Advances in High-Speed Stress Relief

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Introduction

Advances in high-speed stress-relief in the past two years at Pyro are in two areas: advances in Pyrograph simulation software, and advances in equipment in terms of sizes.

Before I talk about what's new, let me go over some basics about the soak time question. It is very important that the reasons that have governed stress-relief practices since the beginning of the industry, I believe, be well-understood before one attempts making any changes.

A) The Soak-Time Illusion

I say "the soak time illusion" because you will see that it is really an illusion after we go through the following explanations:

Figure 1, page 101, shows standard stress-relief tables used in the industry you're all very familiar with. Figure 2, page 102, illustrates the heat-transfer in a loaded batch oven as a function of spring position in the load. The heat-transfer rate is the speed at which the temperature raises in the wire and is a function of the position in the basket. As can be visualized, springs lying against the inlet duct will gain heat much more rapidly than the ones lying in the center of the mass. The standard asks for one hour at 700° F. The springs against the duct will get the heat dose or maybe close to it, but the ones in the center… no one knows how long they will have been at the recommended temperature. Maybe they just barely made it to the right temperature before they were taken out at the end of an hour. So the one hour is not a fixed, proven time at which each and every spring must be kept at to be stress relieved. Rather, it's a guideline for ensuring that all the springs reach the stress-relief temperature that you find in the table.

Ovens are pieces of equipment designed to transfer heat (energy) to a mass of springs. Nothing in the standards that regulates ovens design is said to measure and compare the capacity of ovens to transfer heat. Ovens are calibrated against temperature at set point and temperature within a working volume only. No mention of heat-transfer ability. The long soak time in the table is to make for this lack of standardization. It is deliberately conservative for the less efficient ovens.

Larsen Miller (1948) derived an equal stress-relief function (Figure 3, page 102). Stress-relief is therefore not a fixed recipe of one time one temperature as stated in the table, but a whole lot of possibilities. If you have the proper tool and equipment, you can stress relieve wire very rapidly as we have been doing for Pyro's customers for the past 12 years and illustrated in Figures 3-5, page 102-103, X-ray diffraction illustrations.

As can be seen, five minutes at 800°F is equivalent to 10 minutes at 770°F in a Pyro. There you see the Larsen Miller law. And secondly, 10 minutes at 770°F in a Pyro is equivalent to 25 minutes at the same temperature in the oven of the current process. This speaks of the different heat-transfer power of a Pyro machine over a regular oven.

In other words, to be stress relieved, a wire just needs to be heated to the core and not for very long. Now how do you go about heating springs to the core for just the exact time each and every time?

You need very consistent ovens and a method on how to use them. We have at Pyromaitre developed over the years, and significantly over the past two years, a computer assisted tool called the "Pyrograph."

B) Pyrograph: Science on the Shop Floor

"Prove to me that the wire is heated right through the core!" That's the remark made several years ago by a springmaker that triggered the development of Pyrograph software.

Pyrograph is a piece of software based on Heisler (1948) unsteady-state heat-transfer equations for infinite cylinders. Figure 7, page 104, shows the temperature gain on the surface and

MATERIAL	SPECIFICATIONS	TEMPERATURE	TIME
		DEGRE F	MINUTES
Music Wire	ASTM A228	450	30
Music Wire tin coated	ASTM A228	300	30
Music Wire cadmium-zinc coated	ASTM A228	400	30
Music Wire	ASM 5112	540	60
O.T.M.B.	ASTM A229	450	30
H.D.M.B. CLASS I OR II	ASTM A227	450	30
High tensile Hard Draw or iii	ASTM A679	450	30
Galvanized M.B. class i or ii	ASTM A674	450	30
Chrome-Silicon	SAE J157 OR ASTM A401	700	60
Chrome-Silicon (Lifens)	SAE J157	725	60
Chrome-Vavadium	ASTM A 231	700	60
Stainless Steel 301	*	650	30
Stainless Steel 302	AMS 5688	650	30
Stainless Steel 304	ASTM A313	650	30
Stainless Steel 316	ASTM A313	600	60
17-7-PH	ASM 5678	900	60
Phosphore Bronze grade a	ASTM B159	375	30
Hasteloy C	*	500	30
Monel 400	*	625	60
Inconel 600	*	850	90
Inconel x750 spring temper	AMS 5699	1200	240
Inconel x750 /1 temper	ASM5698	*	*
Brass wire	ASTM b134	375	30
Berilium-Copper	ASTM B194 or ASTM B 197	600	120
Blue Temper	N/A	450	30

Figure 1: Stress-relief table.

through the core of a 250 in. and a 5 in. wire placed in a 700°F oven. For one thing, it settled the surface-core-temperature issue.

