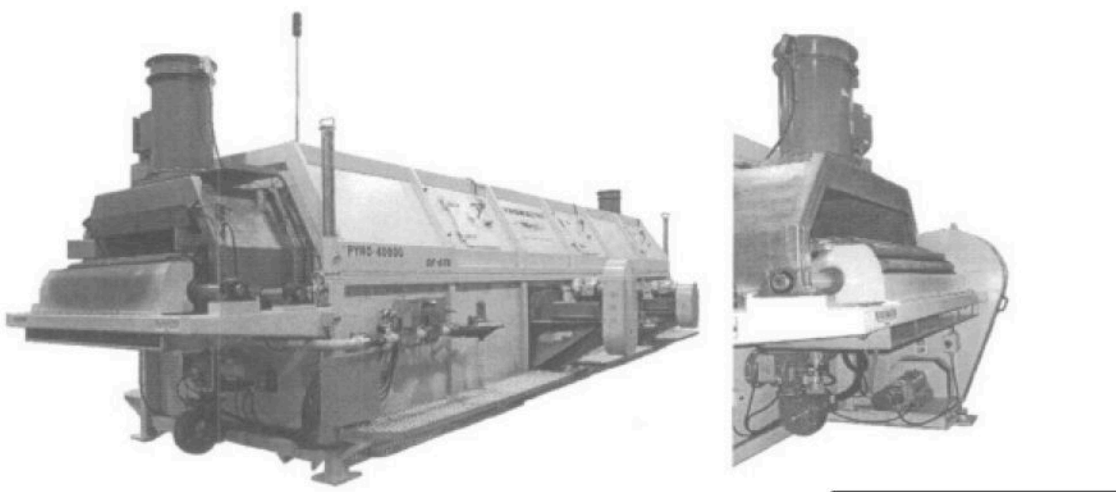
Report on the trials [redacted]

Day of visit: March 26, 2002

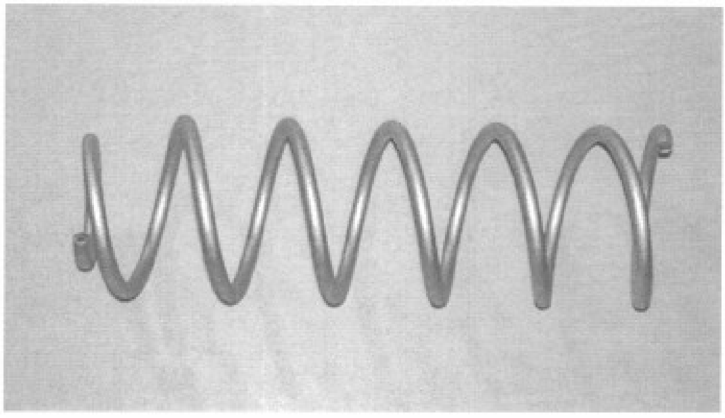
We met: [redacted] process engineer [redacted]

In order to assess the heat treatment result of a Pyro-furnace we visited [redacted] plant. Approximately two years ago [redacted] purchased one Pyro-furnace for suspension springs and carried out several test programs. On the [redacted] side [redacted] was in charge of these tests. The Pyro-furnace has a length of approx. 12 m which are divided into two heating zones with individual temperature setting. The conveyor chain has a width of 1,2 m. [redacted] owns and runs 4 other Pyro-stoves in a hardening process of gear-type parts in the [redacted]-plant and is very content with their reliability and running behaviour.

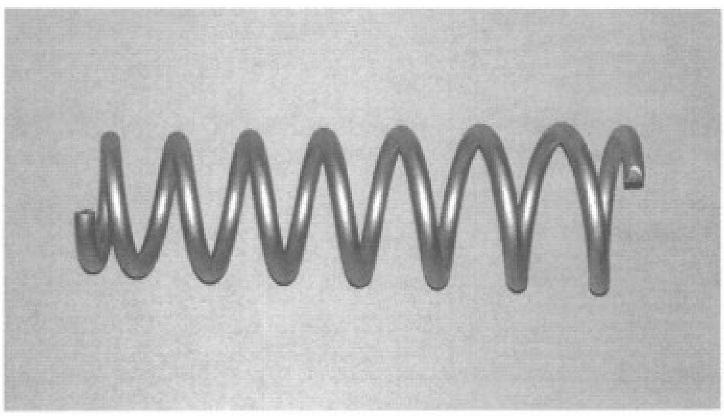


Pyro-furnace [redacted]

