# Stress Relief

by:
Daniel H. Herring
"The Heat Treat Doctor"®, President
The HERRING GROUP, Inc.
P.O. Box 884
Elmhurst, IL 60126-0884 USA
www.heat-treat-doctor.com

**Stress relief is a simple heat-treating operation for wire products that depends strongly on the proper selection of temperature and time at temperature as well as a proper cooling rate for success.**

Stress relief is one of the most common heat-treating processes used in spring manufacturing. Like any manufacturing step, if not performed properly this simple operation can have disastrous consequences. Drawing, forming and machining induce stresses in all wire products.

These stresses can cause loss of tolerance, cracking and distortion, and contribute to in-service failures. For these reasons, stress relieving is often necessary, and in some cases, mandatory.

A stress relief operation is typically used to remove internal (residual) stresses that have accumulated in the material. The stress relief process is performed by heating in an oven (as seen in **Figure 1**) or furnace to a temperature (for steel wire) below the lower critical temperature ($Ac_1$) and holding at that temperature long enough to achieve the desired reduction in residual stresses.

**Fig. 1 — Typical stress relief oven for wire coils (photo courtesy of Wisconsin Oven).**

The steel is then cooled at a sufficiently slow rate to avoid formation of excessive thermal stresses. No microstructural changes occur during the stress relief process.

In addition to removing stresses, the stress relief process returns the material to a strength level approximately equivalent to where it was prior to forming. Studies have shown[1] that the interstitial elements pin the lattice defects in the atomic structure of the metal, resulting in this increase in mechanical strength.

## Cycle Times

Temperature, time and time at temperature are key process variables (**Table 1**). In general, heating steel to a temperature of about 165°F (75°C) below the transformation temperature ($Ac_1$) for an hour (or until the entire part reaches the temperature), will allow for removal of most internal stresses. Typical temperature ranges are:

- 1025°F to 1200°F (55°C to 650°C) for unalloyed and low-alloy steels.
- 1115°F to 1300°F (600°C to 700°C) for hot-work and high-speed tool steels.

For many alloy steels, little or no stress relief occurs at temperatures less than approximately 500°F (260°C), while approximately 90% of the stress is relieved by 1000°F (540°C). The maximum temperature for stress relief is limited to 55°F (30°C) below the tempering temperature used after quenching from the hardening process. After removing from the furnace or oven, the wire must be cooled in still air. If cooled in any other

**Table 1[2]. Oven Stress Relief Temperatures & Times for Wire.**

| Material | Specification | Temperature °F (°C) | Time [1] (minutes) |
|---|---|---|---|
| | | | |
| Beryllium Copper | ASTM B 134 or ASTM B 197 | 600 (315) | 120 |
| Blue Temper | n/a | 450 (230) | 30 |
| Brass Wire | ASTM B 134 | 375 (190) | 30 |
| Chrome-Silicon | ASTM A 401 or SAE J157 | 700 (370) | 60 |
| Chrome-Silicon (Lifens) | SAE J157 | 725 (385) | 60 |
| Chrome-Vanadium | ASTM A231 | 700 (370) | 60 |
| Galvanized M.B. Class I or II | ASTM A 674 | 450 (230) | 30 |
| Hastaloy C | - | 500 (330) | 30 |
| H.D.M.B Class I or II | ASTM A 227 | 450 (230) | 30 |
| High Tensile Hard Drawn | ASTM A 679 | 450 (230) | 30 |
| Inconel 600 | - | 1200 (650) | 90 |
| Inconel X700 Spring Temper | AMS 5699 | 1200 (650) | 240 |
| Inconel X750/1 Temper | AMS 5699 | 1200 (650) | 240 |
| Monel 400 | - | 800 (425) | 60 |
| | | | |
| Music Wire (tin coated) | ASTM A 288 | 300 (150) | 30 |
| Music Wire (cadmium-zinc coated) | ASTM A 288 | 400 (205) | 30 |
| Music Wire | AMS 5112 | 540 (280) | 60 |
| O.T.M.B. | ASTM A 229 | 450 (230) | 30 |
| Phosphorous Bronze | ASTM B 159 | 375 (190) | 30 |
| (Grade A) | | | |
| 301 Stainless Steel | - | 650 (345) | 30 |
| 302 Stainless Steel | AMS 5688 | 650 (345) | 30 |
| 304 Stainless Steel | ASTM A 313 | 650 (345) | 30 |
| 316 Stainless Steel | ASTM A 313 | 650 (345) | 60 |

manner, stresses are reintroduced into the part.

Note: it is reported[2] that rapid stress-relieving technology reduces total stress relieving time for many materials. For example, tests on 0.630" (16 mm) diameter chrome-silicon wire have shown that time at temperature can be reduced from approximately 60 minutes to 10 minutes or less.

## Process Examples

To completely eliminate residual stresses in helical springs through stress relief, the material must be heated high enough to fully recrystallize. This is not practical in spring manufacturing since the recrystallization process significantly reduces the material's strength and therefore its usefulness in spring applications.

On the other hand, an elevated temperature recovery process (for example, stress relief) can eliminate the majority of residual stresses without significantly deteriorating the material's strength (as seen in **Figure 2**).

The temperature required to accomplish the recovery process depends on the material type and processing history (i.e., carbon steel versus alloy steel, cold drawn versus oil tempered, etc.). Additional recommendations for proper recovery are found in the *SMI Encyclopedia of Spring Design*[3].