As you can see in Figure 7, the surface and the core temperature of a 250 in. wire soon meet one another and, after a few minutes, overlap one another. We gradually added features one after the other and soon found out that this could become a very powerful simulation tool, enabling the springmaker to see beforehand what is happening in the oven. Figure 8, page 104, shows an actual Pyrograph display of a proper setup.

You enter the spring characteristics, alloy, wire size, O.D., free length, parts and weight on the top right section.

The mid-section is where you set the Pyro parameters. The conveyor speed is set in inches of belt traveled per minute and the temperature in each zone of the oven.

The bottom section gives you a process report: cycle time, cost, belt occupation ratio and percentage power usage. Figure 9, page 105, gives you an example of an improper setup. As you can see, the wire temperature doesn't reach the target stress-relief temperature.

A new feature that we have integrated in the software lately is automatic stress-relief-temperature selection according to alloy type as demonstrated in Figures 10 and 11, page 105.

We have also integrated Larsen Miller, and this is the greatest improvement. This feature sets the stress-relief temperature automatically as a function of the cycle time, as demonstrated in Figures 12 and 13, page 106.

As you can see, the stress temperatures necessary to achieve proper relief with three-minute cycle time is higher than the one for the 20-minute-cycle time.

We have also integrated a high-temperature "bumper" so you don't go above it and you don't affect the wire hardness. Figure 14, page 106, illustrates the maximum temperature for CrSi that you don't want to go beyond.

Pyrograph is a very powerful tool. You can visualize beforehand what is going on and be confident that each spring is heated to the core consistently.

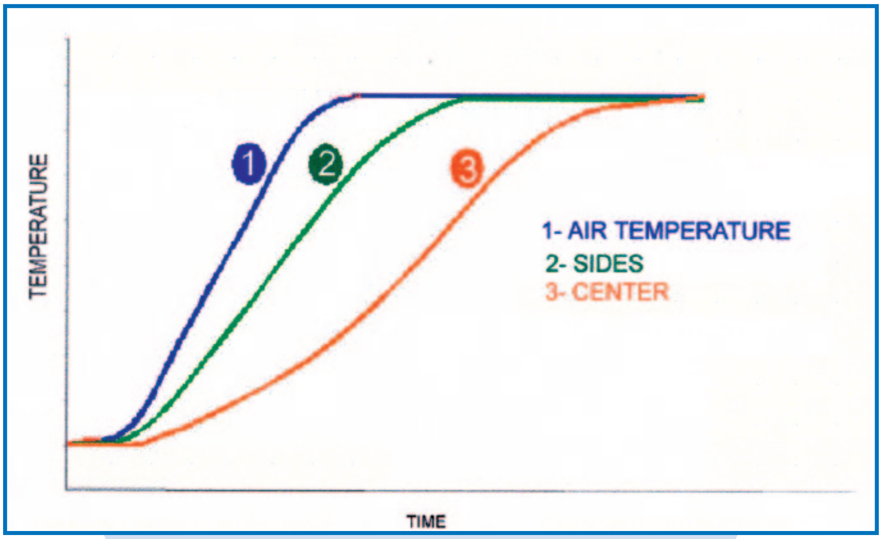


Figure 2: Heat-transfer uniformity.