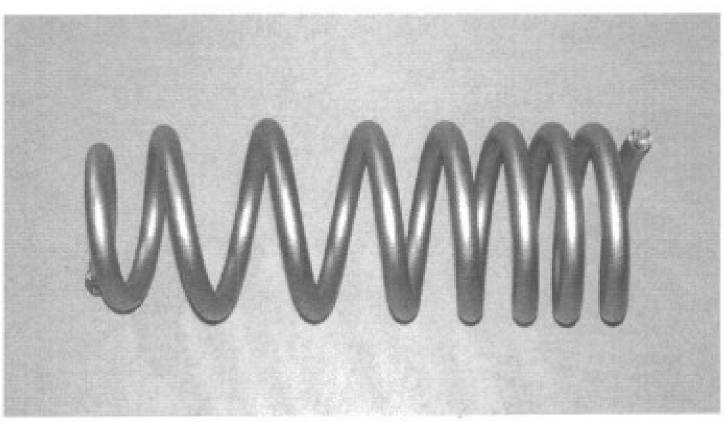
For the trials we chose 3 spring types with different wire diameters and geometries which were currently in production a



[redacted] wire Ø 11,2 mm



[redacted] wire Ø 13,7 mm



[redacted] wire Ø 16,0 mm

Our trials included the following steps:

- Wind 40 springs of each type in the night shift from March 25 to 26.
- Mark and measure length and end angle of each spring.

- Take 10 springs of each type to [redacted] plant on March 26 and do stress relief heat treatment in the Pyro-furnace at noon. With the remaining 30 springs of each type do stress relief heat treatment in a COMPETITOR furnace at Mubea Inc., also at noon. Run 0,6 m long wire pieces through both stoves for later tensile strength tests. Monitor the temperature curves of both stoves with a DATAPAQ-system.
- Measure length and end angle of each spring after heat treatment to quantify the effect of stress relief on the geometry (done at Mubea Inc.).
- Preset 3 springs of each type once, twice and 5 times and measure length and end angle after each loading sequence to determine the loss in length (done at Mubea Inc.).
- Carry out tensile strength tests to determine, whether the heat treatment harmed the material stability (done at IT Spring Wire).
- Carry out a residual stress analysis on one spring of each type for both Pyro and COMPETITOR heat treatment (done at [redacted]).

Temperature curves

The temperature measurements were carried out with a DATAPAQ system to which 3 sensors were connected. The first sensor monitored the air temperature inside the furnace, the 2nd and 3rd were brazed into the core of wire pieces, one with a diameter of a 16,3 mm, the other with a diameter of 10,6 mm.

The COMPETITOR furnace comprises 4 different temperature zones which were set to 410/390/390/390 °C. The target wire temperature of 390 °C was reached after a heat treatment time of approx. 17 minutes. For the large wire diameter 16,3 mm a temperature level of 350 °C was exceeded after 9,2 minutes (see chart 1).

The Pyro-furnace comprises only 2 temperature zones which were set to 450/430 °C. As a result of the higher setting values and the higher air velocities the target of 390 °C was reached after only 7 minutes. For the large wire diameter 16,3 mm a temperature level of 350 °C was exceeded after 5,2 minutes (-43% compared with the COMPETITOR result, chart 2).

It took two trials to determine the right pair of setting temperatures of the Pyromaître furnace (trials 1 and 2, not documented here). Trial 3 was carried out before and trial 4 directly after the heat treatment of the samples. Chart 3 compares the curves of the COMPETITOR and the Pyromaître furnace for the 16,3 mm wire. Besides the shorter heat transfer time of the Pyro-stove, a slight drop of temperature from trial 3 to trial 4, caused by the processed material, becomes visible.

