Feb 2013 ASM Pune Chapter Conference

High Speed Tempering of Gears:
A Comparative Study

Gear Technology Going Global

Authors: Gorphade, P., Gowri, S., Grenier, M (2013)

Abstract

Tempering is a time temperature process mostly governed by the type of equipment used. Tempering is currently conducted using conventional ovens and a fixed time-temperature recipe. Tempering can also be done under special conditions using induction-generated more intense heat for a very short time. Pyro tempering process is known as high speed tempering and is located between conventional and induction ovens, and affords the most cost-effective, lean manufacturing advances. This paper will review the science behind rapid tempering and present a recent comparative-proving study performed on gears.

High Speed Tempering: History of Development

Quest for Quality

The first high-speed unit was developed in 1990 for a high precise torsion spring maker. The springs had two mobile legs moving as a result of stress relieving up to 20° angle position. Final position had to be within +/- 3°. Traditionally stress relief took 1 hour at 350° C. The Pyro oven that was shipped yielded 30% rejected parts.

The final temperature resulted at 460° C which was above the recommended and cycle time was down 3 to minutes total from 60 minutes for CrSi 6 mm wire! No rejects; an in-line, ultra-lean process. Auditors were puzzled. This process has since been consistently proven and reproduced by the most stringent protocols and is now used not only for stress-relieving but also for equal benefits for tempering.

Technology has been described in a number of publications. Newman., Pickett (2006), Grenier.M., Gingras. R. (1997)

In America, one out of every two cars on the road contains at least one part from valve springs, axles, CV Joints, suspension springs, car belt tensioners, processed in one of several hundred Pyro units in operation.

The Science Behind Pyro Heat Transfer

Heat can be transferred to a cold body by 3 different means: Radiation Conduction Convection.

Pyro uses convection as main means of transferring heat to a metal part. Pyro uses the reverse of wind chill effect factor familiar to those living in cold climates. A warm body will cool faster in presence of wind and a given same temperature will feel much colder than the actual temperature, this is known as wind chill factor.

Conversely a cold body will warm up much faster in presence of hot wind. The effect of rapid air movements wiping the body surface serves to break up the insulating layer of air boundary at the surface of the object so that heat can be transferred most directly.

Everything being equal, a Pyro will heat up a cold body between 2 and 3 times faster compared to regular traditional ovens. Using a process of stepped-elevated temperature increments in the different zones will maximize heat transfer further, as we will see later.

