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PROPERTIES OF TORSION SPRINGS BEFORE AND AFTER HEAT TREATMENT

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ABSTRACT

Actual the members of the research group „Wire and Springs“ research the heat treatment on cold-formed springs made from spring steel wire [1][3]. Torsion springs e.g. are one investigation object.

The heat treatment after the cold shaping is used to decrease the internal stresses of torsion springs, but the mechanical characteristics of the spring steel wires alters, too. 8 batches of different test torsion springs are produced. Parameters varied are torsion spring fabrication (coiled around a mandrel or wounded with coil pins), spring index (w = 5/10) and the sequence of the production steps: heat treatment (250°C/30min) before or after cold-shaping.

The spring and wire properties (mechanical characteristics, geometry, residual stresses, yield stress 0.01%) are measured before and after heat treatment.

The tensile strength R_m and yield strength $R_{p0,2}$ rise because of heat treatment up to 200°C (strain aging), but decrease after heat treatments with temperatures more than 200°C. The spring diameter is reduced because of the heat treatment of the torsion springs. A heat treatment period of 5minutes only changes the geometry clearly.

The residual stresses in a torsion spring as a result of the cold forming are directly beneficial, if the spring is used in closing direction. The residual stresses concur with the **half** difference of yield stresses in opening and closing operation of these torsion springs. Heat treatment after cold forming leads to a higher yield stress of torsion springs operated in closing direction in spite of beneficial directed residual stresses.

The strain aging (age hardening) and the reduction of the residual stresses are two contrary processes. Because of the beneficial effect of the residual stresses the reduction of it leads to a decrease of yield stress of the torsion springs in closing operation.

Index Terms –torsion spring, heat treatment, residual stress, yield stress

1. INTRODUCTION

Torsion springs are usually made of spring steel wire. Large residual stresses remains in the wire of the spring after cold forming process. The residual stresses reduce the yield stress (elastic limit) of the spring. Therefore, a heat treatment after the cold shaping is used to decrease the internal stresses of torsion springs. However, this heat treatment also alters the mechanical characteristics of the spring steel wires.

This article shows the variation of the mechanical properties of the wire and the residual stresses in the torsion springs by various heat treatments, and as a result, the properties of the spring can be influenced. Eight different batches of torsion springs are tested.

2. DESCRIPTION OF THE TEST TORSION SPRINGS

There are two manufacturing processes for producing torsion springs: coiling around a mandrel or winding with coil pins. Because of the different production the position of the neutral axis varies. This affects the residual stresses. For this reason the function of the springs varies.

The residual stresses in a torsion spring as a result of the cold forming are directly beneficial, if the spring is used in closing direction only. Is in this case a heat treatment needful or not?

To answer this question, the torsion springs have been produced from already heat treated wire and their properties compared to the springs which have been heat-treated after the cold forming. The heat treatment of the wire before cold-shaping is required to vary the mechanical properties of the wire because of heat aging (strain aging). Furthermore the internal stresses in the wire as a result of the wire drawing process are reduced.

8 batches of different test torsion springs are produced:

- Torsion spring fabrication: coiled around a mandrel or wounded with coil pins,
- Spring index: w = 5 or 10,
- Sequence of the production steps: torsion springs made from wire heat treated (250°C/30min) before cold-forming or made from wire as supplied heat treated after cold-shaping (250°C/30min) as a spring.

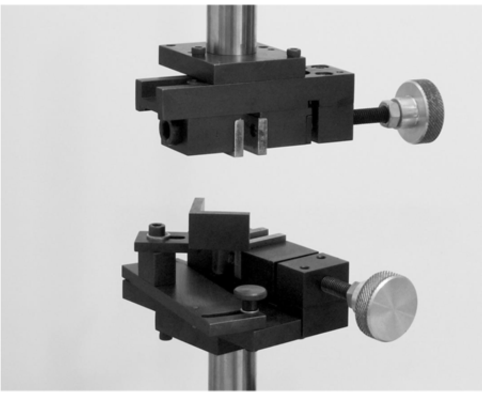
The spring index influences the value of the residual stresses remaining in the spring after cold forming. The full combination of these 3 parameters (torsion spring fabrication, spring index and sequence of the production steps) gives 8 different spring batches. The torsion springs are made from patented drawn spring steel wire (SH) with wire diameter d = 3 mm. The legs of the torsion springs are tangential legs and the springs have a distance between coils because of low friction in function.

