Troubleshooting cracking in induction hardening

PROFESSOR INDUCTION

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Professor Induction welcomes comments, questions, and suggestions for future columns. Contact Dr. Valery I. Rudnev, group director – science and technology, Inductoheat Group, 32251 North Avis Drive, Madison Heights, MI 48071; tel: 248/585-9393; fax: 248/589-1062; e-mail: rudnev@inductoheat.com; Web: www.inductoheat.com.

The development stage was completed, the induction hardening machine was built, run-out was successful, and the machine was shipped to the customer's plant. Either right away or after a number of successful production runs, hardened parts started to crack. Unfortunately, this situation is not uncommon. This column presents a troubleshooting strategy to correct cracking problems in induction hardening.

Figure 1 is a "fishbone" diagram of cracking.[1] It includes the six major groups of factors that might cause unexpected cracking of induction hardened parts.

Material and geometry

If the part does not respond according to the expectations of a previously established induction hardening recipe, the first step to take is to ensure that the material has the correct chemical composition and proper prior microstructure.

Steels having higher carbon contents are more prone to cracking. Although the carbon content of a steel has the greatest influence on its properties, there also are other elements that affect properties and crack sensitivity. The extent depends upon the amounts and combinations of elements present.

Some elements are purposely added to provide specific properties such as strength or toughness. Other elements "just happen to be there," in trace amounts or as residual impurities of raw materials. An unfavorable combination of the latter elements could promote a tendency to crack.[1]

For example, the amounts of sulfur and phosphorus in carbon steel should be minimized to avoid brittleness and crack sensitivity. Sulfur reacts with iron, producing hard, brittle

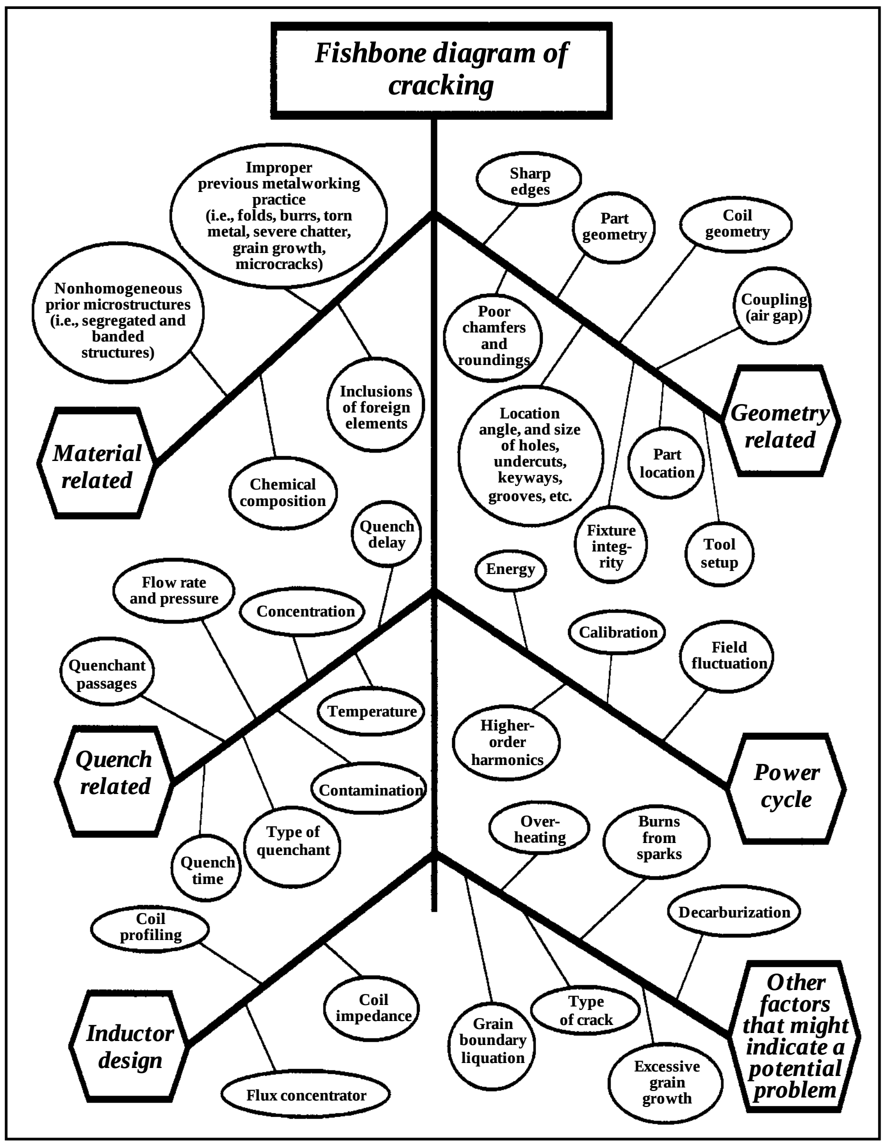

Fig. 1 — The six major groups of factors that might cause unexpected cracking of induction hardened parts. (Ref. 1)

iron sulfides (FeS) that concentrate at grain boundaries. FeS also has a relatively low melting temperature. This combination can lead to grain boundary liquation, increasing brittleness and sensitivity to intergranular cracking (Fig. 2). FeS in carbon steels is minimized by the addition of manganese to form manganese sulfides (MnS) that are distributed within grains rather than at grain boundaries, creating a less brittle microstructure.