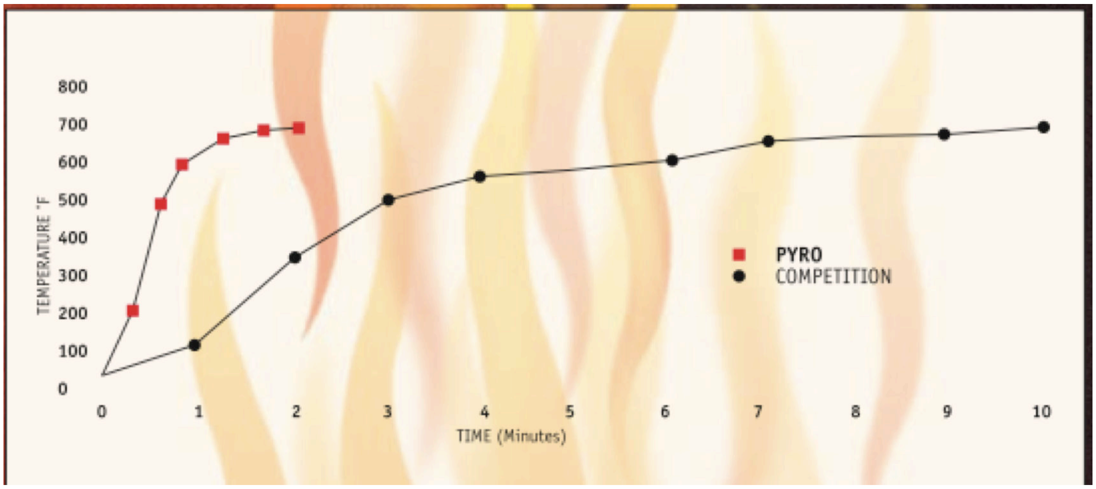

Fig. 1 Comparison between standard ovens and Pyro heat transfer oven

Thermal Effect

Stress relieving and tempering is applying a given amount of energy (Thermal Effect TE) to a part depending on alloy type, process, part geometry and desired results. This has been described scientifically by a number of scientific formulas. (Larson Miller, Hollomount Jaffe)

Each point along the line represents equivalent thermal effect and is equivalent to the recipe(s). Conventional oven processes use lower temperatures for a longer time. Extremely fast induction processes, common for tempering after induction hardening, use much higher temperatures for a much shorter time. The Pyro process works in the middle between the two ranges.

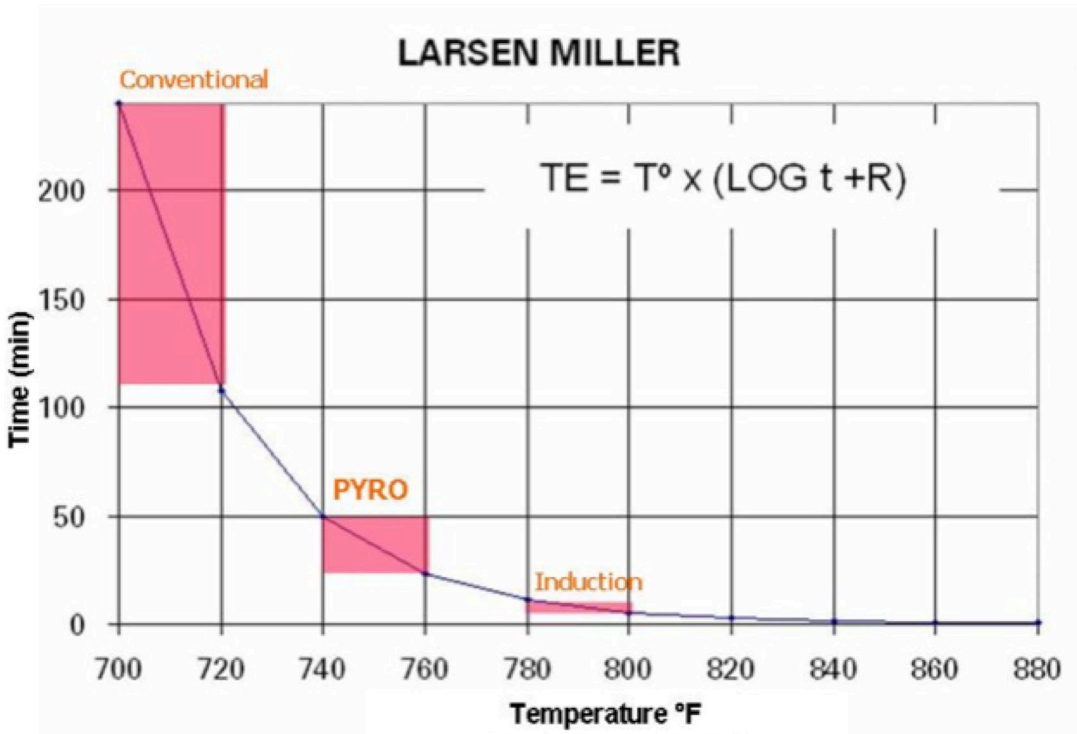

Fig. 2 Larsen Miller Equivalent Thermal Function

Actual Standards and Practices

An oven is a heat transfer machine. However, ovens are calibrated for temperature only and not heat transfer. For instance 2 different ovens can well pass heat uniformity surveys but they will heat the same load very differently.

Therefore, standards were made so that even the worst heat transfer oven (which would be the slowest) can produce good parts.

