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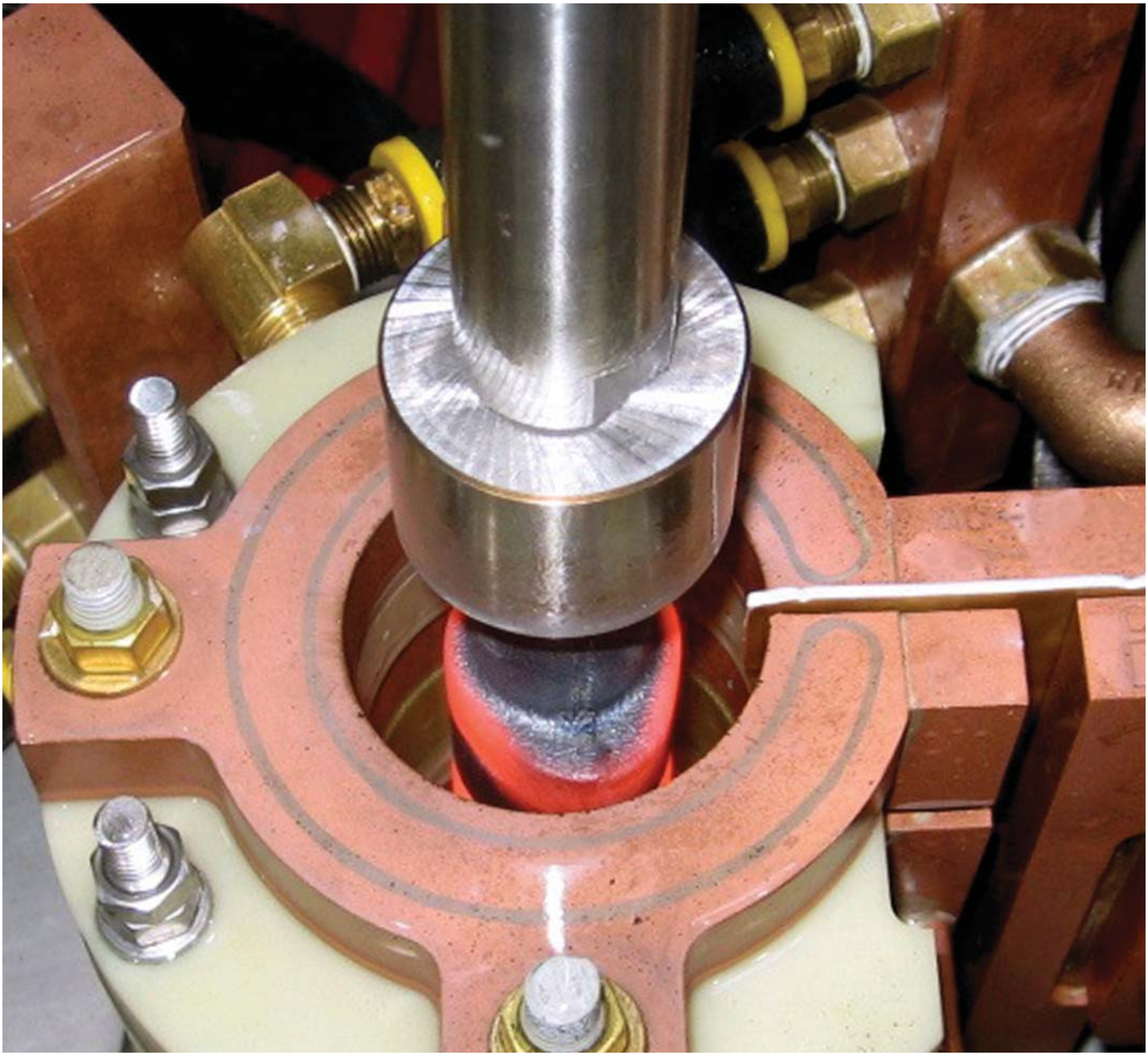

Lean Manufacturing Strategies for Tempering

Jim Demarest – Pyromaitre

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Lean manufacturing is a management process or philosophy by which a manufacturer strives to produce less waste, reduce human effort, utilize less floor space, require smaller investment in capital equipment and tooling, and minimize the engineering time required to develop new products.