3. INVESTIGATION PROCEDURE OF WIRE AND TORSION SPRINGS

The studies investigate the effects of heat treatment to the "spring body" (the coils) only due to the large variety of torsion spring legs. The spring and wire properties are measured before and after heat treatment. The investigation steps are:

- Determination of the spring outer diameter and the leg angle of torsion spring from each batch,
- Determination of the residual stresses (main normal stress) using a x-ray-diffractometer,
- Determination of the torsion moment - rotating angle - characteristic curve up to the plastic range (**pic.1**),
- Determination of the yield stress (plastic deformation 0.01% and 0.05%),
- Tensile tests on different heat-treated wires,
- Different heat treatments of the torsion spring batches,
- Determination of the spring outer diameter and leg angle of the heat-treated springs from each batch
- Determination of the residual stresses (main normal stress) after heat treatment,
- Determination of the torsion moment - rotating angle - characteristic curve of the heat-treated springs up to the plastic range,
- Determination of the yield stress (plastic deformation 0.01% and 0.05%),
- Evaluation.

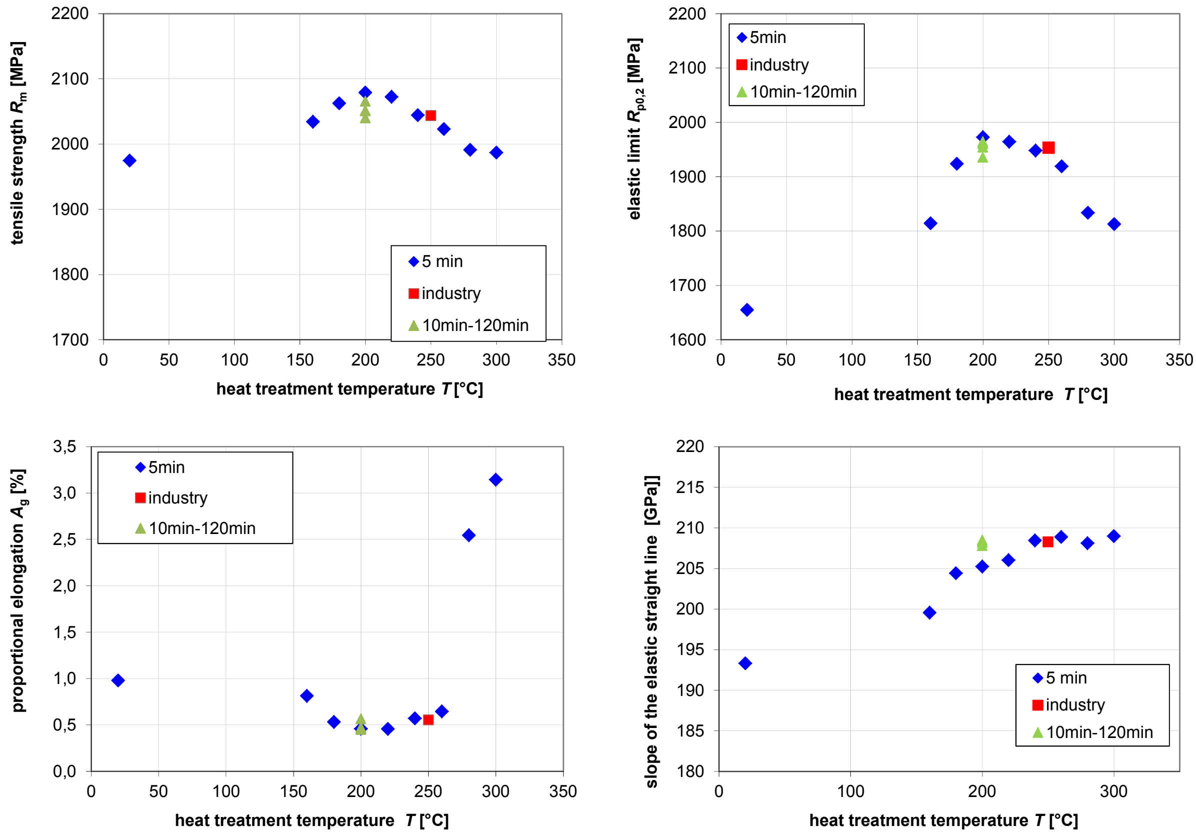
Yield stress is the value of the stress when the plastic deformation of the spring comes up to 0.01% (experiments with loading and releasing of the torsion spring). The values of the yield stress are calculated with the linear-elastic deformation theory for bending in spite of the plastic deformation of 0.01%. That`s why the stress values are very large sometimes.



