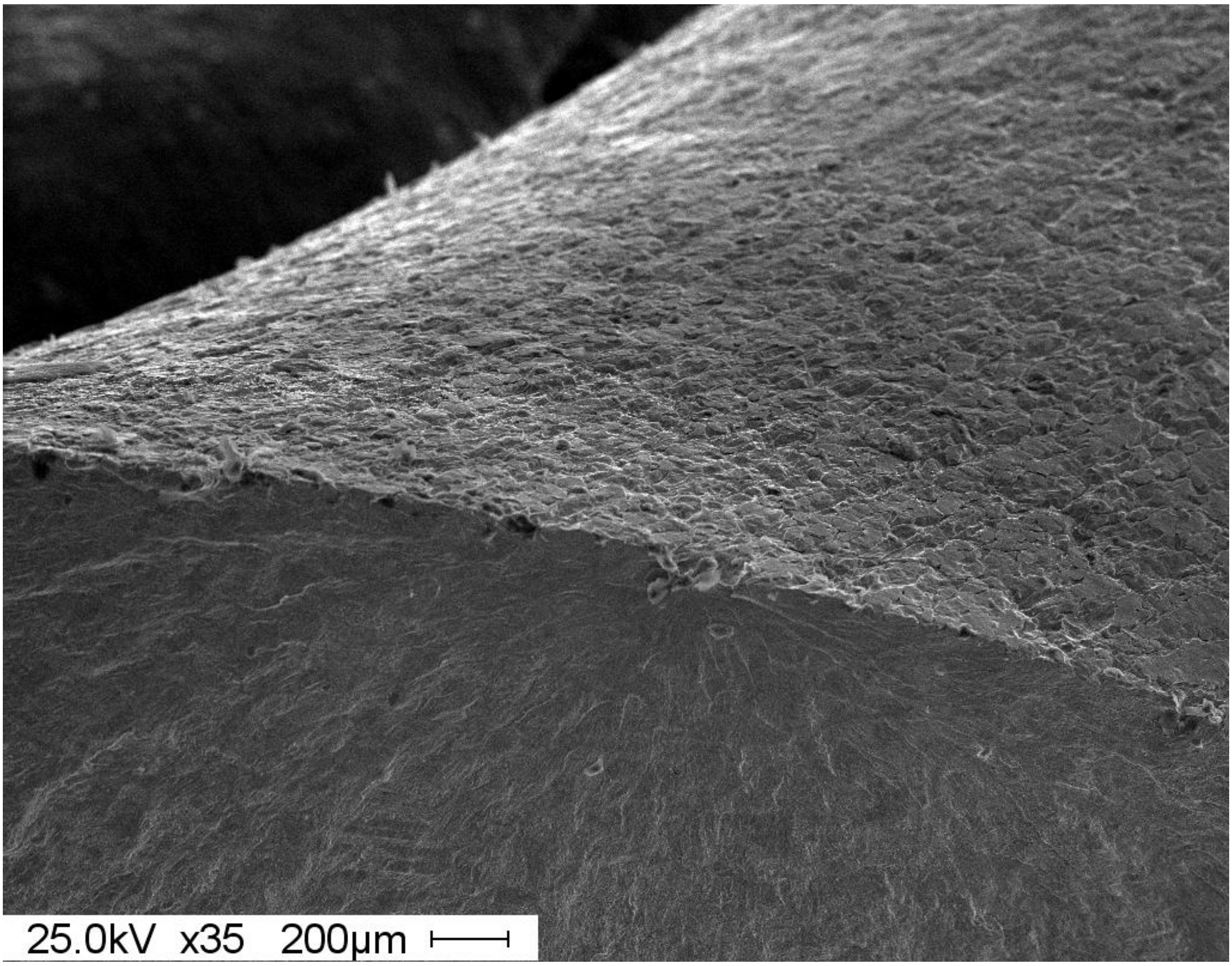


Figure 7

8. Discussion

Innotech performed their normal 50% statistical analysis routines for these springs – IST performed the more simplistic “first failure” analysis normally used on just the 370 MPa test data. In this case the first failure analysis generates more useful information.

The 300 MPa test data did not generate any useful conclusions as all springs survived the fatigue testing unbroken.

Testing at 500 MPa stress range gave very short test durations for all springs making it difficult to distinguish the effect of heat treatment from the normal variability of fatigue testing.

The 370 MPa test data clearly indicated an improvement in fatigue life as heat treatment times increased up to 15 minutes duration, but then a decline if this time was extended to 60 minutes. 450° C heat treatment temperature gave uniformly the worst fatigue lives. 250° C heat treatment gave a significant improvement over 450° C heat treatment, but 350° C was even better. This result surprised IST as there was considerable historical expectation than 450° C would produce the best fatigue lives.

9. Conclusions

On the data available there are indications that the 350° C heat treatment temperature imparts the best fatigue life, with the 15 minute time offering the best improvement. This result was contrary to expectation. Further testing would be justified to confirm this result.

Unfortunately there were insufficient spring samples left at the end of the testing program to be able to perform a residual stress analysis as well, so this report is not as complete as the equivalent carbon steel program..

The inconclusive nature of the results indicates that further testing is required. Additional springs have been requested to allow some additional work to be performed at IST.