If you're like me, you might be wondering why a special management philosophy is needed to achieve such a common-sense goal. The answer might just be that manufacturing has not changed, but the market it serves has. Craft production is the popular term used to describe the origins of manufacturing. Skilled craftsmen fit parts or components at assembly. Everything produced was essentially one of a kind. In the early 1900s, Henry Ford is credited with the development of mass production, which was essentially the development of common gauging standards used to eliminate fitting by skilled craftsmen. By eliminating the hand fitting of components, non-skilled laborers could mass-produce just about anything on an assembly line. Henry Ford's mass production concept has been the working model of manufacturing for a century.

Evolution of Lean Manufacturing

What change occurred that made mass production a term of historical reference? We, the market, changed. As the old saying goes, variety is the spice of life, and that is exactly what competition in our free-market society has delivered. Our craving for variety has had a significantly negative impact on the market share of mass producers. As was the case with mass production, the automotive sector is the breeding ground of Lean Manufacturing.

The development of lean manufacturing is credited to Taiichi Ohno of Toyota. This is why lean manufacturing is synonymous with the Toyota Production System (TPS). Its development is simply an evolution that occurred in a specific environment. Ironically, the U.S. government played a role in defining that environment. Toyota had a workforce it could not reduce, a market that demanded variety, fixed floor space and limited finances. To be successful in this environment, Toyota had to identify a new model of manufacturing. How fortunate that today's manufacturing environment is nearly identical to that of post-WWII Japan.

Buzzword Bingo

The terms associated with lean manufacturing remind me of IBM's Buzzword Bingo commercial, only broadcast in Japan.

- **Muda** – elimination of waste or non-value-added processes
- **Muri** – overburden or unreasonableness, standardized work
- **Poka-yoke** – mistake proofing
- **Mura** – smoothness or flow of work, just-in-time (JIT)
- **Kanban** – visual indication, pull system
- **Kaizen** – continuous improvement, the "5 Whys"

These buzzwords represent the six primary areas of focus or the measure to improve one manufacturing process.

Six Sigma is often associated with lean manufacturing, but it is an independent statistical process measurement and management tool implemented to reduce or eliminate process variation.

The Soak-Time Myth

Is soak time a necessary process required to produce the desired metallurgical prop-

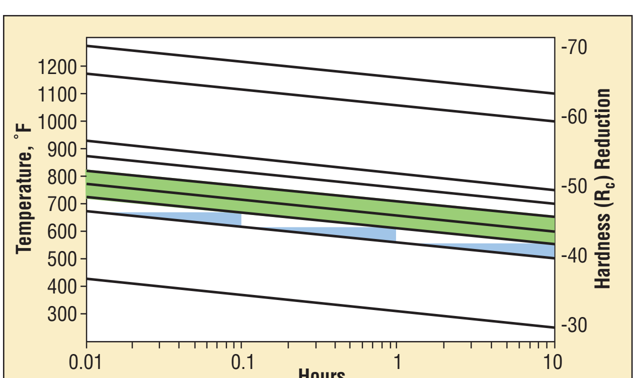

Fig. 1. Hollomon and Jaffe – Time-temperature relations in tempering of steel

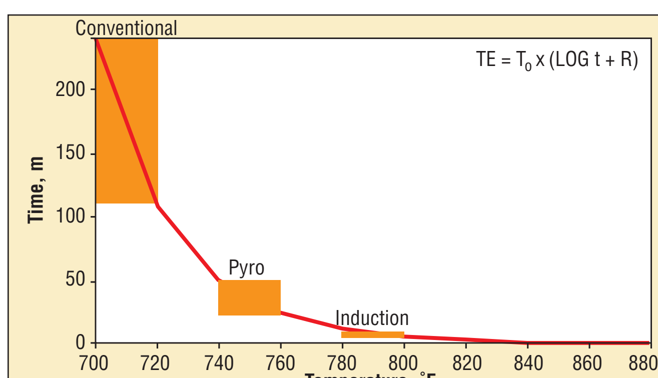

Fig. 2. Larson and Miller – Time-temperature relationship for rupture and creep stresses

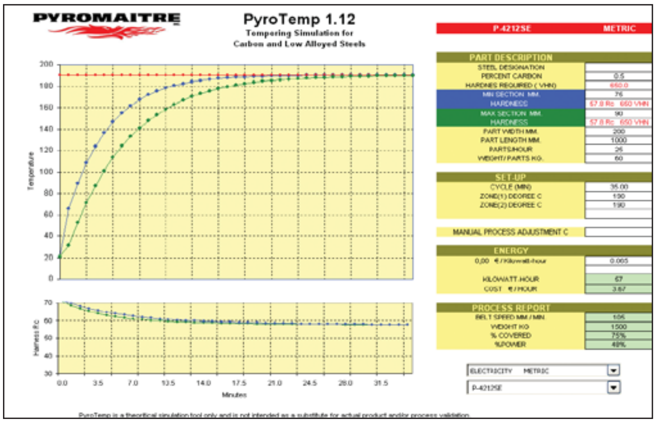

Fig. 3. Pyromaitre PyroTemp™ tempering simulation for carbon and low-alloyed steels