A high level of phosphorous also can cause excessive brittleness, in both steels and cast irons. Typical maximum levels of the element are 0.12% P for gray irons and 0.04% P for ductile irons, for example.

Age strengthening: Note that the reasons for crack development when hardening cast irons might differ from those encountered when hardening plain carbon or alloy steels. For example, age strengthening can occur in gray iron castings but not in steel parts. If age strengthening does occur, some castings may harden relatively easily, while others may crack, even though heating and quenching conditions were identical.

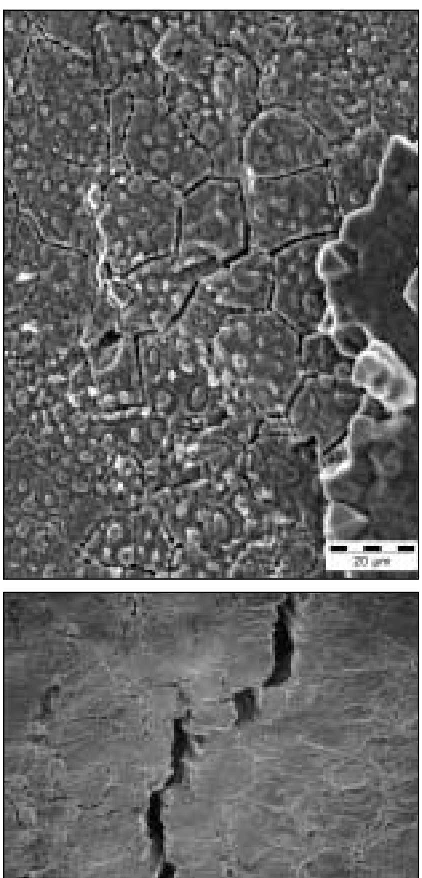

Fig. 2 — Grain boundary liquation and cracking of AISI 1038 modified steel.

In the first systematic study of the age strengthening phenomenon,[2] it was reported that aging at room temperature for about 60 days can strengthen gray iron castings by as much as 12%. The tensile strength-to-hardness ratio also increases because the hardness does not change with time. In a production environment, the time between casting and heat treating can be relatively short, and age strengthening will not occur. Thus, to ensure the reliability and repeatability of a gray iron hardening operation, it is important to conduct a run-off using relatively "fresh" castings. If castings that have been on the shop floor for some time are used for process development or run-off, you may end up hardening age-strengthened parts, which would result in a reduced probability of cracking. Results could be overly optimistic, and cracking might suddenly occur during a production run.

Geometry: It is very important in induction hardening to have correct part-to-coil and coupling (air gap) values, and to ensure proper fixture integrity and tool setup. Otherwise, local overheating could occur, resulting in excessive thermal stresses that might, in turn, cause cracks to form. Also make sure that part rotation is smooth and wobble-free. Other geometry-related factors that can increase the tendency for cracking (see fishbone diagram) include sharp corners and poor chamfering or rounding of holes and edges.

Quench-related factors

A third important group of factors in the fishbone diagram is related to quenching. In induction hardening, after the part reaches an austenitizing temperature, it is rapidly quenched to develop the desired martensitic structure. Quench severity plays an important role in providing the required hardness pattern. Selection of "fast" quenchants ensures proper conditions for martensite formation and eliminates the appearance of upper-transformation products in the hardened layer. On the other hand, quenchants that have a "mild" cooling rate typically help reduce the probability of crack initiation.

Other factors that can cause cracking include high quenchant flow rates and pressures, lower-than-optimal quench temperatures, and improper quenchant concentrations. These and other quench parameters should be periodically verified.

Note that some researchers believe that the effect of cooling rate on crack development can be represented as a bell-shaped curve. According to this interpretation, both a slow cooling rate (mild quenching) as well as an extremely high cooling rate (intensive quenching) can prevent quench cracking.

Technique: Uniformity of the quench is another important factor that should be carefully examined to prevent quench cracking. Nonuniform quenching significantly increases the probability of crack development.

Spray quenching is by far the most popular method for induction hardening applications. However, all heat treat quenchants, including water and water-based polymer solutions, have a tendency to clog quenchant-exit holes. When a particular orifice becomes clogged, the quenchant flow will be redistributed among the other holes without affecting total flow. This results in a nonuniform quench that could lead to steep local thermal gradients and cracking. Therefore, by monitoring both quenchant flow and pressure, the heat treater might be given early warning of a nonuniform quench due to the plugging of a significant number of orifices.

Do note that adoption of a quench monitoring system would not eliminate the need for regular visual inspection of the orifices.

The other factors shown on the fishbone diagram of cracking, including those related to power cycle and inductor design, also may indicate a tendency to cause a cracking problem, and should not be ignored when troubleshooting an induction hardening cracking problem. **HTP**

References

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2. "Age Strengthening of Gray Iron, Phase II: Nitrogen and Melting Method Effects," by W.M. Nicola and V. Richards: Paper 00-127, *AFS Transactions 2000*.