Chart 1: Temperature curves of the COMPETITOR-furnace

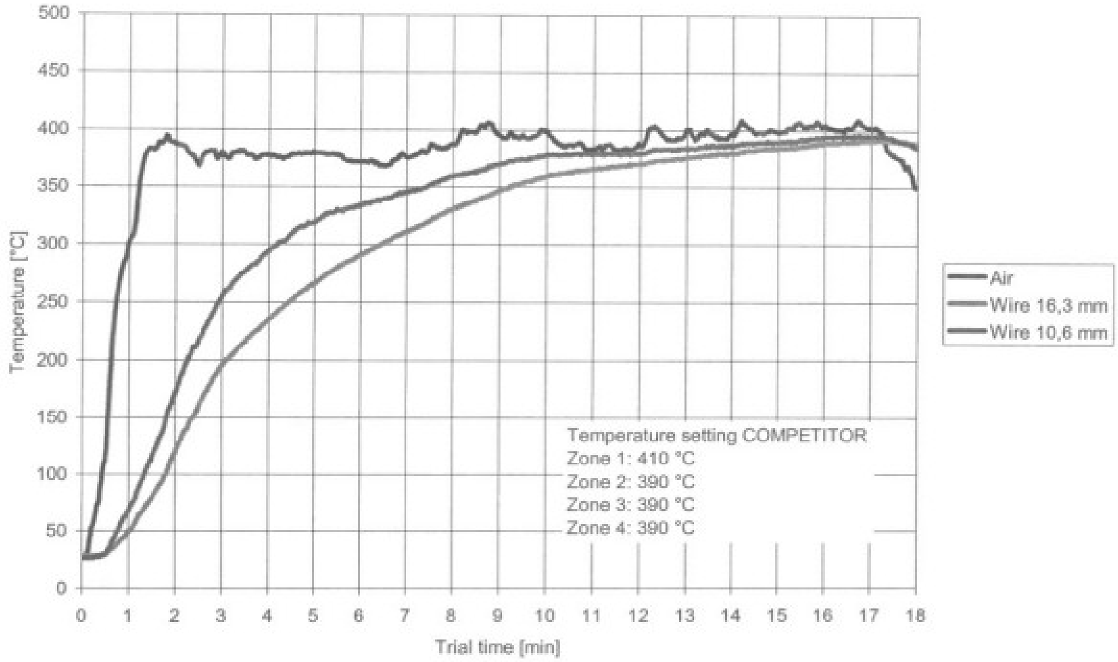


Chart 2: Temperature curves of the Pyromaître-furnace (trial 3)

