Cautionary Tales

Part IX Heat Treatment ~ Stress Relief

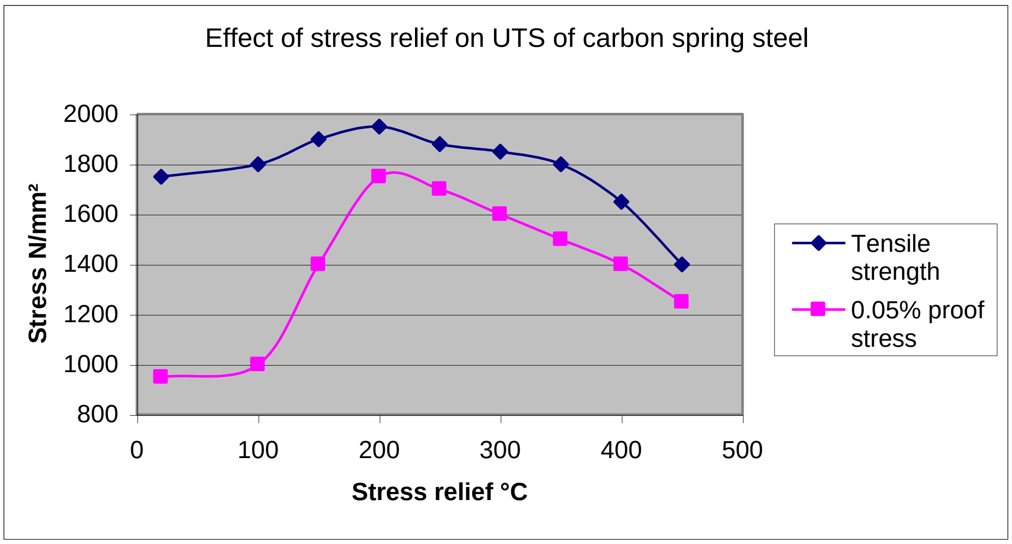
Those of you who read this column regularly, and there are many of you, will notice that this tale has exactly the same title as part VIII, but you will recognise that what I have to say adds to what I said last time, but does not contradict it. This is in response to questions received, and an accusation that I over-simplify. I do indeed over-simplify. My description of strain-age-hardening, dimensional stabilisation and relief of residual stress that happens when drawn carbon steel (ASTM A227) and music wire (ASTM A228) springs are stress relieved is incomplete but correct. I make no apology for keeping these articles relatively simple – *IST*'s aim is to explain in terms that non-metallurgists will understand without explaining fully, but also without compromising the facts.

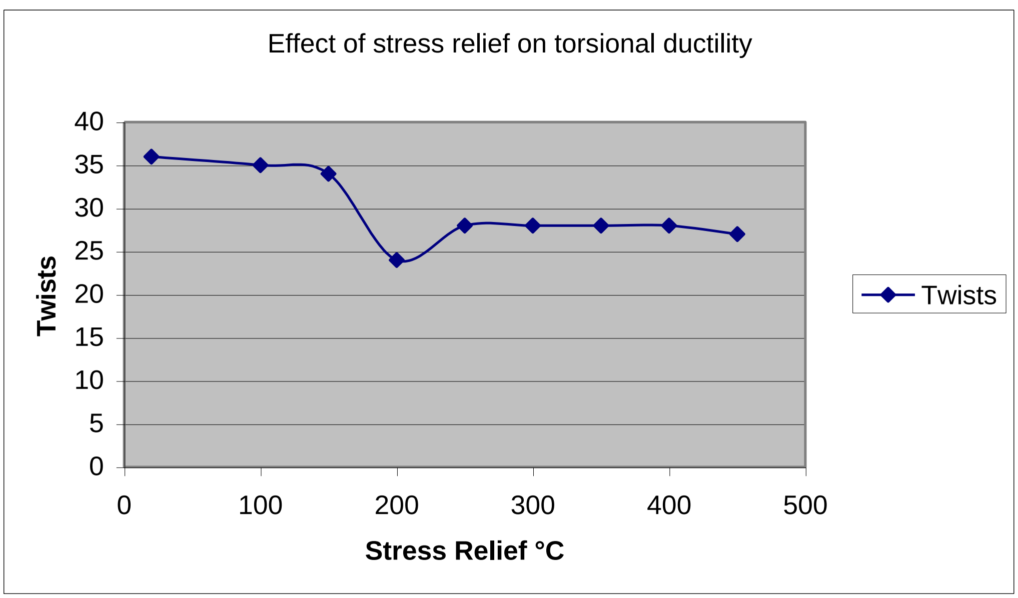
IST recommend that A227 and A228 wire springs are stress relieved after forming within the temperature range 200°C (400°F) and 375°C (700°F). The 200°C minimum is to ensure that the strain age hardening reaction occurs. Strain age hardening is metallurgically complicated – it involves 'blocked carbon atmospheres and the pinning of dislocation movement by decorating glissile dislocations with carbo-nitride precipitates'. This is far from a full explanation, but the important point is that heat treating at any temperature between 200°C and 375°C will cause an increase in the elastic limit of the wire. 375°C is the maximum temperature because at higher temperatures softening will occur, as shown on the attached graph.

200 – 375°C is a very wide temperature range – the temperature control of nearly all spring manufacturers' ovens is good enough to hit this range! One springmaker asked me what he should put on his FMEA sheet about the potential failure modes that could come about if his stress relieving temperature 260°C (500°F) drifted by 20°C. I suggested that the only effect would be a slight change in the outside diameter, but no significant risk arises of failure due to this relatively big change in temperature.

Another enquirer asked about the change in residual or internal stress distribution due to this heat treatment. This is a very complicated subject, which would doubtless benefit from further research, but the residual stresses from wire drawing will be altered by both coiling and heat treatment. However, it is the residual stress at the spring surface resulting from bending springback that is usually most important. At 200°C, about 50% of the residual tensile bending stress at the inside surface of the spring is relieved. This is a temperature often used for stress relieving extension springs (so as to retain as much initial tension as possible) and torsion springs (so as to retain 50% of the residual compressive stress at the outside surface of the spring – the outside surface being the critical surface for a wind-up torsion spring). At 350°C about 90% of the residual tensile bending stress is relieved – note that stress relieving is a good name – the residual stress from forming is seldom, if ever, eliminated completely, it is relieved. This high temperature is not often used but a small, measurable performance benefit is gained by stress relieving compression springs at this temperature rather than 250°C or 300°C.

Finally, it was pointed out that I made no reference to blue brittleness or the ductility trough that occurs when stress relieving A227 or A228 wire at 200°C (400°F), but the Stress/Strain graph implied its existence. The number of twists in a torsion test is a good measure of ductility of spring wire and when plotted against stress relief temperature the graph below can be drawn, which shows minimum ductility, or blue brittleness at 200°C.





Does this brittleness matter? *IST* does not think so, because the stress relief is undertaken after all forming is complete (except prestressing) and springs do not fail due to impact loads alone. Impact loading of a very brittle spring (designed within the usual rules) could result in premature fatigue failure, but not sudden brittle fracture. This fact is just as well because many springmakers employ precisely the temperature that results in blue brittleness in all their springs!

The moral of this cautionary tale is that a full understanding of complicated heat treatment mechanisms is not necessary for establishing a strategy for optimising the stress relief heat treatment of springs.

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