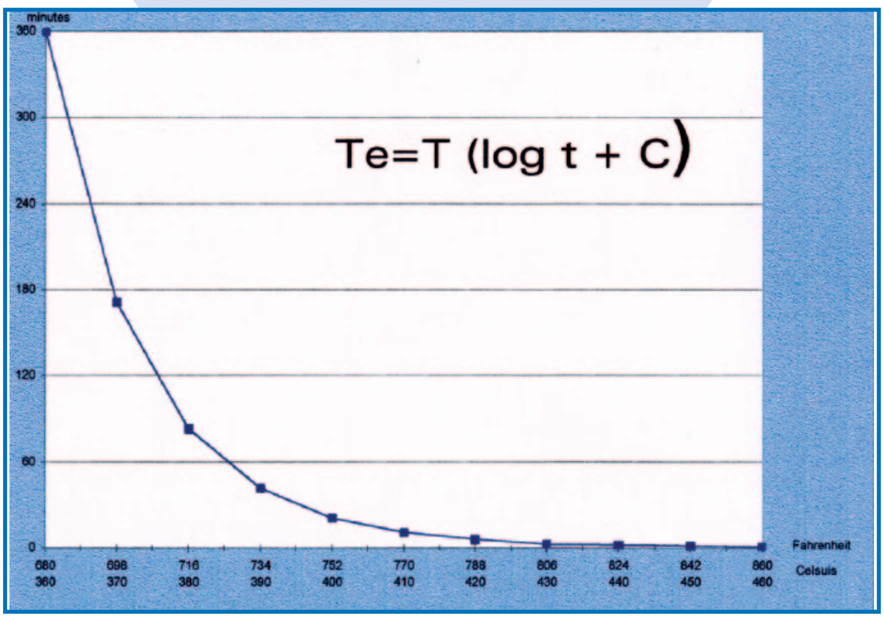


Figure 3: Larsen Miller curve.

C) Equipment

Evolution of stress-relief equipment:

Springs were originally stress-relieved in batch ovens, and that is where the standards were established as can be seen from what preceded.

Then came the in-line ovens. The first in-lines (and there are a lot of these in operation in modern spring shops), more or less lengthened batch ovens with two doors and were connected by a conveyor to transport the springs. Very often, springs would be put in baskets on the belt and would stay in for as long as if they were in a batch, except that they were moving, thus saving the handling.

Then came the portable at the coiler type in-line. Great innovation, improved product quality and saved handling are provided by this oven type. It is primarily used on small wire and at a shortened cycle time in some instances.

Pyro distinctive features

The Pyro is a line of ovens originally and exclusively designed for high-precision stress relieving of large wire at high speed. You can refer to the presentation of two years ago (SMI's first technical symposium) where the history of development was reported. The speed is a means to reach precision–the only goal being precision and consistency.

Pyro comes in three classes of machines, with the top-of-the-line being high-capacity gas-fired models. Here are the main features that make the Pyro heat-transfer machines different:

• Precise control of temperature. Top-of-the-line temperature controllers. Very fast power switching through SSR devices for electric models or fast-modulating motors for the gas-fired models. The objective is to maintain set-point accuracy within a few degrees under varying loading conditions.

• Sufficient reserve power for quick recovery at startup of a load.

• Precise control of time: The Pyros come standard-equipped (for top-of-the-line E and G series, optional on the HE), with digital closed-loop speed controls. Calibrated in inches of belt travel per minute, the closed loop acts as a cruise control on a car and maintains accurate cycle time regardless of the variations introduced by simple potentiometric controller by friction, load and voltage. This is a very important feature since, on a four-minute trip, a few seconds make a difference. This system is accurate to within 0.4 seconds on four-minute cycle time.

• Heat-transfer uniformity: A high-precision oven needs to be uniform not only temperature-wise but also heat transfer wise. The Pyro uses convection as the primary source of heat-transfer and radiation as secondary on electric models. The turbines, their number and position, the shape of the chambers and the conveyor are such as to maximize the air velocity at the part. Not only the velocity is maximized but it is maximized in a uniform manner all along the spring path. This is what is meant by "heat-transfer uniformity."

• Pyro saves floor space. They can be up to 10% the size of current large ovens. Because of the reduced size, they are also more energy efficient.

• Capacity: We now manufacture machines that process 0.625-inch CrSi wire in six minutes total cycle at rates of 20,000 lbs./hr.

Areas of development in the years to come

- Larger gas-fired models.
- Smaller portable gas fired units.

