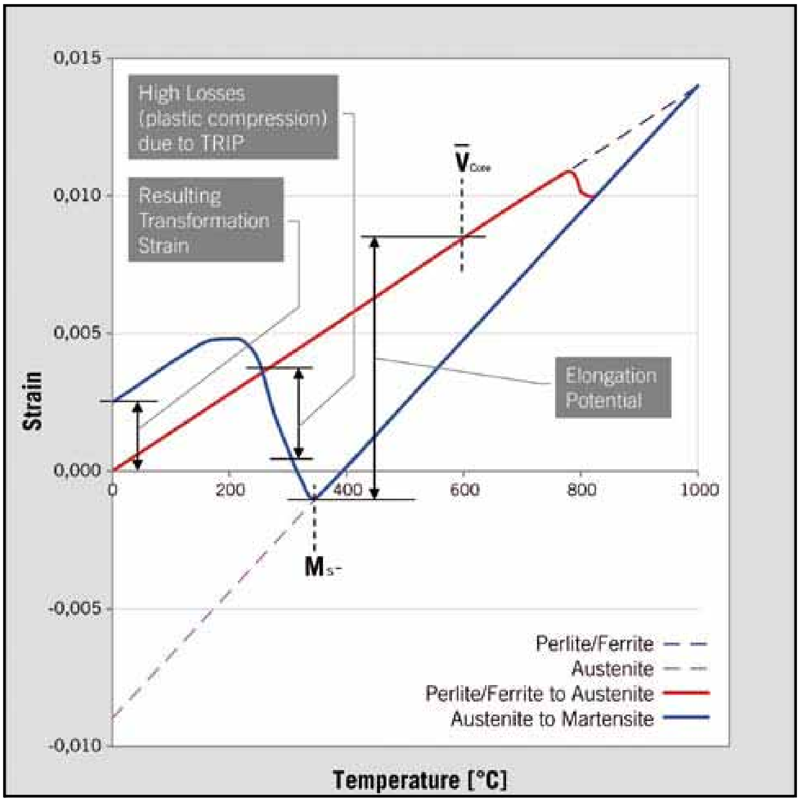
Optimizing the performance of vehicle components

The elongation potential model simplifies the explanation of residual stress creation during surface hardening



Dilatometer curve with elongation potential

It is widely accepted that residual stress can have a significant impact on the fatigue strength of hardened components. Hardening methods such as carburizing and surface induction hardening are known to normally produce beneficial compressive residual stress at the components surface. As our understanding of this complex area improves, it is becoming clearer that process conditions can have a major influence on the resulting residual stress.

The fact remains, however, that it is difficult to understand how residual stress is created during surface hardening, and complex and time-consuming to carry out simulations. Fast heating cycles, such as those employed during induction hardening, and many interacting parameters that change drastically due to phase transformation and temperature, make it difficult to get a clear picture of the creation of residual stress. This in turn makes it difficult to optimize manufacturing processes. Part of the problem lies with the existing simulation tools. Finite Element Method (FEM) simulation, for instance, can be used to visualise what happens during induction heating. But it can still be difficult to see the relations, and FEM simulation is a time-consuming, complex method that demands expensive software and hardware.

Fortunately, there is an easier, simpler alternative. The described model consists of a few key definitions, some basic knowledge of the component's metal, and a dilatometer curve.

The two mechanisms behind compressive residual stress in the hardened zone are the resulting volume expansion caused by phase transformations, and the resulting plastic elongation.

The core, here defined as the interior of the part that does not reach transformation temperature, expands thermally as a function of its average temperature. Compressive stress in the hardened zone causes tensile reaction stress in the core. This is because the forces within the part always have to balance, and the mechanisms causing the stress have to create the stress as well as its reaction stress.

Knowing these basics and the thermal and phase transformation strain curve for the actual steel - the so called dilatometer curve - we can explain the process.

The quenching phase is of particular interest. This is because as the surface layer cools, it shrinks, resulting in plastic elongation that reaches its maximum at the point where martensite transformation commences (Ms-temperature). We define the elongation potential as the difference between the core strain, which is a function of the average temperature of the core at this time, and the strain of the surface layer at Ms-temperature. The elongation potential has three elements: the elastic strain of the surface layer; the elastic strain due to the reaction stress of the core; the plastic strain of the surface layer.

Process parameters strongly influence the elongation potential. The plastic strain part of it gives a good indication of the resulting plastic elongation when taking into account that, due to transformation plasticity (TRIP), some of it is lost during the phase transformation.

The resulting expansion due to phase transformations is a linear function of the amount of carbon in solution. Expressed as linear strain, it is typically equivalent to the losses of plastic elongation due to plasticity effects during the martensite phase transformation.

To produce high compressive stress in the hardening zone a process optimized to give large elongation potential is therefore required. And since it depends on the average temperature of the core, it is crucial that process parameters be optimised for the geometry and physical size of the component.