

EFFECT OF SURFACE HARDENING OF CARBON STEEL BY HIGH FREQUENCY INDUCTION HEATING ON ITS SUSCEPTIBILITY TO STRESS CORROSION CRACKING

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It was demonstrated that the conditional static corrosion-fatigue limit of steel 40Kh under stress-corrosion conditions depends on the depth of surface quench-hardened layer and on the initial structure of the steel.

Surface hardening of carbon steel by high frequency induction heating (HFIH) produces a considerable increase in its resistance to stress corrosion [1, 2]. The magnitude of this increase depends on the depth of surface hardening, on the strength of the specimen core, and on other factors whose influence was studied in this investigation.

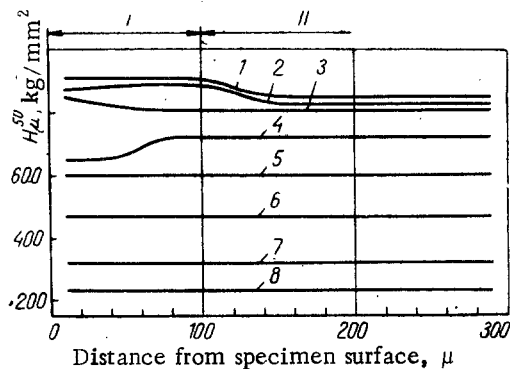


Fig. 1. Microhardness plotted against the distance from steel specimen surface. Curves 1-4 relate to specimens surface-hardened by HFIH and having the following initial structure: 1) pearlito-ferritic; 2) martensitic; 3) troostitic; 4) sorbitic. Curves 5-7 relate to specimens given an ordinary quench-hardening treatment followed by tempering at 5) 180°C; 6) 350°C and 7) 550°C; curve 8 relating to annealed specimens.

steel with the initial pearlito-ferritic structure is substantially higher after surface hardening than after ordinary quench-hardening (Fig. 2, curves 1, 4, 5, 6).

Increasing the surface-hardening depth from 0.8 to 2.5 mm produces a slight increase in the conditional static corrosion-fatigue limit (stress-to-rupture). The optimum surface-hardening depth for steel with an initial pearlito-ferritic structure is 1.8 mm. A larger increase in the conditional static corrosion-fatigue limit is produced by surface hardening of specimens with a harder (in comparison with pearlito-ferritic) core. And so, surface hardening by HFIH produced a 2.5-2.8 increase in the conditional static corrosion-fatigue limit of specimens which initially had a martensitic, troostitic or sorbitic structure (see Fig. 2), the optimum surface-hardening depth being 0.6, 1.2 and 1.4 mm, respectively.

Although the stress-corrosion resistance of steel after surface hardening is usually higher than after ordinary quench-hardening, the latter treatment followed by tempering at 550°C ensures a much higher resistance to stress corrosion (Fig. 3). Consequently, the surface hardening by HFIH may be recommended as a means of improving the stress-corrosion resistance of parts working under conditions that require a high surface hardness.

Data plotted for specimens with different structures surface-hardened to the same depth (Fig. 3, curve 2) or to the optimum depth for a given structure (Fig. 3, curve 3) shows that in both cases the maximum value of the conditional static corrosion-fatigue limit after surface hardening by HFIH was recorded for steel with a troostitic structure and the lowest for specimens with a pearlito-ferritic structure.

The differences in the stress-corrosion resistance of steel given a surface-hardening treatment are associated with

The surface hardening of steel 40Kh specimens was done by heating them continuously and progressively in a single-coil inductor of a HF induction set LGPZ-60 (frequency = 200-300 kc, power rating = 60 KW). The initial structural state of the specimens varied: some had a pearlito-ferritic structure (produced by annealing) while some consisted of martensite, troostite or sorbite (produced by quenching the specimens from 850°C and tempering them for 2 hr at 180, 350, or 500°C, respectively). The depth of the surface-hardened layer was 0.8, 1.8 mm in martensitic specimens, 1.2 and 1.8 mm in specimens consisting of troostite, and 1.4 and 1.8 mm in the case of specimens with a sorbitic structure. The depth of surface hardening was uniform in both the radial and axial directions. After the surface hardening, the specimens were tempered (2 hr at 180°C) and ground to a Class 8 surface finish. The hardness of surface-hardened layer was HRC = 55-57; the variation in the microhardness with the distance from the specimen surface is shown in Fig. 1.

Stress-corrosion tests were carried out on cylindrical specimens (20 mm diam.) stressed in tension in a 20% H<sub>2</sub>SO<sub>4</sub> solution at room temperature.

The results showed that the stress-corrosion resistance of

differences in the structure of the material and in the magnitude of residual stresses produced in the metal surface layers (Fig. 4).\*

Surface hardening by HFIH of specimens with an initial pearlito-ferritic, troostitic or martensitic structure produced surface layers consisting of two zones (I, II) possessing different microhardness (Fig. 1) and structure.