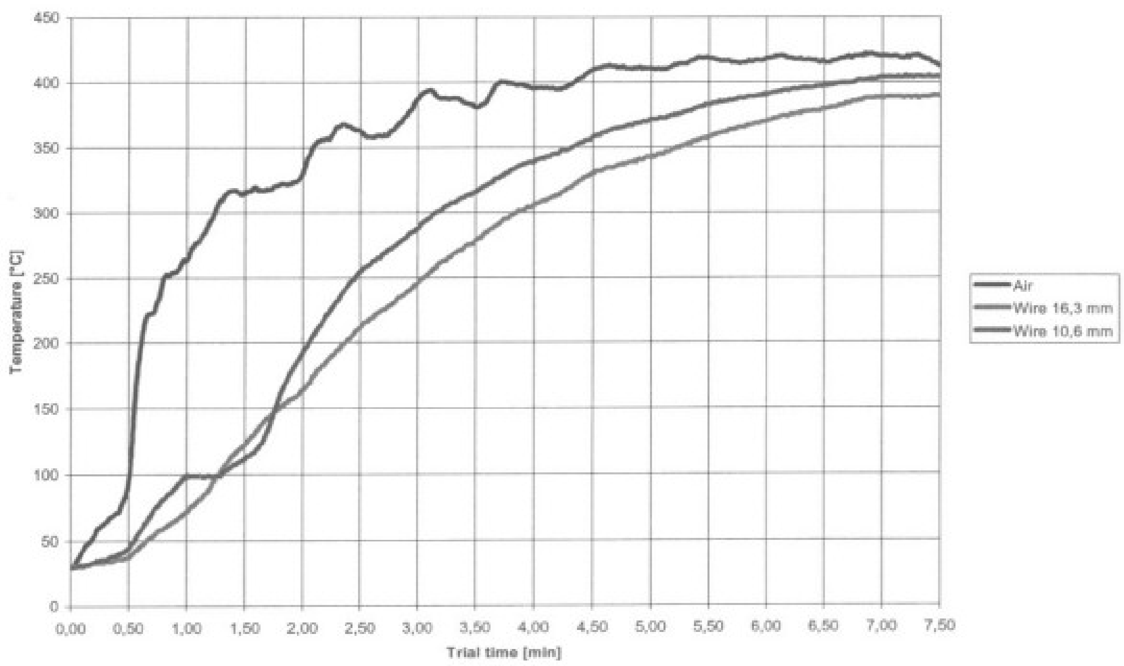
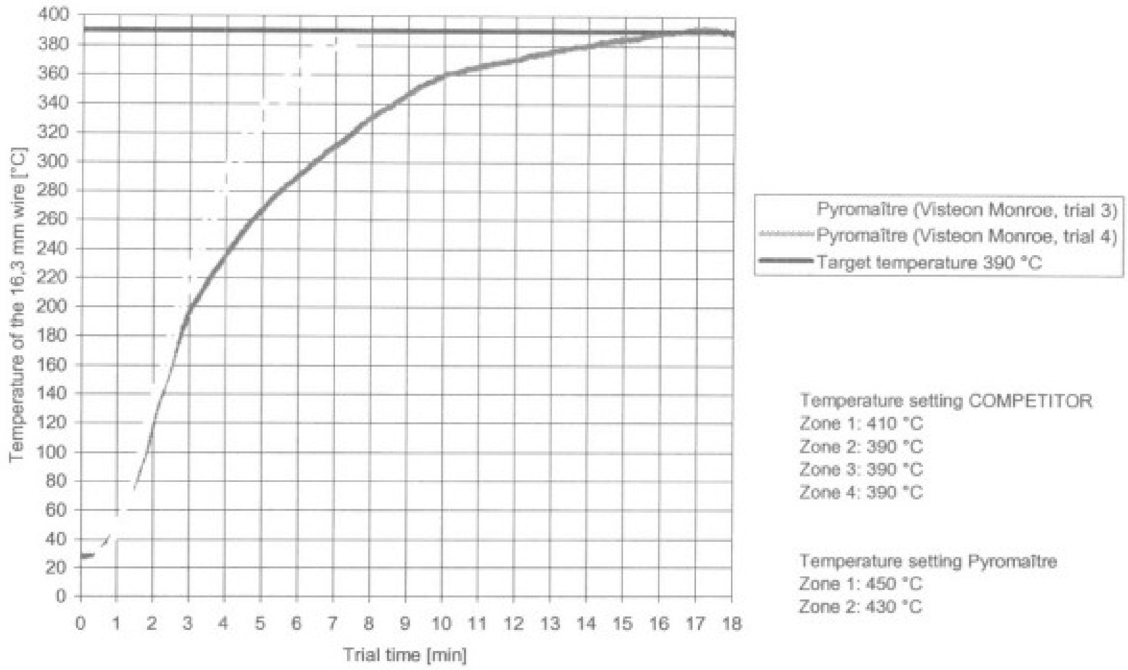


Chart 3: Temperature comparison for the 16,3 mm wire



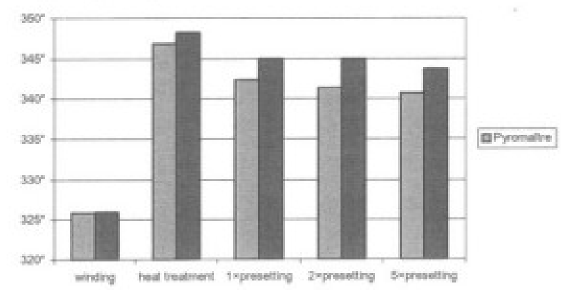
Geometrical analysis

In order to make the impact of the different heat treatments on the spring geometry visible, the spring length and the angle between both wire ends ("end angle") were recorded after each step of the trials. The diagrams show the average values for the analysed three spring types:

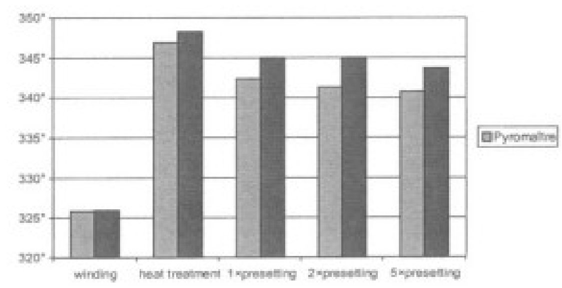
- Winding and heat Treatment – Pyromaître: 10 samples, COMPETITOR: 30 samples of each spring type.
- Presetting – both Pyromaître and COMPETITOR: 3 samples of each spring type.

UB 152 BD

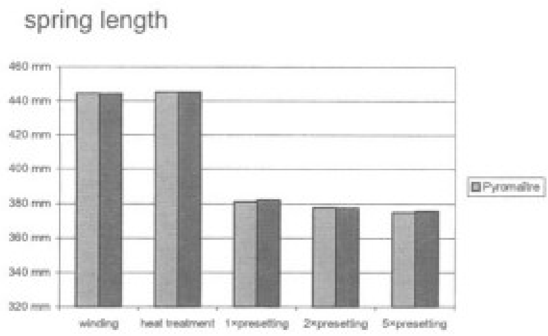
spring length

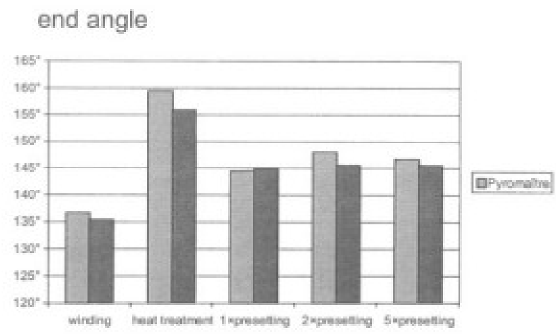


end angle

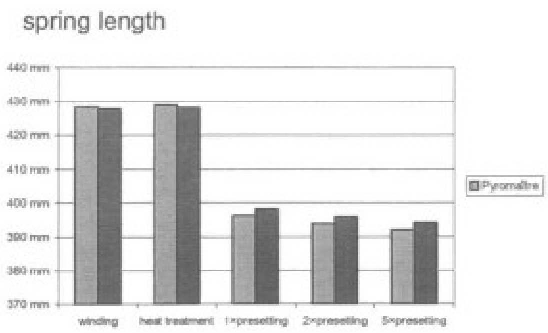


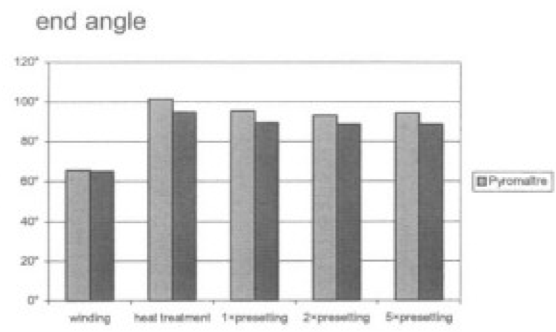
[redacted]





[redacted]





While in both heat treatments – Pyromaître and COMPETITOR – the lengths of the springs appeared to remain the same, the end angles increased by an almost constant value of approx. 20°. During the first presetting sequence, depending on the spring type, the springs lost between 8 and 15% of their initial length. The following presettings caused almost no further loss in length.

In all trials the differences of the two heat treatment approaches (compare the blue versus the pink bars) remained to be fairly small.

For the whole set the standard deviation of the measurement results remained below 3% of the average value, in most cases actually below 1%! The reliability of the results seems to be sufficient.

Residual stress analysis

The residual stress analysis was carried out for the two spring types with the small and the large wire diameter ([redacted] at 11,3 mm and U 152 BD at 16,0 mm). In the trials with both furnaces the characteristic drop of residual tensile stress by 400 N/mm² (from approx. 800 N/mm² down to 400 N/mm²) was achieved. The differences of the determined values were very small.