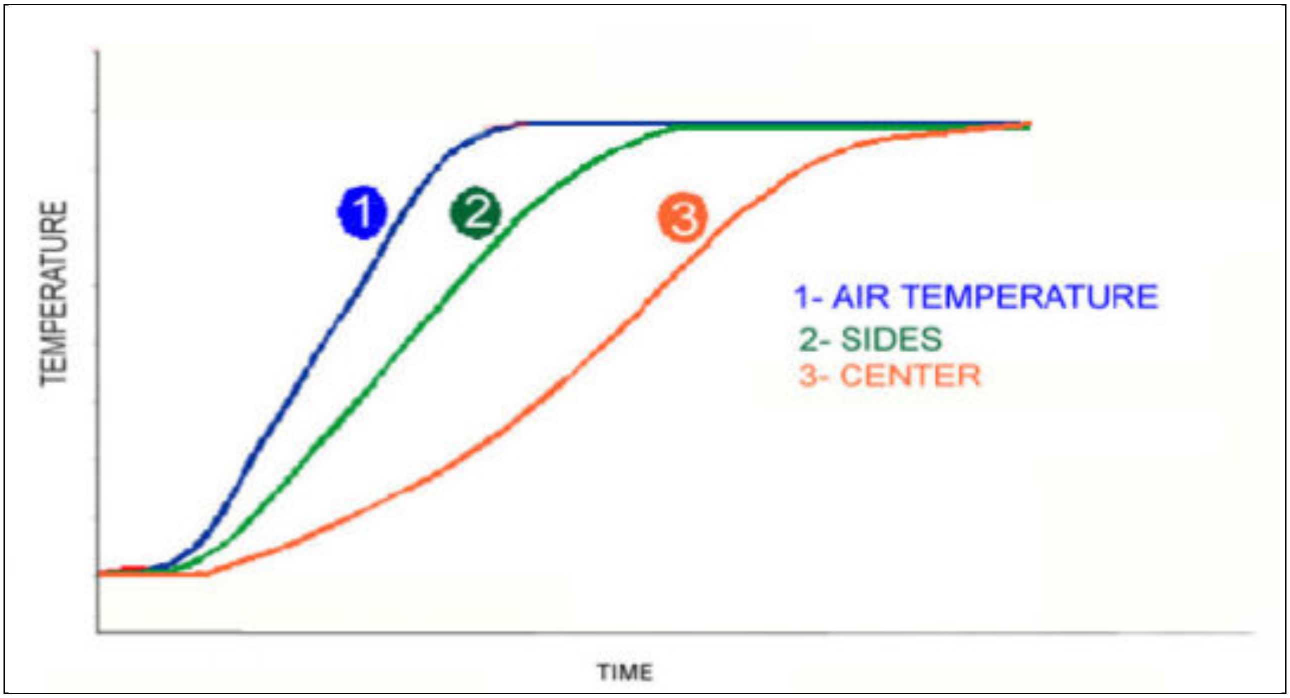

Fig. 3 Typical heat transfer with a batch oven

Automotive components are tempered to enhance mechanical properties. Tempering cycle times are approximately 60 to 180 minutes.

Trials

To demonstrate this process, trials were conducted on counter shaft 4th gear (20 Mn_5Cr_5, case carburized) and rear axle shaft (SAE 1541 & 40 Cr_4B, Induction Hardened) at High Temp Chennai.
Detailed results given below in Table 1 and Table 2. Hardness with reference to tooth root, drop from surface and hardness drop are shown in Fig. 4, 5 and 6 respectively.