Pic. 1: equipment for determination of the torsion moment - rotating angle - characteristic curve of torsion springs

4. TENSILE TEST

The tensile strength R_m and yield strength $R_{p0,2}$ rise because of heat treatment up to 200°C (strain aging) (Pic. 2). R_m and $R_{p0,2}$ decrease after heat treatments with temperatures more than 200°C. The elongation before reduction of area A_g (proportional elongation) decreases slightly with increasing heat treatment temperatures at first and rises clearly after a heat treatment with 280°C or more.



Pic. 2: results of tensile tests on wires with different heat treatments

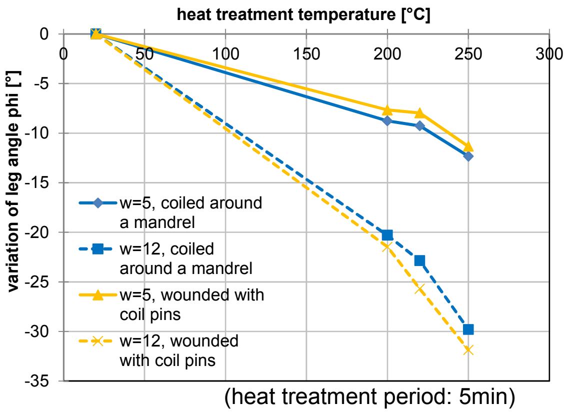
industry: heat treatment 250°C/30min in an industrial furnace (red rectangle) in the manner common for this sector of industry,
200°C: heat treatment period varies: 10 / 30 / 60 /120 min (green triangles)

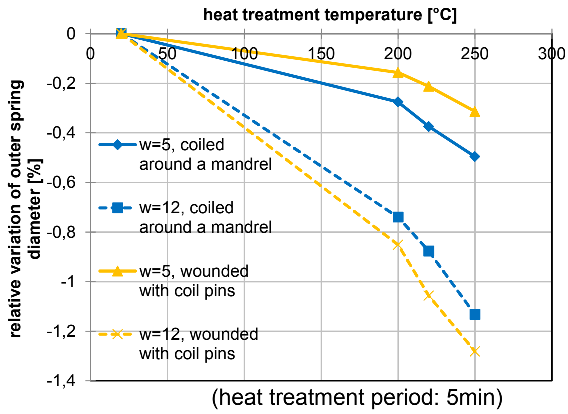
5. EFFECT OF HEAT TREATMENT TO THE TORSION SPRING GEOMETRY

The spring diameter is reduced because of the heat treatment of the torsion springs. That`s why the angle between the legs φ is varied. **Pic. 3** and **pic.4** show the variation of the leg angles and the outer spring diameter caused by a 5minutes heat treatment with different temperatures.