Residual Stress Analysis

Date: 17.04.02
In charge: [redacted]
Done by: Gü / WN

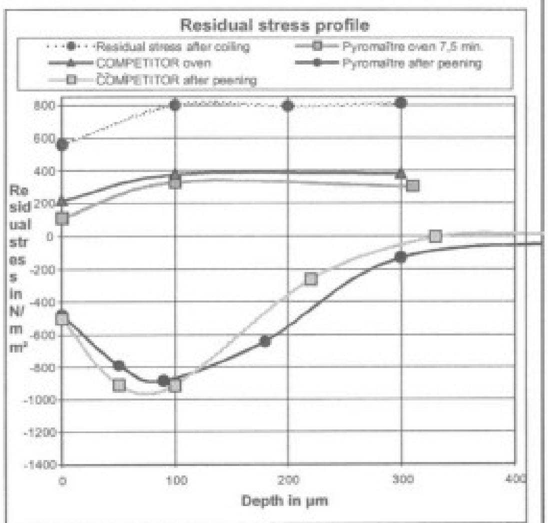
Project: Residual stress analysis
Part: [redacted]
Charge:
Material: [redacted]
Wire 11,3 mm
Class "C"

Nr. 1	Nr. 2	Nr. 3	Nr. 4	Nr. 5	
Residual stress after coiling	Pyromaître oven 7,5 min. target 390°C	COMP. oven 20 min. target 390°C	Pyromaître after peening	COMP. after peening	

Test: Residual stress profile
Test angle - 45°

Remark: Comparison of the heat treatment in a COMPETITOR and a Pyromaître

	Surface	Depth 1	Depth 2	Depth 3	Depth 4	Depth 5
Nr.1						
Depth	0	100	200	300		
Value	560	801	794	812		
Nr.2						
Depth	0	100	310			
Value	113	331	304			
Nr.3						
Depth	0	100	300			
Value	220	378	382			
Nr.4						
Depth	0	50	90	180	300	490
Value	-476	-784	-882	-640	-129	-28
Nr.5						
Depth	0	50	100	220	330	430
Value	-500	-908	-911	-262	-4	17



Result of the spring [redacted] (11,3 mm wire)

Residual Stress Analysis

Date: 17.04.02
In charge: Höhne
Done by: Gü / WN

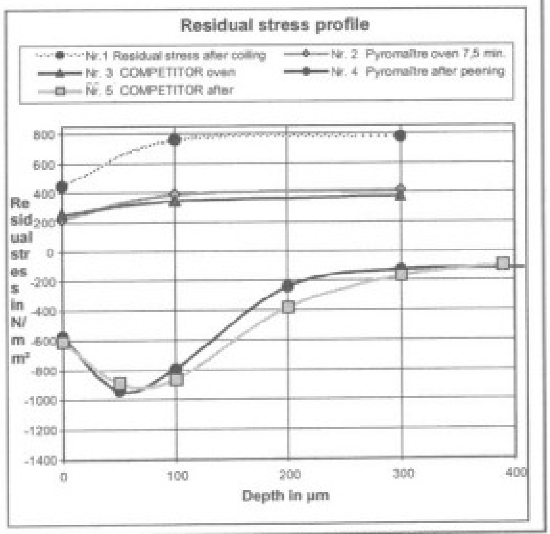
Project: Residual stress analysis
Part: [redacted]
Charge:
Material [redacted]
Wire 16,0 mm
Class "C"
Lieferant:
Kunde:

Nr. 1	Nr. 2	Nr. 3	Nr. 4	Nr. 5	
Residual stress after coiling	Pyromaître oven 7,5 min. target 390°C	COMP. oven 20 min. target 390°C	Pyromaître after peening	COMP. after peening	