Mario Grenier is president of Pyromaitre in St-Nicolas, Quebec, Canada. He attended the university to study psychology. Fascinated by brain processes, he did graduate research in sensory transposition. He proposed and proved a method on how the skin could be used by the hearing impaired to give them better access to speech sounds. At the same time, he was doing ceramic as a hobby and, in 1973, he started building firing kilns. In 1977, after completing a master's degree in psychology, he went on to push forward his work on tactile perception of speech. During weekends and at night, he kept on building firing kilns. He bought more tools, and his customers list grew. In 1981, he developed an apparatus and a method to do hearing tests in infants as young as six months of age. In 1981, being more and more busy with the kilns, and feeling that the public system wouldn't fulfill his entrepreneur's mind on the long run, he decided to work part time and he started Pyromaitre. In 1984, he left the security of the government job for the heat of private enterprise. With a small team, he developed a large variety of industrial ovens and furnaces. His first encounter with the spring industry occurred in 1986. The development of the high-speed stress-relief process started in 1989 and has never stopped since then, with the continuous development of model lines, Pyrograph software, market penetration and so on. ⌘

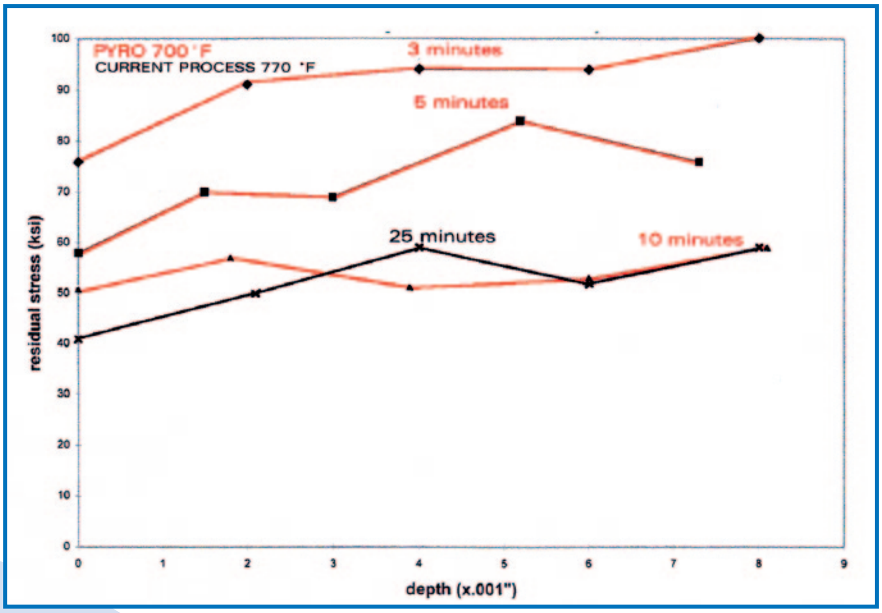


Figure 4: Pyro-residual stress-relief experiment.

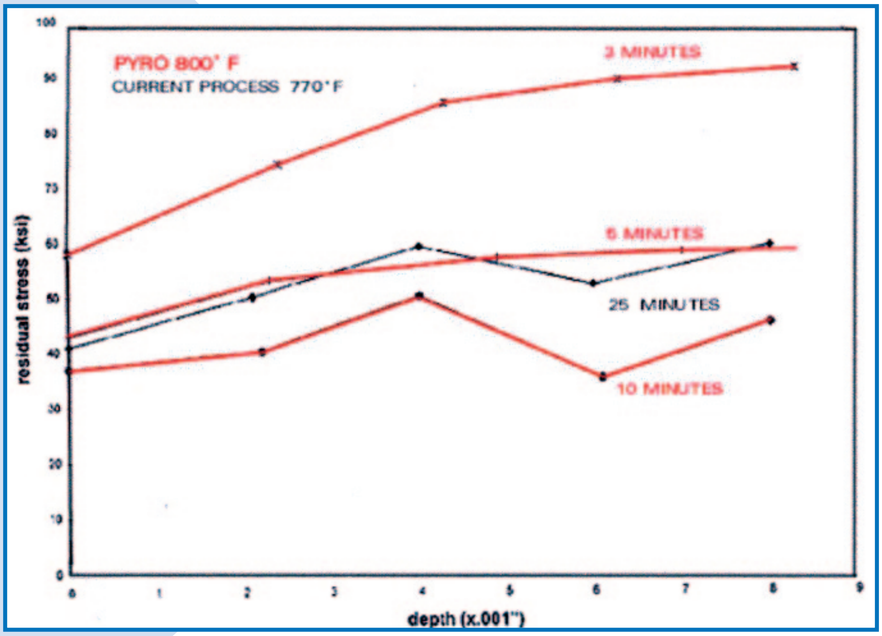


Figure 5: Pyro-residual stress-relief experiment.

