Title: On the effects of heat treatment on the properties of extension springs

Author: Mark Hayes, Technical Advisor to IST

Abstract: In a programme of work undertaken in 2013, prompted by numerous questions asked by spring manufacturers, carbon and stainless steel spring wires were made into extension springs. These springs were measured and load tested to evaluate their initial tension and elastic limit. The results point to the need to revise EN 13906-2.

## Background

Spring manufacturers are aware that the stress relief heat treatment carried out on extension springs in manufacture has the following effects:

1. The outside diameter, and hence spring rate, changes.
2. The initial tension, wound in during coiling, is reduced.
3. Some may also know that the elastic limit increases.

According to EN 13906-2 the maximum (uncorrected) design stress for extension springs is 45% Rm. That is to say, you may load the body of an extension spring up to an applied stress of 45% of the wire tensile strength and no plastic deformation will occur. This assumes that the springs were stress relieved after coiling. It is the author's contention that this definition of the elastic limit is often too high. This investigation is designed to study the elastic limit, and how it is affected by the heat treatment temperature. At the same time, the opportunity was taken to investigate the effect of heat treat temperature on the outside diameter, initial tension and spring rate.

Most extension springs have a theoretical load / deflection characteristic like that of the test springs studied in this investigation, figure 1.

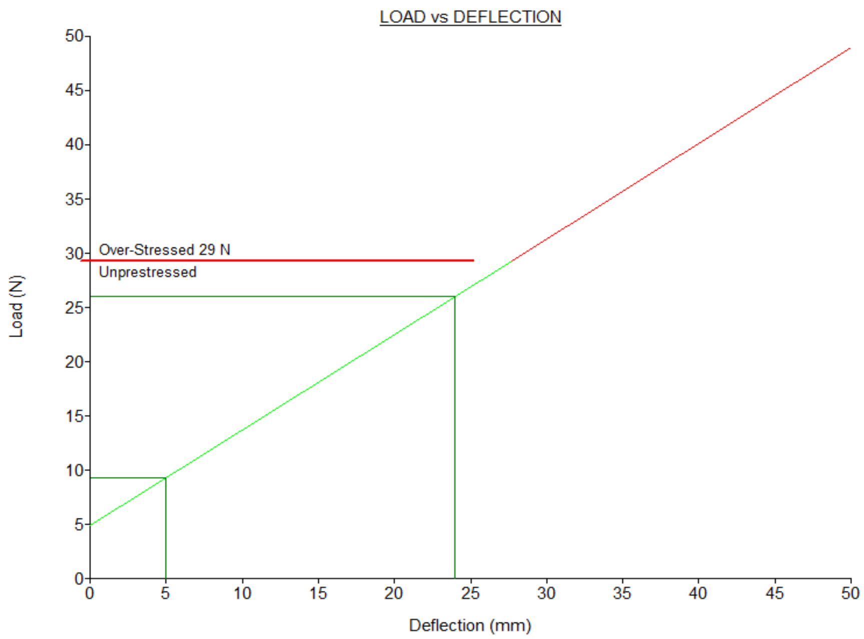


Figure 1 Load / deflection characteristic

The assumption is that when an extension spring is loaded beyond its elastic limit (29N in figure 1), all the plastic deformation is in the body of the spring, manifest as a reduction in the initial tension. Most extension springs have hooks that are made to the same nominal outside diameter as the spring body, and this applies to the springs made for this investigation, which are shown in figure 2.

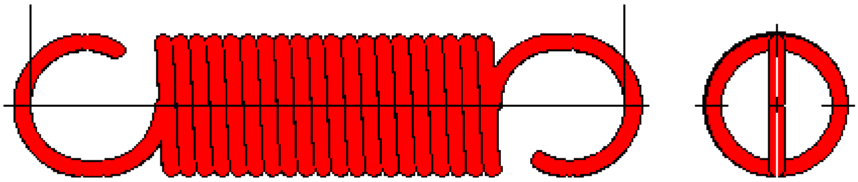

Figure 2 Test springs

The assumption of all international extension spring design standards is that the hooks are perfectly rigid and do not deflect elastically or plastically up to their maximum design stress. This assumption is incorrect, but for extension springs with more than 20 body coils the error incurred by ignoring hook deflection is genuinely quite small.

