Handbook of Residual Stress and Deformation of Steel

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Induction Hardening

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INDUCTION SURFACE HARDENING offers a number of advantages over other heat treatment methods. The most important advantages are short heat treatment times, good repeatability concerning the hardened-layer quality, small or negligible subsequent distortion, and a minimum subsequent product surface oxidation. Induction hardening offers good possibilities for automation and can be incorporated into a manufacturing cell (Ref 1, 2).

Induction surface hardening is applicable to axi-symmetric or near-axi-symmetric steel or cast iron machine parts that are produced in substantial volumes. There are two basic techniques for induction hardening of machine parts: "single shot" and "scanning." The former employs selective heating and quenching to harden a specific area or areas of the machine part in one operation. The latter is usually applied to progressively harden long, continuous sections such as shafts and spindles. In this instance, the scanning inductor traverses the length of the section, heating only a relatively small area at any given time, and is followed closely by the quench arrangement, which is often an integral part of the inductor (Ref 1, 3).

A basic characteristic of induction hardening is that heat is generated in the workpiece due to the skin effect. If a ferromagnetic material is surrounded by a load coil or inductor through which high-frequency alternating current passes, flow of eddy currents is induced in the surface layer of the workpiece due to the alternating magnetic field. The flow of these currents heats the workpiece. The mode of heating may be influenced by the workpiece arrangement in the inductor as well as by electric parameters. Heating is very fast and very reliable. Consequently, induction heating, that is, induction hardening, has become successfully established in automated production systems. Induction heating is suited to small, medium-size, and large, as well as extremely large, machine parts since, by varying energy input, heating to the required temperature and the specified case depth may be ensured.

Flame hardening is suited mostly for individual hardening of parts with large dimensions and of comparatively uncomplicated shapes. A characteristic of flame hardening is that a gas mixture is burning at the blowpipe outlet and thus indirectly heating the part surface. The machines, devices, and accessories used in flame hardening are comparatively simple and inexpensive, but the process requires an operator with much experience in blowpipe positioning if a uniform case depth without softer areas within the hardened layer is to be obtained (Ref 4, 5).

Recent hardening processes related to surface hardening are laser hardening (Ref 6, 7) and electron beam hardening (Ref 8). In both cases, heat is generated in the surface layer of the workpiece due to the interaction of the beam and the material. From the heat treatment point of view, laser can be considered a versatile and flexible high-intensity heat source that can operate in air. It is capable of undertaking a range of processes, essentially simultaneously, since the laser beam can be directed through air by metal mirrors and switched and shared among a number of workstations. Manipulative techniques using mirrors allow the beam to be directed to the areas not accessible by other techniques, for example, the bores of tubes (Ref 6, 7).

Deficiencies of laser hardening are a very low-energy efficiency in transformation of electric energy into heat energy and a comparatively high cost of investment. Laser hardening has lately become successfully established for the following specific applications only:

- Hardening of small products of intricate shapes, which are hard to adapt to induction heating
- Hardening of small internal surfaces such as small bores holes for which inductors small enough are not available
- Hardening of parts with exacting shapes, with which admissible distortion is exceeded in induction hardening

From the technology viewpoint, these surface hardening processes are very much alike since they all have to ensure adequate energy input and the case depth required. In the same manner, regardless of the hardening process applied, in the same steel the same microstructural changes, very similar microhardness variations, and similar variations of residual stresses within the hardened surface layer may be achieved.

In induction hardening, a number of suitable materials—usually plain carbon or low-alloy steels or cast irons—is austenitized and then quenched to produce a hard martensitic surface layer, which is usually tempered in a subsequent operation. Case depths normally range between 0.5 and 5 mm. Case hardnesses amount typically to around 700 HV after hardening and range between 600 and 650 HV after tempering at 180 to 220 °C (Ref 1).

Normally the hardening process also introduces compressive stresses into the surface layers, leading to an improvement in fatigue properties. Hardened parts—always ground because of their high hardness—require a minimum level of final grinding. This can only be achieved by a minimum oversize of a surface layer after hardening, thus shortening the final grinding time and reducing costs of the final grinding to a minimum. With an automated manufacturing cell, one should be very careful when selecting individual machining processes as well as machining conditions related to them. Ensuring the required internal stresses in a workpiece during individual machining processes should be a basic criterion of such a selection. In those cases when the internal stresses in the workpiece during the machining process exceed the yield stress, the operation results in workpiece distortion and residual internal stresses. The workpiece distortion, in turn, results in more aggressive removal of the material by grinding as well as a longer grinding time, higher machining costs, and a less-controlled residual stress condition. The workpiece distortion may be reduced by subsequent straightening, that is, by material plasticizing, which, however, requires an additional technological operation, including appropriate machines. This solution is thus suited only to exceptional cases when a particular machining process produces the workpiece distortion regardless of the machining conditions. In such cases, the sole solution seems to be a change of shape and product dimensions so that material plasticizing during the machining process can be prevented.

It is characteristic of induction hardening that machine parts show comparatively high compressive stresses due to a lower density of the martensitic surface layer. The compressive stresses in the surface layer act as a prestress on the most stressed part of the machine part, which increases the load capacity of the machine part and prevents crack formation or propagation at the surface. The machine parts treated in this way