Test: Residual stress profile
Test angle - 45°

Remark: Comparison of the heat treatment in a COMPETITOR and a Pyromaître

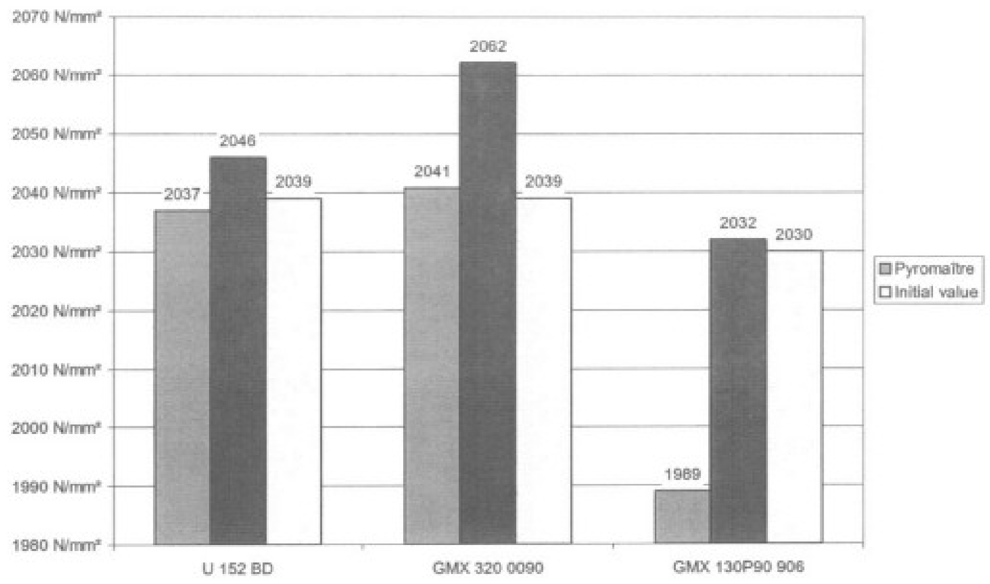
	Surface	Depth 1	Depth 2	Depth 3	Depth 4	Depth 5
Nr.1						
Depth	0	100	300			
Value	450	760	780			
Nr.2						
Depth	0	100	300			
Value	225	387	414			
Nr.3						
Depth	0	100	300			
Value	255	343	377			
Nr.4						
Depth	0	50	100	200	300	410
Value	-572	-939	-792	-240	-124	-113
Nr.5						
Depth	0	50	100	200	300	390
Value	-610	-887	-863	-381	-166	-93



Result of the spring [redacted] (16,0 mm wire)

Tensile strength analysis

In order to determine the loss of material stability as a result of the heat treatment, wire pieces were analysed in a tensile strength test (Initial value: 1 sample, Pyro: 4 samples, COMPETITOR: 5 samples). All COMPETITOR-samples appeared with a slight increase in strength (+0,1%...+1,1%). Within the Pyro samples, the springs with the larger wire diameters ([redacted] and [redacted]) remained at the initial strength level (±0,1%) whilst the [redacted] springs lost 2% of their initial strength. Obviously, the temperature level of the Pyro-furnace had been to high for the fine wire.



Conclusion

The evaluation of the trials at [redacted] and [redacted] can be summarised with the following statements:

1. The geometrical differences of the Pyromaître and COMPETITOR springs in length and end angle were negligibly small.

2. Although the Pyromaître-furnace had a remarkably low process time (7,5 min. compared with 18 min. of the COMPETITOR-furnace) the reduction of residual stresses turned out to be the same.

3. The tensile strength results of all three diameters 11,3 mm, 13,7mm and 16,0 mm showed a slight increase for the COMPETITOR trials. The Pyromaître process caused almost no change of the tensile strength for the 13,7mm and 16 mm wires. In the trial with the 11,2 mm wire the Pyro springs were warmed up slightly above the 400 °C line. This resulted in a loss of material strength (the measurement showed a loss of firmness of 40 MPa). The furnace settings were determined

with a 16,3 mm wire. Obviously, a heat treatment with small process times is more sensitive than the old fashioned way: For the Pyromaître furnace settings have to be adapted to the wire diameter.

4. The measurement of the hardness distribution across the wire cross section revealed no significant difference between the Pyromaître and the COMPETITOR springs.

5. The texture inspection of the polished cross sections also revealed no difference between the Pyromaître and the COMPETITOR springs.

6. The firmness against blocking of the springs was given for both the Pyromaître and the COMPETITOR springs.

7. The differences in lifespan of the springs are still subject to running examinations, which will be completed in May 2002.

The different heat treatment processes for stress relieve (Pyromaître and COMPETITOR) led to approximately same results. The trials gave no hint for technological disadvantages of the Pyro-process.