Pic. 5 shows the effect of the heat treatment period with temperatures of 200°C (blue lines) or 250°C (red lines) to the diameter of the spring. Even heat treatment period of five minutes changes the spring diameter because of the decrease of the residual stresses. Heat treatments of more than 30 minutes do not lead to more changes of the diameter of the springs or the residual stresses.

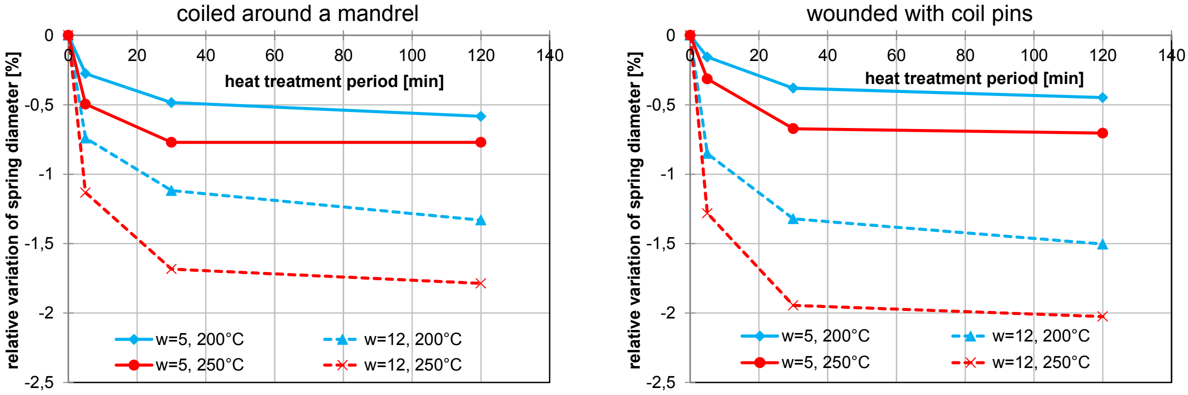
The relative change of spring diameter depends on the spring index.





Pic. 3: variation of the leg angle;
parameter: temperature of the heat treatment after forming

Pic. 4: relative variation of the outer spring diameter;
parameter: temperature of the heat treatment after forming

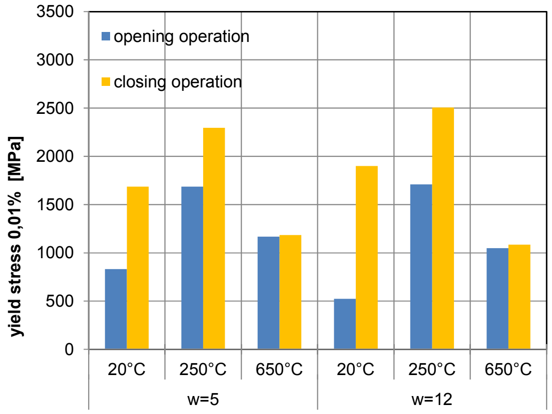


Pic. 5: decrease of spring diameter caused by heat treatment
parameter: torsion spring fabrication, spring index, heat treatment temperature