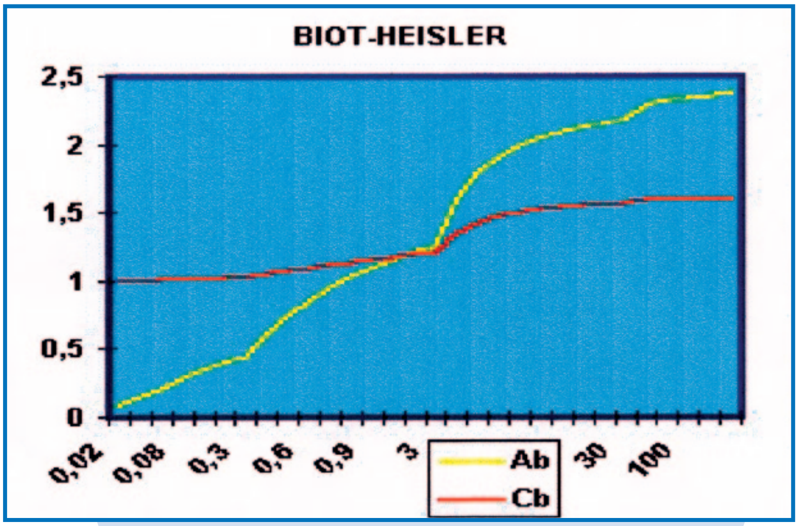


Figure 6: Biot-Heisler function.

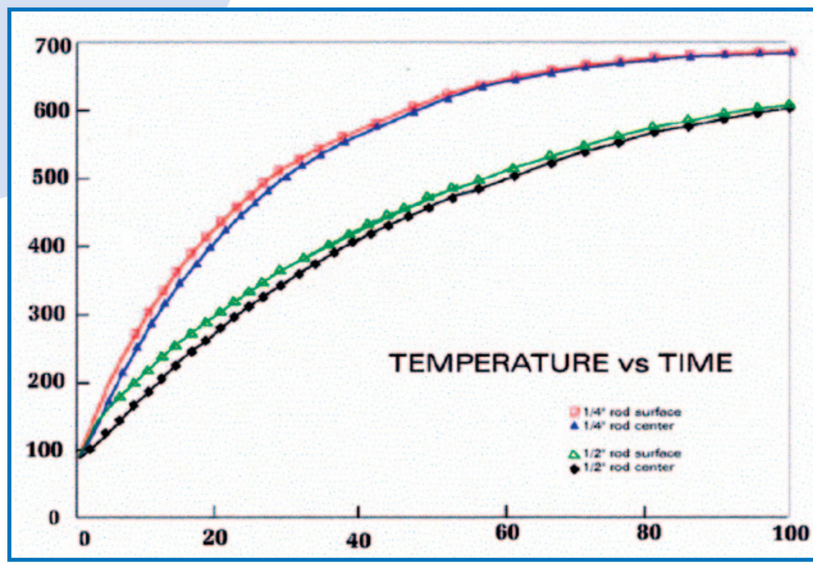


Figure 7: Heat-transfer, ¼ in. and ½ in. rods.