Table 1

Counter shaft 4th gear				
Material	20 MnCr$_5$ as per SS: 4027 used for gears. All gears are from same batch.			
Tempering Process		**TML Cycle 160º C - 90 min**	**Fast tempering Cycle 200º C - 40 min**	**TML Specification**
Hardness Traverse				
Hardness Drop	Distance (mm)	Hardness (Hv1)	Hardness (Hv1)	--------
	0.1	686	689	
	0.2	686	716	
	0.3	686	698	
	0.4	660	707	
	0.5	660	689	
	0.6	636	675	
	0.7	613	626	
	0.8	591	571	
	0.9	571	542	
	1	551	469	
	1.1	533	402	
	1.2	533	394	
Case depth (mm)		1	0.9	0.9-1.2
Surface Hardness HRC		59-60	58-59	60±2
Core hardness HV1		400-413	319-318	-
TB hardness Hv1		436-443	329-331	-
Core strength		130	99-103	87 Kg/mm2 min
Tooth base strength		142-145	106-109	105-145 kg/mm2

Table 2

Rear axle shaft					
Material	**SAE 1541 and 40 Cr_4 (B) shafts are used for induction hardening and Pyro Tempering**				
Tempering Process		**Conventional Tempering** 180ºC - 120 min		**Pyro Tempered** 195ºC -30min	
Hardness Drop	Distance (mm)	40 Cr_4(B)	SAE 1541	40 Cr_4(B)	SAE 1541
	0.1	584	592	610	614
	0.3	604	615	617	630
	0.5	612	621	625	632
	1	610	621	632	621
	2	619	608	641	625
	3	619	594	638	600
	4	584	571	540	565
	5	261	378	277	257
	6	260	248	277	269
	7	259	244	261	270
	8	254	257	266	257
Case depth (mm)		4		4	
Surface hardness HRC		53	54-55	55-56	59-58
Core hardness (HRC)		20	19-20	22	19-20