The overwhelming majority of extension springs are either made from drawn carbon steel (sometimes with a Zn or Zn/Al coating) to EN 10270-1 or drawn stainless steel to EN 10270-3, grade 1.4310 or 302 type. Hence these are the two materials studied here.

Springs

The springs for this investigation were supplied, courtesy of Advanex (2) in Nottingham, UK. They were coiled on an automatic machine that formed both hooks, and soon after coiling the author collected the springs so as to undertake the heat treatment under carefully controlled conditions without excessive delay after coiling. The springs were made from 0.71mm wire, and they had a nominal outside diameter of 6.03mm, 19.5 coils, a relatively large amount of initial tension, and English or crossover end hooks. The tensile strength of the carbon steel was 2465MPa and that of the stainless was 1981MPa. The design of the carbon steel springs, as represented in SCP (3), and using EN13906-2 as the design method is shown as figure 3.

| | | | | |
|---|---|---|---|---|
| | | | Date: | 17/03/2013 12:19:26 |

| | |
|---|---|
| Identifier: | Advanex |
| Part Number: | Investigation springs |

**Spring Type: Round Wire Extension**

| | | |
|---|---|---|
| Designed To: | EN 13906-2: 2001 | |
| Tolerance Standard: | DIN 2097: 1973 | |

**Material**

| | | |
|---|---|---|
| EN 10270-1 Drawn | | |
| Youngs Mod (E): | 206000 | N/mm^2 |
| Rigidity Mod (G): | 81500 | N/mm^2 |
| Density: | .00000785 | Kg/mm^3 |
| Unprestress: | 0-45 | % |
| End Type: | Crossover Loop | |
| Loop Selection | Equal to Body Dia. | |
| Loop Outside Diameter: | 6.03 | mm |

**Design Parameters**

| | | | |
|---|---|---|---|
| Wire Diameter: | 0.710 | mm | |
| Outside Diameter: | 6.03 | mm | |
| Total Coils: | 19.50 | | |
| Spring Rate: | 0.880 | N/mm | (Calculated) |
| Initial Tension: | 4.92 | N | |
| Free Length: | 25.00 | mm | |

**Calculated Data**

| | | |
|---|---|---|
| Estimated Free Length: | 23.78 | mm |
| Initial Tension Stress: | 186.33 | N/mm^2 |
| Body Length: | 14.55 | mm |
| Body Length (Max): | 14.76 | mm |
| Stress Factor: | 1.19 | |
| Spring Index: | 7.50 | |
| Inside Diameter: | 4.61 | mm |
| Mean Coil Dia. | 5.32 | mm |
| Loop Inside Diameter: | 4.61 | mm |
| Wire Length: | 361.06 | mm |
| Weight / 100: | 0.112 | Kg |
| Natural Freq: | 27958 | RPM |
| Available Deflection (SL): | N/A | mm |
| Available Deflection (SM): | 22.35 | mm |
| Available Deflection (DM): | 22.35 | mm |
| Available Deflection (SH): | 25.86 | mm |
| Available Deflection (DH): | 25.86 | mm |

**Stress Data**

| | | | Operating Positions % Tensile | |
|---|---|---|---|---|
| | Lower Tensile | I. T. | 1 | 2 |
| SL | NO DATA | | | |
| SM | 2070 | 9 U | 17 U | 48 O |
| DM | 2070 | 9 U | 17 U | 48 O |
| SH | 2330 | 8 U | 15 U | 42 U |
| DH | 2330 | 8 U | 15 U | 42 U |
| Specified | 2465 | 8 U | 14 U | 40 U |