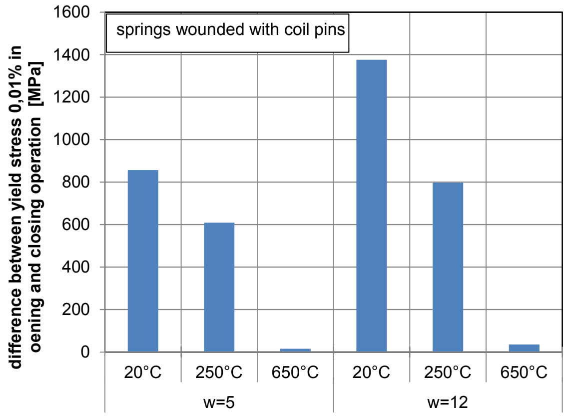
6. EFFECT OF HEAT TREATMENT TO THE TORSION SPRING FUNCTION

6.1 Comparison of operation in closing and opening direction [2]

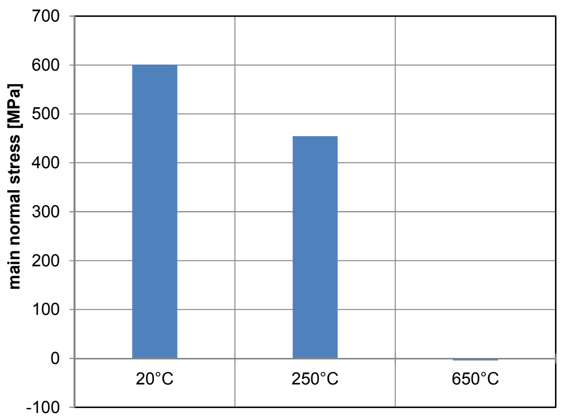
The residual stresses in a torsion spring as a result of the cold forming are directly beneficial, if the spring is used in closing direction. That`s why the yield stress determined in closing operation is larger than in opening operation (**pic. 5**). **Pic. 7** shows the difference between the yield stresses determined in closing and opening operation. The residual stresses determined as main normal stresses (**pic. 8**) concur with the **half** difference of yield stresses in opening and closing operation of these torsion springs.



Pic. 6: Yield stress ($\sigma_{0,01\%}$) of opening or closing operation (coiled springs) (heat treatments: 250°C/30min or 650°C/60min)

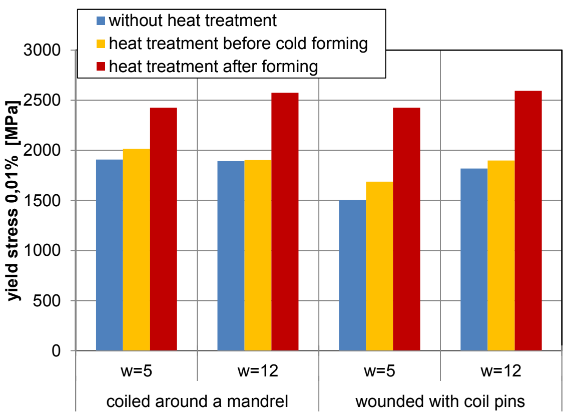


Pic. 7: Difference between yield stress ($\sigma_{0,01\%}$) of opening and closing operation (coiled springs)



Pic. 8: Main normal stress on the inner side of a coiled spring (w=12) after different heat treatments

6.2 Effect of sequence of the production steps [2]

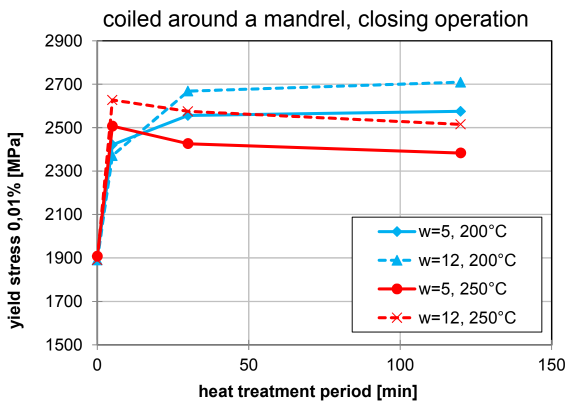


Pic. 9: Effect of heat treatment 250°C/30min before or after cold forming to the yield stress in closing operation direction