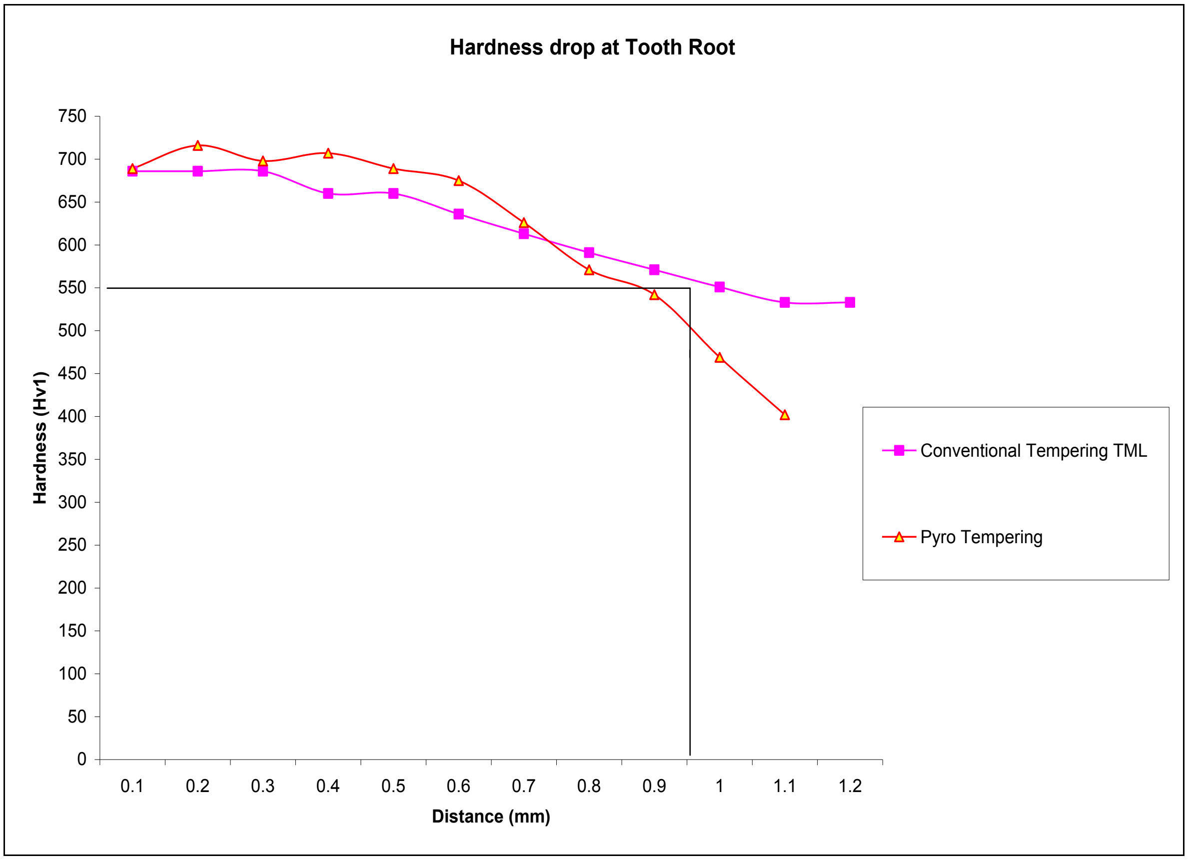

Fig. 4 Hardness drop for case carburized Counter shaft 4th gear

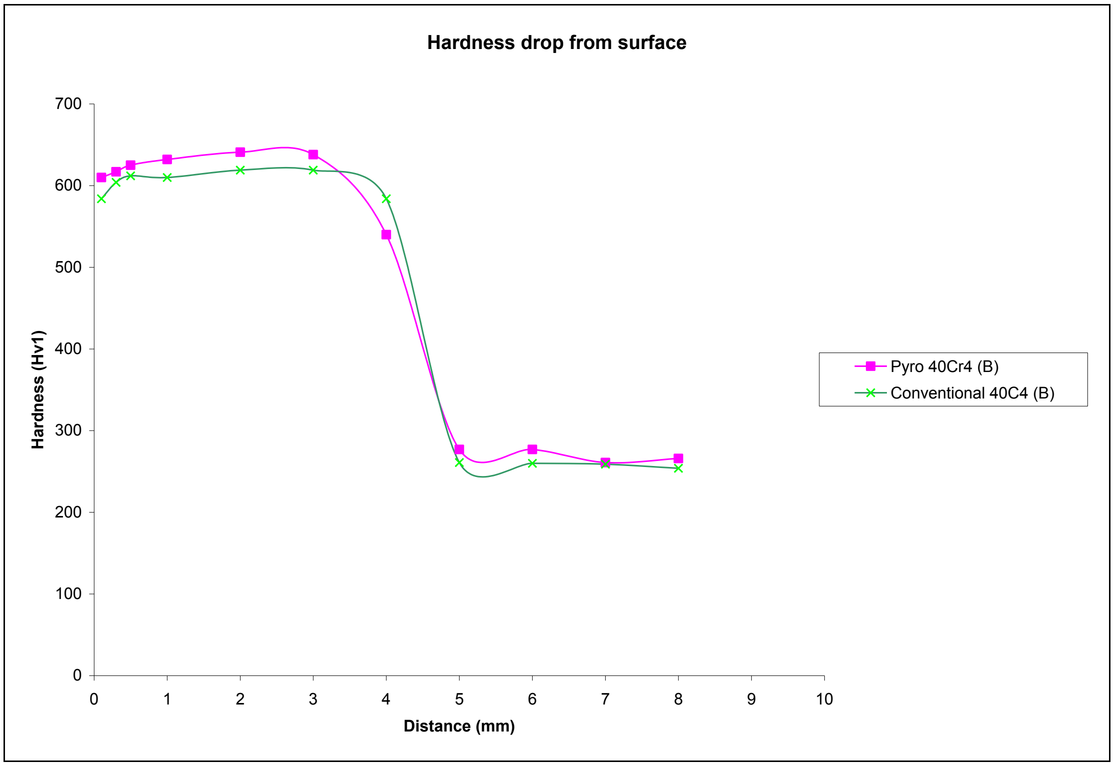

Fig. 5 Hardness drop for rear axle shaft (40 Cr_4 (B) material)