**Operating Data**

| | Operating Positions 1 | 2 |
|---|---|---|
| Length (mm) | 30.00 | 48.95 |
| Load (N) | 9.32 | 26.00 |
| Deflection (mm) | 5.00 | 23.95 |
| Body Stress (N/mm^2) | 353 | 985 |
| Loop Stress (N/mm^2) | 807.07 | 2252.3 |
| Load Tol. Grade 1 (N) | 0.891 | 1.05 |
| Load Tol. Grade 2 (N) | 1.41 | 1.67 |
| Load Tol. Grade 3 (N) | 2.26 | 2.66 |



Figure 3 Nominal design of the carbon steel spring assuming springs had been heat treated.

## Heat Treatment

The springs were subject to heat treatment (LTHT) in an oven, courtesy of IST (4), that could be set and maintained to within +/- 5°C, and the total heat treatment time was always 20 minutes. A thermocouple placed among the springs showed that they attained the oven set temperature within 2 minutes of placement within the oven. Batches of 20 springs were heat treated – carbon steel at 150, 200, 250, 300 and 350°C, and the stainless steel at 200, 250, 300, 350, 400 and 450°C.

## Load testing

The springs were load tested according to the following regime, courtesy of IST (4). The free length of the springs was measured on the load tester (actually the length at a load of 0.1N), and then the load at 30 mm was measured. It was checked that loading to 30 mm had no effect on the free length and then the springs were load tested at progressively longer lengths, each time going back to check that the free length had not been significantly altered, and then re-measuring the load at 30 mm. Testing was continued until the loss of load at 30 mm was at least 2%.

A typical set of results is shown in table 1.

| Load / N @ | Load/ N @ 30mm | Free Length /mm | Loss of load /N @ 30mm |
|---|---|---|---|
| 9.15 @ 30mm | 9.15 | 25.005 | 0 |
| 17.61@ 40mm | 9.13 | 25.010 | 0.02 |
| 21.81@ 45mm | 9.12 | 25.020 | 0.03 |
| 24.33@ 48mm | 9.10 | 25.020 | 0.05 |
| 26.00@ 50mm | 9.07 | 25.020 | 0.08 |
| 27.63@ 52mm | 9.02 | 25.020 | 0.13 |
| 29.23@ 54mm | 8.91 | 25.030 | 0.24 |
| 30.80@ 56mm | 8.72 | 25.030 | 0.43 |

Table 1 Example result for a carbon steel spring heat treated at 250°C

Two to five springs were tested at each heat treatment temperature, and the results were averaged. The results are summarised in table 2 for the carbon steel.

| LTHT / °C | Initial Tension N | % Rm | Load at which 0.1N loss | % Rm | Load at which 0.2N loss | % Rm | Spring Rate N/mm | Outside Diameter mm |
|---|---|---|---|---|---|---|---|---|
| - | 9.15 | 14.2 | 17.6 | 27.3 | 19.6 | 30.4 | 0.810 | 6.13 |
| 150 | 6.77 | 10.5 | 24.3 | 37.7 | 26.5 | 41.1 | 0.840 | 6.10 |
| 200 | 6.16 | 9.5 | 26.8 | 41.5 | 28.8 | 44.6 | 0.850 | 6.06 |
| 250 | 5.12 | 7.9 | 26.6 | 41.2 | 28.6 | 44.3 | 0.850 | 6.03 |
| 300 | 3.72 | 5.8 | 25.0 | 38.7 | 27.2 | 42.1 | 0.856 | 6.03 |
| 350 | 2.16 | 3.3 | 24.0 | 37.2 | 26.0 | 40.3 | 0.881 | 6.03 |

Table 2 Results for the carbon steel springs

It is immediately clear that LTHT is enormously beneficial to extension spring performance and so it is right that the world's design standards always assume that LTHT has been carried out after coiling. Further examination of these results shows that as the outside diameter became smaller at higher LTHT temperatures, the spring rate became larger as expected, but the spring rate is always lower than theory would predict (see figure 3) because theory ignores the elastic deflection of the hooks. However, the theoretical rate for a spring with an outside diameter of 6.13mm would be 0.834N/mm, and with an outside diameter of 6.03mm would be 0.882N/mm. This suggests that the spring rate results are approximately consistent with the spring dimensional changes during LTHT.