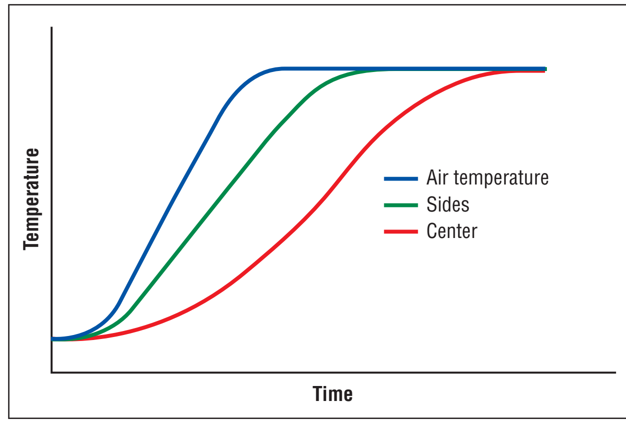

Fig. 4. Illustration of temperature non-uniformity typically present in conventional batch ovens

erties – full transformation to tempered martensite? Is soak time merely a poka-yoke devised to compensate for varying furnace designs or the myriad of loading/processing arrangements? Is soak time muda, and can it be eliminated?

Necessary

Tempering, like many manufacturing processes, has its fair share of rules of thumb. One such handy rule is one hour per inch of cross section. This nice linear relationship is easy to remember, but this is clearly not a rule based in science. If it were, how would you explain induction tempering?

In 1945, Hollomon and Jaffe published their works to describe the time-temperature relationship of tempering. Their Hollomon-Jaffe[1] tempering parameter depicts the correlation of change in hardness of martensite in steel as a function of temperature and time. The rate of carbide growth or coalescence from martensite, which produces the decrease in hardness during the tempering process, is affected by both time and temperature.

In Figure 1, you'll see yet another tempering rule of thumb – one-point HRC drop in hardness for each 25°F increase in temperature. Time, on the other hand, has a far less significant impact – a 10X increase in treatment time at a given temperature produces only an approximate 2 HRC decrease in hardness. Larson-Miller[2] described this time-temperature relationship as a Thermal Effect (TE) function. As time decreases, temperature must increase to achieve equivalent results. Please note in Figure 2 that as treatment temperature increases, the process window, or time, decreases. In other words, going fast requires precision.

Pyromaitre has integrated the work of Hollomon-Jaffe and Larson-Miller into our proprietary PyroTemp™ heat-transfer simulation software (Figure 3). The program is based on Heisler unsteady heat transfer in cylindrical body formulas, and it gives a graphical representation of the temperature gain at the surface and at the core of a cylinder as a function of time and temperature in the furnace. For carbon and low-alloyed steels, the application will calculate the as-tempered hardness for your simulated recipe. It has proved to be a valuable process-development tool for our customers.

Poka-Yoke

A tempering oven is a heat-transfer machine, yet, in current practice, ovens are standardized around a heat- or temperature-uniformity procedure. There is no true standard procedure for heat-transfer measurement. Soaking at temperature is merely the mistake-proofing method, or poka-yoke, for making heat transfer uniform.

A conventional batch oven is probably the best example to illustrate why soak time is a poka-yoke. The parts on the outside edges of the load come up to temperature significantly faster than those in the center of the load (Fig. 4). This delta T during the heat-up can be several hundreds of degrees, and there is typically no indication when the parts in the center of the load have actually reached set point.

Oven design, type, age and manufacturer, as well as loading density and method, are all factors impacting heat transfer. Wasteful excess time is merely the equalizer.

Muda

As demonstrated in the following automotive-industry examples, it becomes quite clear that soak time is a non-value-added process, or muda. Eliminating this wasteful process and maximizing productivity and quality requires a bit more effort than simply touching the up arrow on your temperature controller. Precision is mandatory – not only precision of temperature uniformity but precision in repeatability of heat-transfer rates. Furnace design is a key factor in the performance of the tempering process further down the Larson-Miller curve.