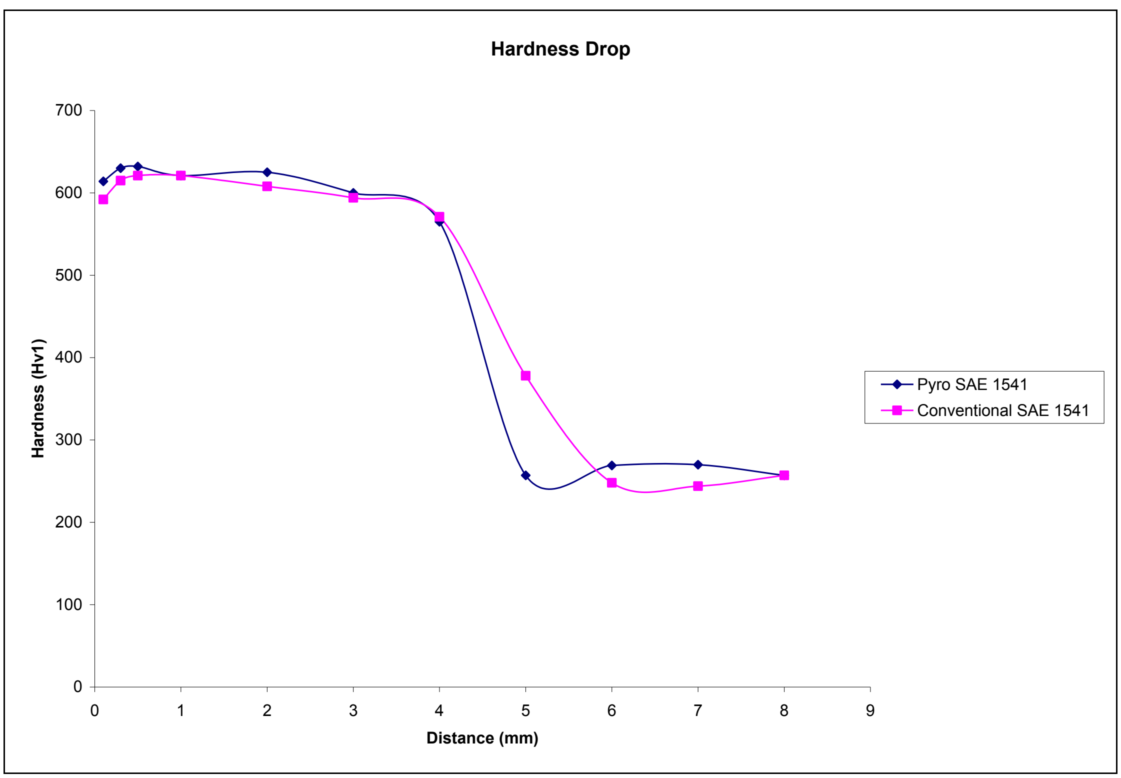

Fig. 6 Hardness drop for rear axle shaft (SAE 1541 material)

Conclusion

Fast tempering was compared to regular tempering. To demonstrate this process, 4^{th} speed counter shaft gear and rear axle shaft (Part. in SAE 1541 and 40 Cr_4 (B) material) were tested.

The cycle time reduction achieved was 40 min versus conventional 90 min for carburizing gears, and 30 min versus 120 min for induction hardening.

The reduction in tempering cycle time helps to reduce cost, fuel consumption, throughput time, and carbon footprint**.** Demarest (2008)

Bibliography

Demarest (2008) Lean Strategies for Tempering, *Industrial Heating*, May 2008

Newman.T., Pickett.T. (2006) Rapid Tempering of Automotive Axle Shafts, *Heat Treating Progress,* March/April 2006

Grenier.M., Gingras.R (1997) High Speed Stress Relief, *Wire Technology Journal,* March 1997