Not only does theory ignore the elastic deflection of hooks, it also ignores the plastic deformation that occurs before the elastic limit of the body coils is reached. If the elastic limit of body coils is defined at a loss of 0.1N, then part of this loss is due to the plastic deformation of the end hook. Indeed the results show in table 1 that when 0.1N is lost, the free length has increased by 0.015mm, which equates to more than 10% of this load loss.

The actual load/deflection graph to the load at which there is a 0.1N loss is shown as figure 4

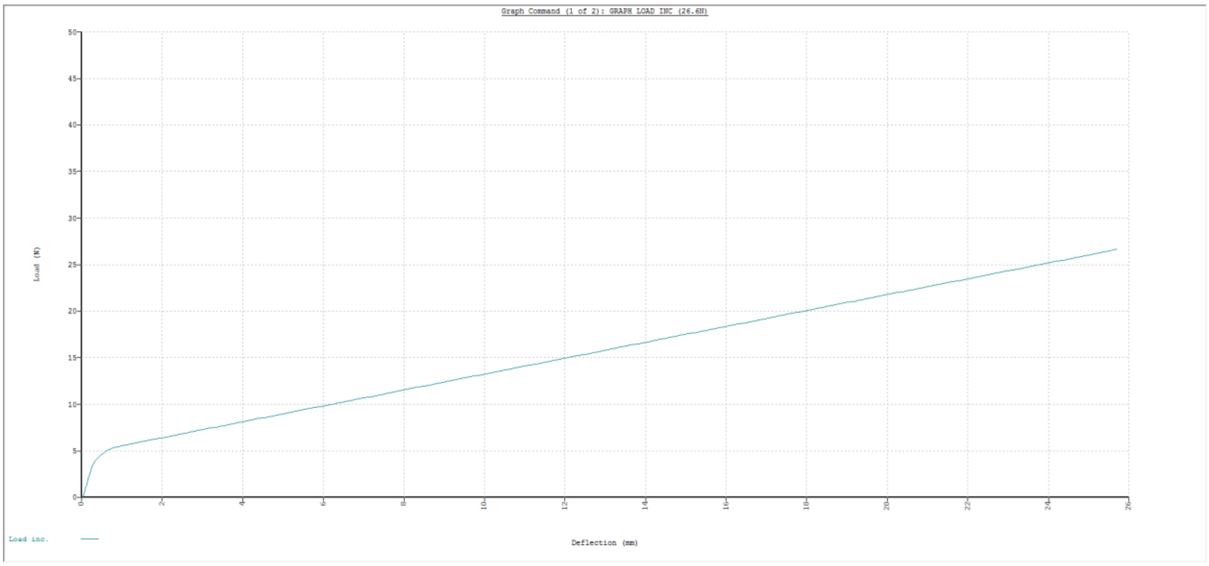


Figure 4 Load/Deflection characteristic of a carbon steel extension spring heat treated at 250°C

The stainless steel springs were processed in a similar manner to the carbon steel except that they lost load at much smaller deflections.  The results are shown in table 3.