In another example[4], stress relief yields maximum mechanical properties in 302 stainless steel wire between 600°F (315°C) and 900°F (480°C). The fatigue properties of the wire are optimum at a stress relief temperature of 1200°F (650°C). However, mechanical properties such as yield strength, modulus of resilience, modulus of toughness and ultimate strength are reduced as much as 30% when compared to similar properties at 600°F (315°C).

Also, the capacity of 302 stainless steel wire to stretch elastically continuously decreases at room temperature as the stress relief temperature is increased beyond 600°F (315°C). Not all springs, however, require stress relief to improve properties. For example, torsion springs loaded in bending are subject to a number of different residual stresses (see **Table 2**) only some of which are harmful.

Other parts that benefit from stress relief are complex shapes, parts with tight dimensional tolerances and machined parts that have had a lot of stock removal performed.

## Dimensional Changes

Stress relief will change spring dimensions as a function of temperature, length of time in the oven and material type. It is important to anticipate these changes so final product specifications are met. In general, the following is true:

- Extension springs: reduction in initial tension; change in hook position; change in spring diameter.
- Compression springs: reduction in initial tension; change in spring diameter.
- Torsion springs: reduction in initial tension; low temperature stabilizes position of ends.

In general, if you change a wire diameter by 1%, the

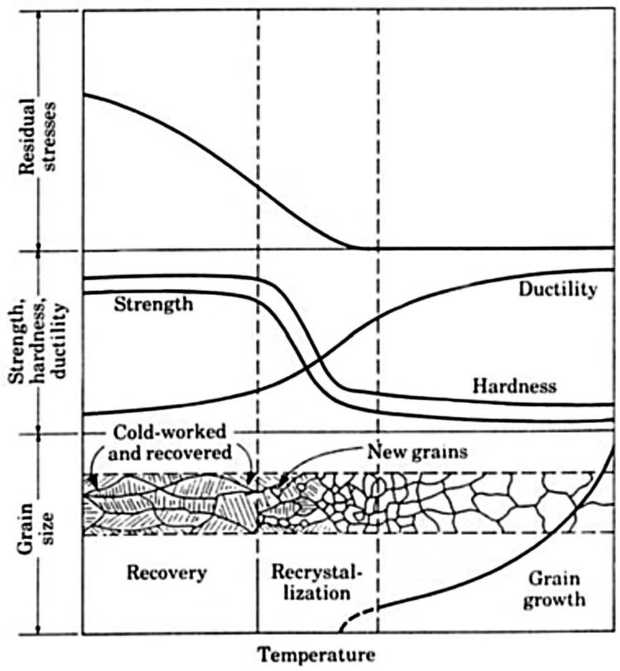


**Fig. 2 — Effects of recovery and recrystallization on grain structure.**

**Table 2[5]. Process Induced Residual Stress Benefits for Torsion Springs.**

| Manufacturing Process | Residual Stress Type | Torsional Load Application | |
|---|---|---|---|
| | | Tighten Coils | Loosen Coils |
| | | | |
| Cold Drawing Wire | Longitudinal and Transverse (Hoop) Tension | Bad on OD | Bad on ID |
| Oil Tempering Wire | Transverse (Hoop) Tension | Negligible | Negligible |
| Coiling | Longitudinal Tension on ID, Longitudinal Compression on OD | Beneficial | Detrimental |
| Grinding | n/a | n/a | n/a |
| Shot Peening | Triaxial Compression | Detrimental if peened on ID, potentially beneficial if peened on OD | |
| Preset | n/a | n/a | n/a |

spring rate will change by 4%. So an increase in wire size by 1% will result in a 4% stronger spring. The converse is also true. A decrease in wire size of 1% will result in a 4% weaker spring. In addition, it is common to see up to a 3% change in torsional stress.

## Corrosion Resistance

Corrosion resistance is another important consideration in certain wire products, especially those constructed of stainless steel. The corrosion resistance in these alloys is primarily a function of stress relief temperature.

Stress relief at temperatures below 750°F (400°C) is an acceptable industry practice, but results in only a modest level of stress reduction. Stress relieving at 800°F to 1700°F (425°C to 925°C) significantly reduces residual stresses that otherwise might lead to stress corrosion cracking or dimensional instability in service. One hour at a temperature of 1600°F (870°C) typically relieves about 85% of the residual stresses. However, stress relieving in this temperature level can also precipitate grain boundary carbides, resulting in sensitization that severely impairs corrosion resistance in many media. To minimize these effects, it is strongly recommended that a stabilized stainless steel (grade 321 or 347) or an extra-low-carbon type (304L or 316L) be used, particularly when a lengthy stress relieving operation is required.

## In Conclusion

Stress relief is a simple heat-treating operation for wire products that depends strongly on the proper selection of temperature and time at temperature for its success. A proper cooling rate is also a surprisingly important factor.

So, the next time that your products need stress relief, be sure that your heat treater fully understands what it is that you are trying to achieve.

*www.heat-treat-doctor.com* **WFTI**

### *References:*


[1] *Bartel, Terry, Heat Treating, SPRINGS, October 2007.*

[2] *Grenier, Mario and Gingras, Roger, Rapid Tempering and Stress Relief Via High-Speed Convection Heating, Industrial Heating, May 2003.*

[3] *Sebastian, D. et al., Fundamentals of Spring Design, SMI, Oak Brook Illinois, 2000, p. SM-5.*

[4] *Bhonsle, S.R. and C.D. Van Karsen, Mechanical and Fatigue Properties of Stress Relieved Type 302 Stainless Steel Wire, Journal of Materials Engineering and Performance, Volume 1, Issue 3, pp. 363-369.*