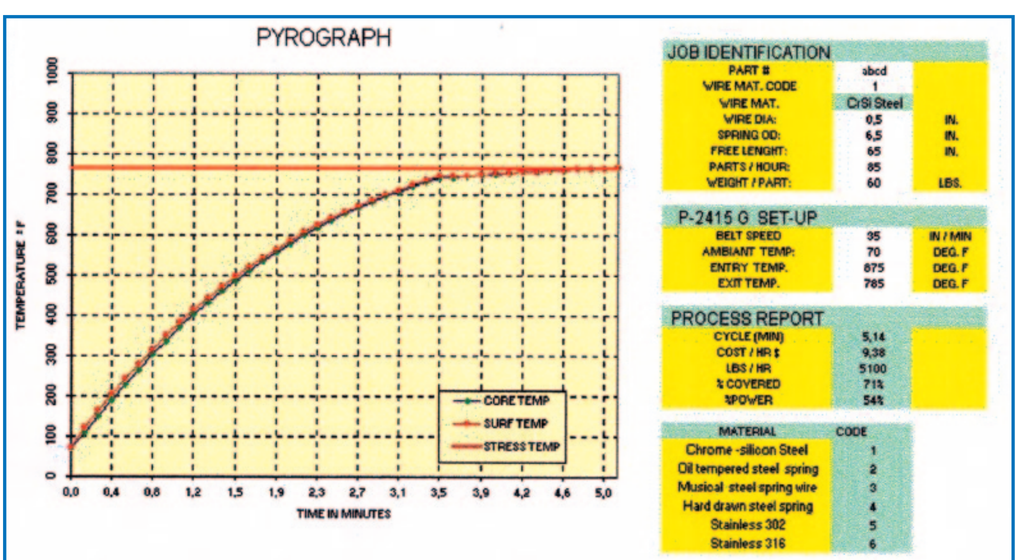


Figure 8: Pyrograph proper setup.

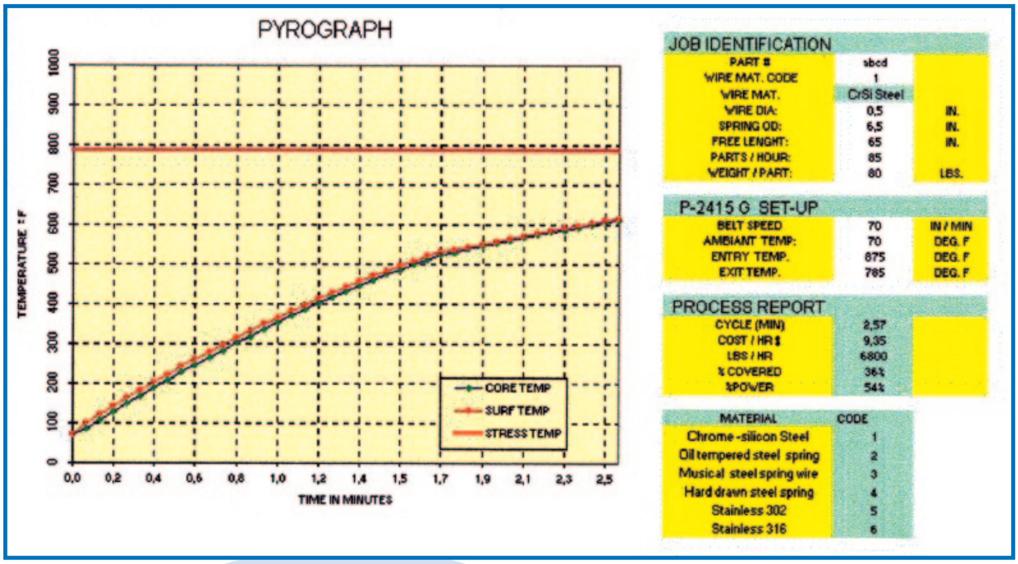
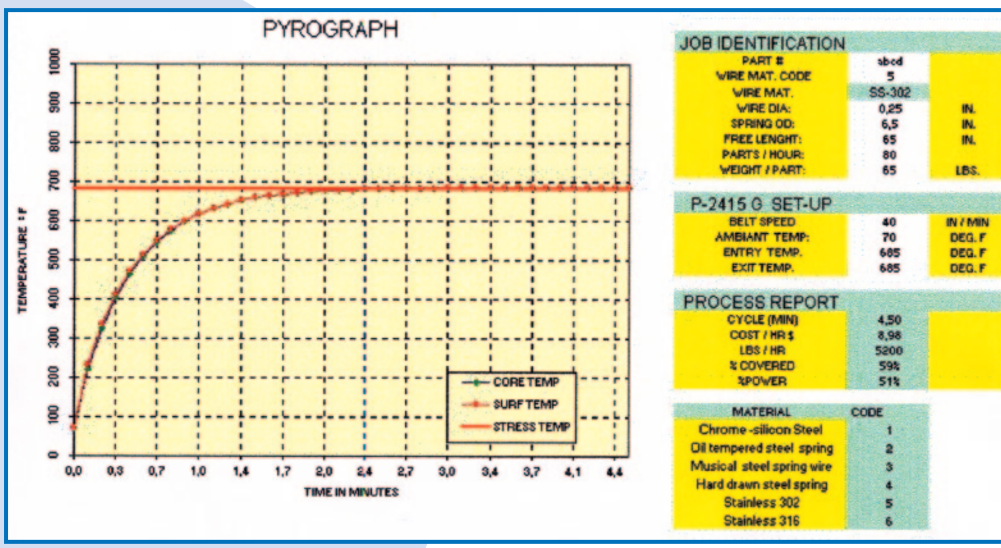


Figure 9: Pyrograph improper setup.