| LTHT / °C | Initial Tension N | % Rm | Load at which 0.1N loss | % Rm | Load at which 0.2N loss | % Rm | Spring Rate N/mm | Outside Diameter mm |
|---|---|---|---|---|---|---|---|---|
| - | 5.78 | 11.3 | 12.7 | 24.7 | 14.5 | 28.2 | 0.740 | 6.12 |
| 200 | 5.30 | 10.3 | 15.4 | 30.0 | 17.4 | 33.9 | 0.750 | 6.12 |
| 250 | 4.90 | 9.5 | 16.3 | 31.7 | 18.2 | 35.4 | 0.760 | 6.13 |
| 300 | 4.65 | 9.1 | 16.6 | 32.3 | 19.2 | 37.4 | 0.767 | 6.12 |
| 350 | 4.35 | 8.5 | 16.6 | 32.3 | 19.0 | 37.0 | 0.770 | 6.13 |
| 400 | 4.00 | 7.8 | 15.6 | 30.3 | 18.5 | 36.0 | 0.765 | 6.14 |
| 450 | 2.85 | 5.5 | 15.3 | 29.8 | 18.2 | 35.4 | 0.770 | 6.14 |

Table 3 Results for the 302 stainless steel springs

The spring rate increased slightly as the LTHT temperature was increased despite the outside diameter increasing. This is because the torsional modulus, G, increases with the heat treatment temperature, as shown in the European Standard for stainless steel spring wire, EN 10270-3.

Load/ deflection graphs for a stainless steel spring, heat treated at 350°C, loaded until it had lost 0.1N is shown in figure 5, and the same spring until it had lost 1.2N in figure 6.

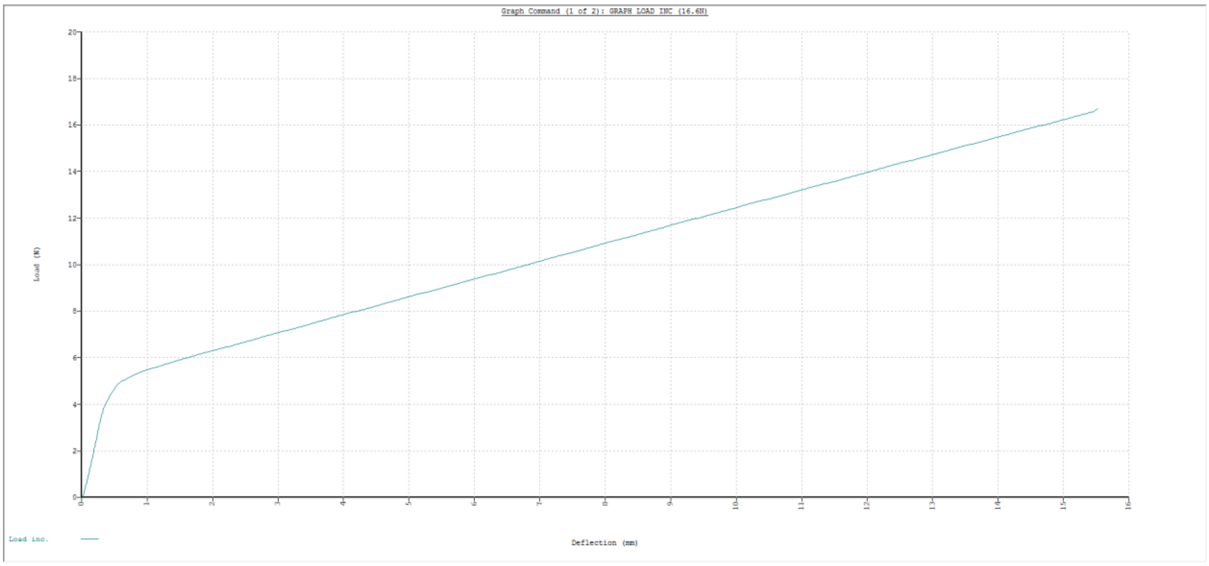


Figure 5 Load/Deflection characteristic of a stainless steel spring loaded to its elastic limit of 16.6N or 640MPa, equivalent to 32.3% of the wire tensile strength.