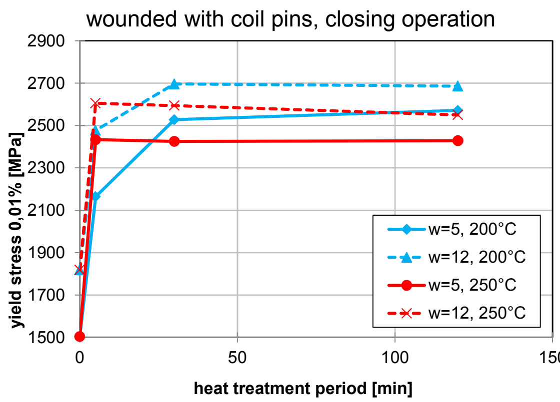
Pic. 9 contain the comparison of torsion springs made from wire heat treated (250°C/30min) before cold-forming or made from wire as supplied. Heat treatment after cold forming leads to a higher yield stress of torsion springs operated in closing direction in spite of beneficial directed residual stresses. This means that the production sequence "cold-forming", then "heat treatment" is also applicable for closing operated torsion springs for the highest possible loading up to 0,01% plastic deformation (yield stress).

Because of the cold shaping the yield strength $R_{p0,2}$ reduce clearly. The heat treatment process after cold forming leads to a significant rise of the yield strength $R_{p0,2}$ and that´s why the torsion moment - rotating angle - characteristic curve of the torsion springs has a larger elastic range and therefore the yield stress of the springs increases.

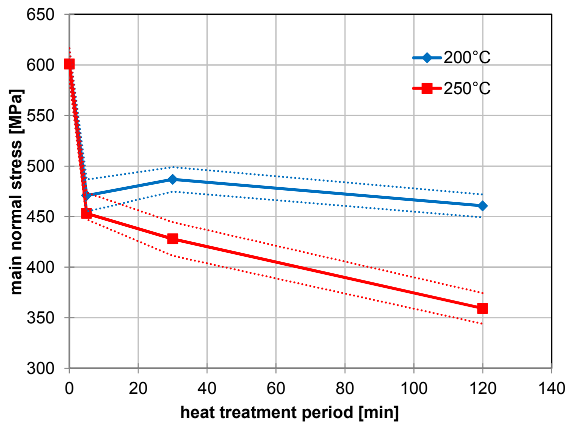
6.3 Effect of heat treatment period and temperature [2]



Pic. 10: Effect of heat treatment to the yield stress of torsion springs coiled around a mandrel operated in closing direction with different spring index



Pic. 11: Effect of heat treatment to the yield stress of torsion springs wounded with coil pins operated in closing direction with different spring index



Pic. 12: Main normal stress and its tolerance (broken line) of wounded torsion springs with w=12 after different heat treatments

The yield stresses measured at the different torsion springs are influenced by the heat treatment. **Pic. 10** and **pic. 11** show the yield stresses in closing operation of different torsion springs after various heat treatments. The period and the temperatures of the heat treatments vary. The torsion spring fabrication diversifies.

The yield stresses increases significantly by the heat treatment generally (in the contemplated temperature range). This is due to the strain aging in the wire. This process is very fast. After a heat treatment period of five minutes only, a significant increase in the yield stresses is recorded. The rise of the yield stress is larger after a five minutes heat treatment with 250°C than a five minutes heat treatment with 200°C. The rate of aging increases with increasing temperature.

If the heat treatment process is longer than five minutes two different effects are to be seen: The strain aging (age hardening) and the reduction of the residual stresses are two contrary processes. Because of the beneficial effect of the residual stresses the reduction of it leads to a decrease of yield stress of the torsion springs in closing operation.

The torsion springs, five-minutes-heat-treated at 250°C, age faster and therefore their yield stress is higher than the yield stress of springs five-minutes-heat-treated at 200°C. With increasing tempering time, the beneficial directed inertial stresses are degraded more after a heat treatment with 250°C than after a heat treatment with 200°C (**pic. 12**). The effect of the different heat treatments to the main normal stresses measured by x-ray-diffractometer is to be seen in **pic. 12**.

The aging of the torsion springs heat-treated with 200°C continues with the heat treatment period. Therefore the yield stress of the springs after a 30-minutes heat treatment with 200°C is larger than after a five-minutes-heat treatment. The beneficial-directed inertial stresses are reduced less than after a heat treatment with higher temperatures.

7. ACKNOWLEDGMENT

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