Figure 10: SS-302 setup.



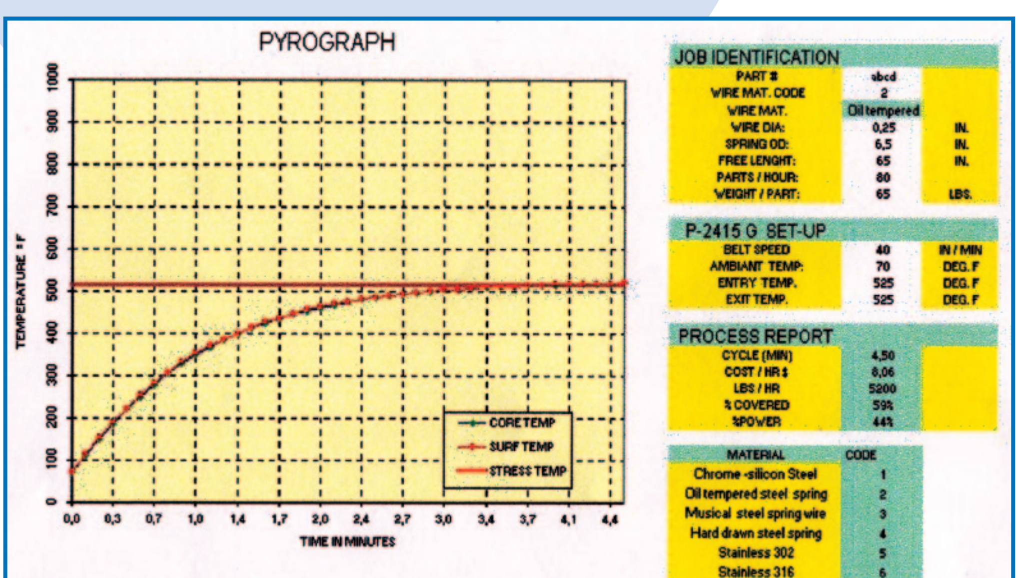


Figure 11: Oil-tempered setup.

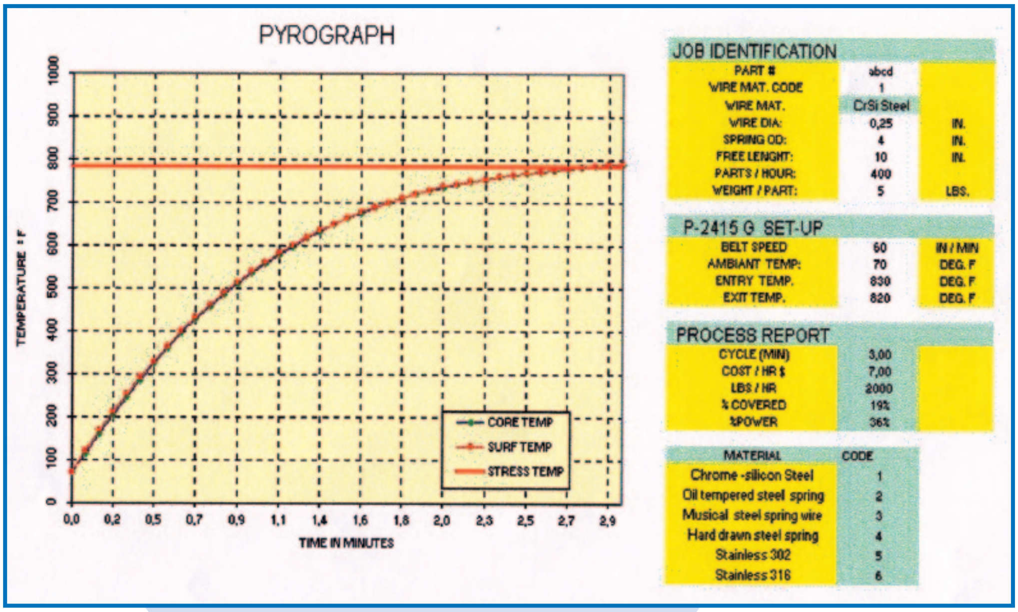


Figure 12: CrSi three-minute cycling time.