Lean Tempering in Action

CV Joints

The constant velocity (CV) joint is one of the best examples of success with high-speed convection tempering. With nine systems installed at three different global CV-joint manufacturers, acceptance of soak-time elimination is now past tense. One manufacturer replaced a 90-minute batch temper (200 parts in process) with a 10-minute continuous-tempering process (20 parts in process). Another manufacturer replaced their in-line induction-tempering process with an in-line 20-minute continuous high-speed convection temper. By eliminating the bottleneck of their 40-second induction-tempering process they were able to nearly double the line throughput – an amazing return on such a modest capital investment.

Axle Shafts

Axle shafts are another great example of precision tempering. Three systems were installed with two global manufacturers, producing over 1 million axle shafts annually. In one example, a mezzanine-mounted, monorail-trolley conveyor tempering furnace at 100-minutes cycle time and 350 parts in process was replaced with a floor-mounted 20-minute tempering process with only 70 parts in process.

Transmission Gears

The lone batch-type application of high-speed, high-precision Pyro tempering is gears for an all-wheel-drive power take-off unit. These vacuum-carburized and high-pressure, gas-quenched gears utilize a consistent loading arrangement with ample spacing for repeatable convective-heating performance. Four systems performing both pre-oxidation and tempering were delivered, utilizing a 40-minute cycle for a 1,400-pound gross load. The conventional process called for a 120-minute cycle time and would have involved multi-tray continuous ovens. The high-speed in/out batch solution delivered maximized process flexibility, reduced floor space, reduced in-process inventory and fewer alloy fixtures.

Torsion Tubes

The most recent success story involves the tempering of hydro-formed torsion tubes. The conventional process was a 60-minute continuous-batch process with an incredible 1,056 parts in process. The lean solution being delivered to three continents utilizes a 10-minute process with only 60 parts in process. High-speed processing provided the opportunity for single-piece work flow – eliminating part fixtures and external-fixture handling equipment – a simplified and more robust robotics program and a significantly reduced capital investment.

Leaf Springs

An expansion of Pyromaitre's core market, the leaf-spring market, has presented several recent opportunities for conversion to lean tempering. In addition to the significant speed advantages – 40 minutes as compared to the conventional 120 minutes – these leaf-spring machines deliver further operating cost advantages. The conventional ovens required a 3-million-BTU burner system, while the high-speed oven required only 1.5-million-BTU for the same capacity. The reduced length of the oven enabled the use of air for cooling rather than the traditional use of water. The waste heat from the air-cooling chamber is used to heat the building during the winter months, offsetting monthly plant heating bills. The operators were also quite fond of clean, dry parts and were able to throw away their rubber aprons and gloves.

Suspension Springs

The suspension-spring market represents the most aggressive example of a customer's acceptance and grasp of Pyro tempering – wire of 16mm (0.630") in diameter tempered and/or stress relieved in six minutes! Conventional furnaces are well on their way to extinction in this customer's plant. The list of savings these powerful, virtually JIT machines deliver is nearly endless. A tremendous amount of plant floor space has been opened up for growth without brick and mortar.

Conventional Batch Tempering

Keeping on with this Lean theme, why do so many heat treaters temper their expensive nickel-alloy trays and fixtures?

The Muda: The energy required to heat the fixtures, the capital cost of additional fixtures to fill the heat-treat system and the energy required for the longer heat and soak times.

The Mura: Cycle time reduced from hours to minutes and in-process inventory minimized.

The Poka-yoke: Either lights-out automation systems with SCADA packages or operators with clipboards, and load/job tracking forms are required to ensure hardened loads are tempered.

Even Six Sigma: 1-D temperature uniformity vs. 3-D and an identical repeatable heat-transfer rate for every part.

Lean and Green

What's the next big movement in manufacturing? In the author's humble opinion, it's Lean and Green. Lean will expand beyond the manufacturing process to encompass complete business structures and processes. Have you ever wondered why manufacturers like Linamar and Magna are comprised of literally hundreds of smaller companies? Look up how much it cost DaimlerChrysler to combine and then separate. Lean business structure makes more than cents. It makes dollars. Linamar and Magna sure seem to be operating rather successfully. The Green is not what you're expecting. I envision a shift away from global trade of products to global trade of intellectual properties. We will begin to see more manufacturers shift to local manufacturing and/or assembly in each of the markets they serve. We might even see them advertise or tout the Green impacts of domestic manufacturing and their responsibility to their customer's communities. You have been following Toyota, haven't you? **IH**

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Additional related information may be found by searching for these (and other) key words/terms via BNP Media SEARCH at www.industrialheating.com: lean manufacturing, soak time, continuous tempering, induction tempering, convection temper

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