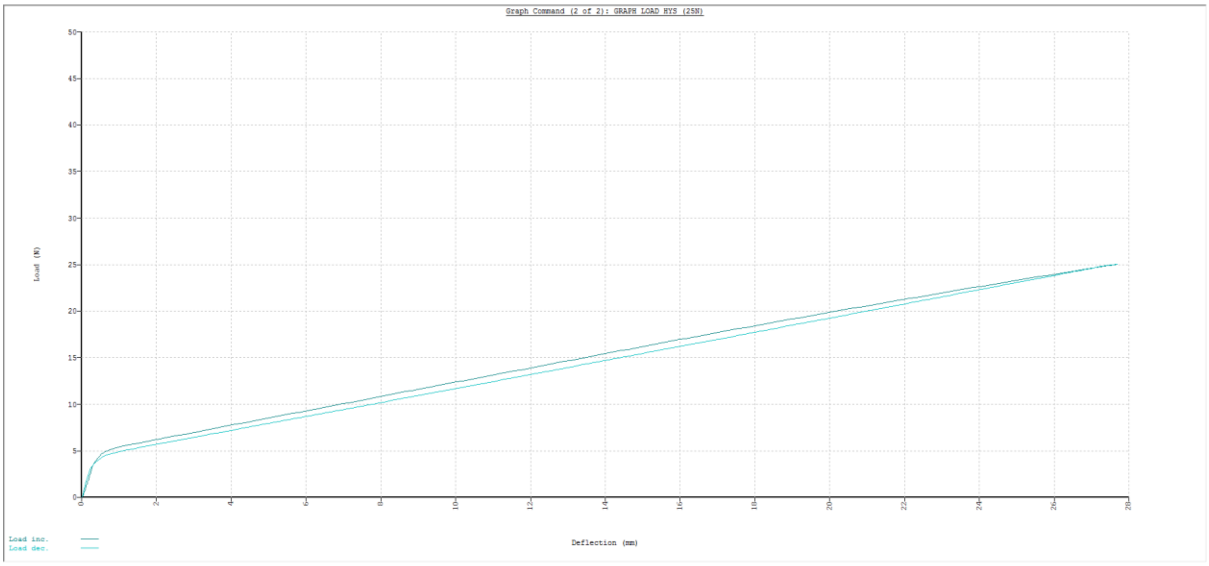


Figure 6 Load / Deflection characteristic in the loading and unloading direction for the same spring as in figure 5. It had been loaded to 25N, which equates to 48% of the wire tensile strength – it had lost more than 1.2N on first application of load, which was manifest as a loss of initial tension mostly, but there was also a small permanent elongation of the hooks.

Conclusion

It is reasonable to define the elastic limit of extension springs as the deflection at which more load is lost than the calculated repeatability of load tests, which in this case, was 0.1N. Hence the elastic limit of carbon steel extension springs, heat treated at between 200 and 250°C, would be 41% of Rm. If the elastic limit allows for a loss of load of 0.2N in 28N, then the elastic limit would be approximately 44% of Rm. Both these values are below 45%, which is the value given in EN 13906-2. The effect of heat treatment temperature on the initial tension and elastic limit is shown in figure 7.