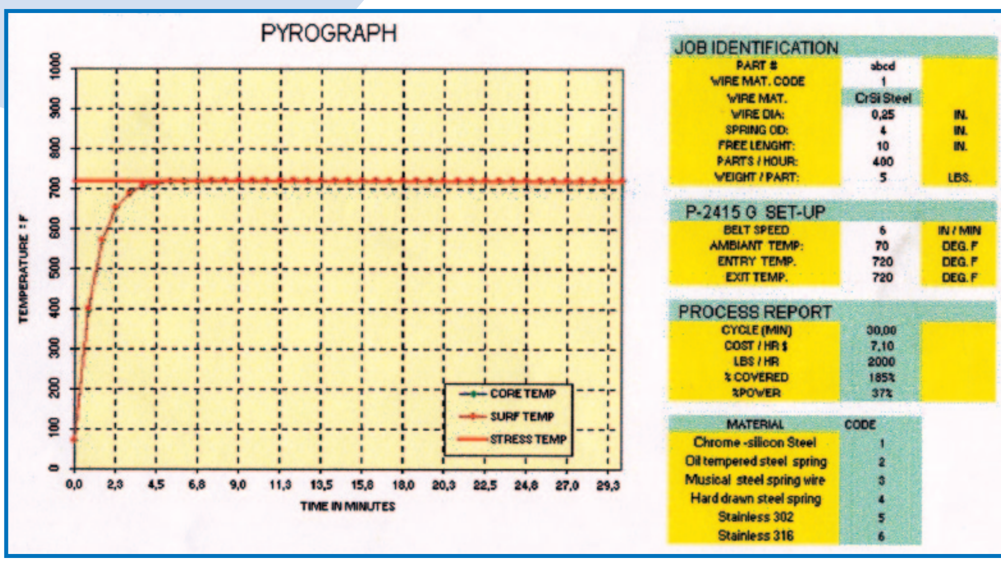


Figure 13: Maximum temperature limit.

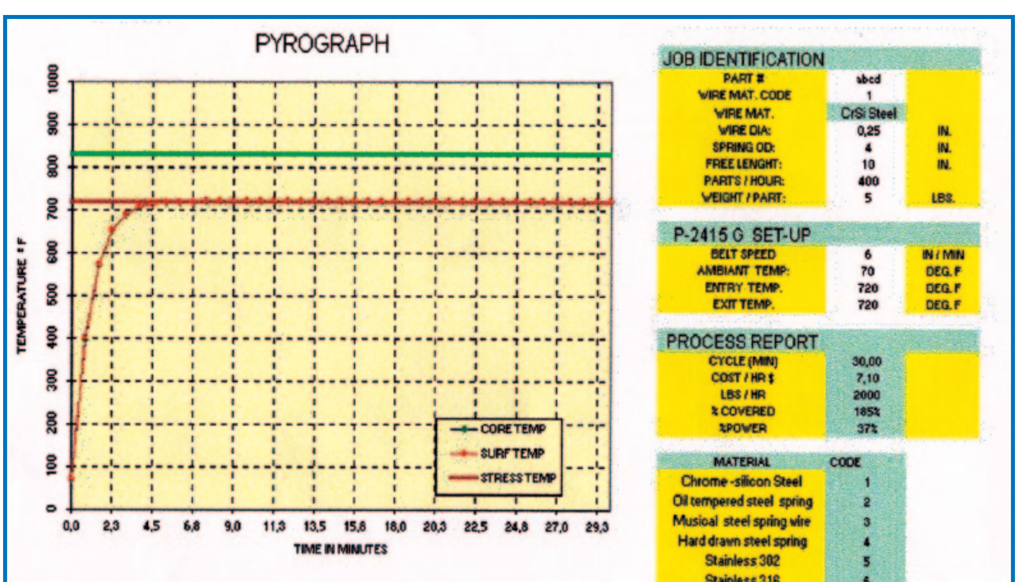


Figure 14: Maximum temperature limit.