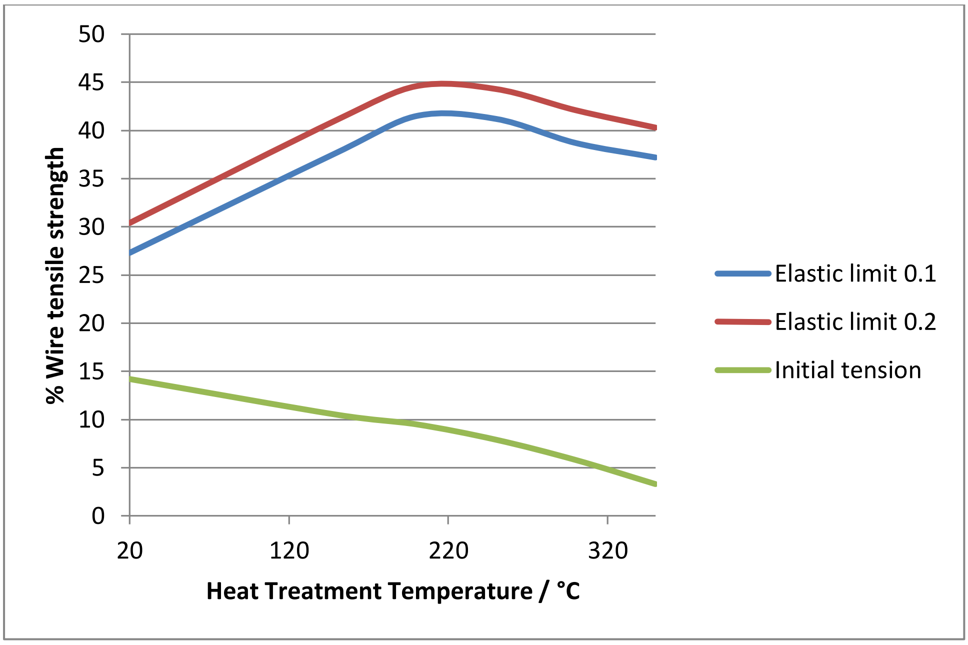


Figure 7 Effect of temperature on initial tension and elastic limit of carbon steel extension springs

The elastic limit of stainless steel extension springs is much lower than for carbon steel. A limit of 32% of Rm would be recommended for high precision springs and 37% for commercial quality springs. Furthermore, a LTHT temperature after coiling of 300 – 350°C would be recommended to retain initial tension, and to simultaneously maximise elastic limit, shown in figure 8.

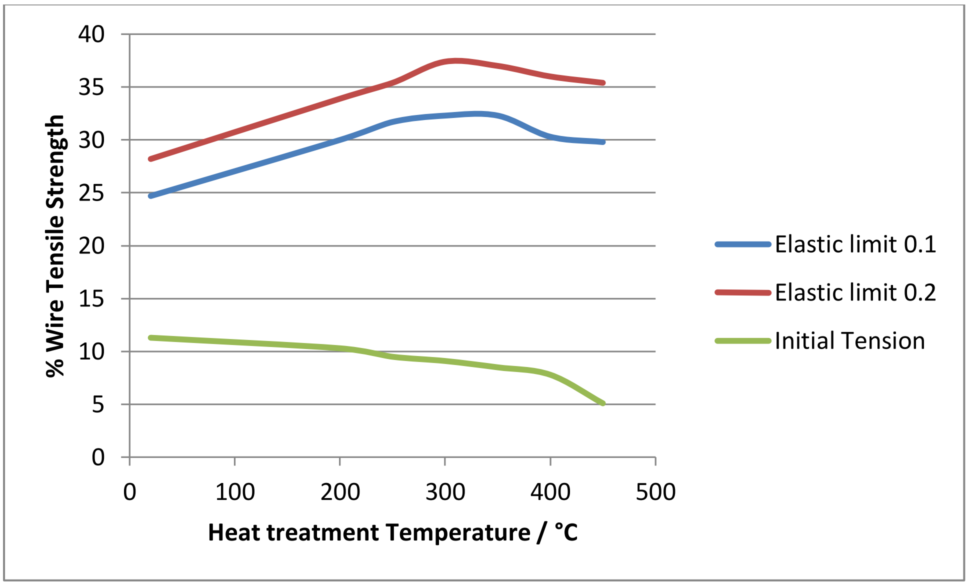


Figure 8 Effect of temperature on initial tension and elastic limit of stainless steel extension springs

References


1. Spring Expert www.springexpert.co.uk
2. Advanex www.advanex.co.uk
3. Spring Calculator Professional design software supplied by IST www.springcalculator.com
4. Institute of Spring Technology www.ist.org.uk