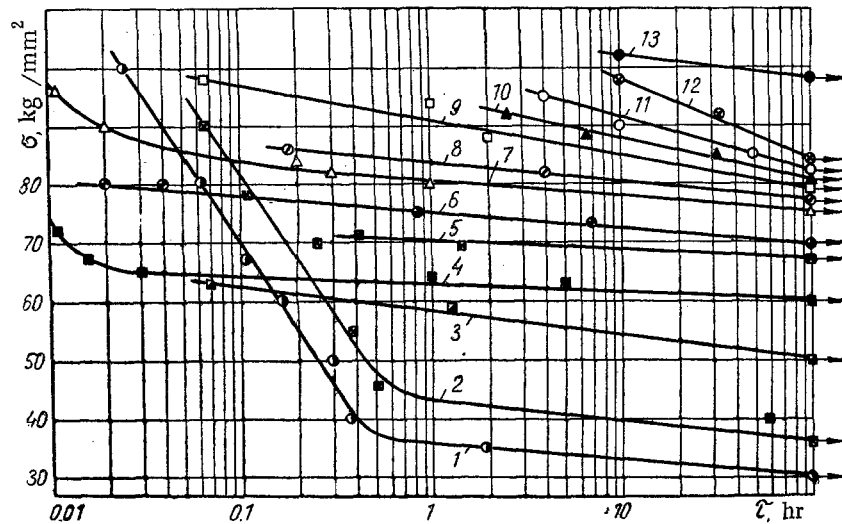


Fig. 2. Stress-corrosion curves of steel 40Kh specimens after the following heat treatments: 1, 2, 13) ordinary quench-hardening followed by tempering at 180, 350, and 550°C, respectively; 3, 4) surface hardening of steel with a pearlito-ferritic structure by HFIH to a depth of 0.8 mm, curves 3 and 4 relating to specimens with one and several surface cracks, respectively; 5, 6) surface hardening of steel with a pearlito-ferritic structure by HFIH to a depth of 2.5 and 1.8 mm, respectively; 7, 10) surface hardening of steel with a sorbitic structure to a depth of 1.8 and 1.4 mm, respectively; 8, 11) surface hardening of steel with a martensitic structure to a depth of 1.8 and 0.6 mm, respectively; 9, 12) surface hardening of steel with a troostitic structure to a depth of 1.8 and 1.2 mm, respectively.

The microstructure of the surface layer of steel with an initial pearlito-ferritic structure is characterized after surface hardening by a highly dispersed martensitic structure and a high microhardness (Fig. 1, curves 1, 5); a certain reduction in microhardness observed in zone II is attributable to a larger grain size.

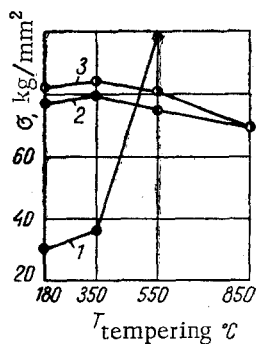


Fig. 3. Conditional static corrosion-fatigue limit plotted against the tempering temperature of specimens given the following treatment: 1) ordinary quench-hardening- 2) surface hardening by HFIH to a depth of 1.6 mm; 3) surface hardening by HFIH to the optimum depth.

In the case of specimens with an initial troostitic structure, surface hardening led to the formation of surface layers consisting of acicular martensite with an increased troostite content and having, as a result, a slightly lower microhardness (Fig. 1, curve 4, zone I); this zone changes gradually to finely dispersed martensite with a higher microhardness (Fig. 1, curve 4, zone II).

Surface hardening of specimens with an initial martensitic structure produces surface layers which consist of finely dispersed martensite changing to a more coarsely-crystalline martensite with small troostite regions; the maximum microhardness is observed in zone I (Fig. 1, curve 2).

\*The determination of residual axial stresses was done by measuring the strain of specimens from which successive surface layers were removed by dissolution [3].

Surface layers produced by surface hardening in specimens with an initial sorbitic structure have a more homogeneous structure (finely dispersed martensite) whose microhardness does not vary much with the distance from the specimen surface (Fig. 1, curve 3).

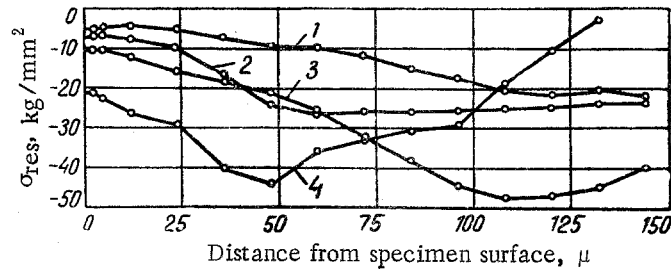


Fig. 4. Distribution of residual stresses after surface hardening by HFIH of steel specimens with a pearlito-ferritic structure to a depth of 0.8 and 1.8 mm (curves 1 and 4, respectively), with a sorbitic structure to a depth of 1.4 mm (curve 2), and with a martensitic structure to a depth of 0.6 mm (curve 3).

And so, rapid HFIH during surface hardening of steel specimens with various initial structures leads in every case to a refinement of the crystal structure and to an increase in microhardness. As a result, residual compressive stresses are produced in metal surface layers; their extent and distribution depend on the depth of surface hardening, heating and cooling rates, changes in the specific metal volumes and other factors.

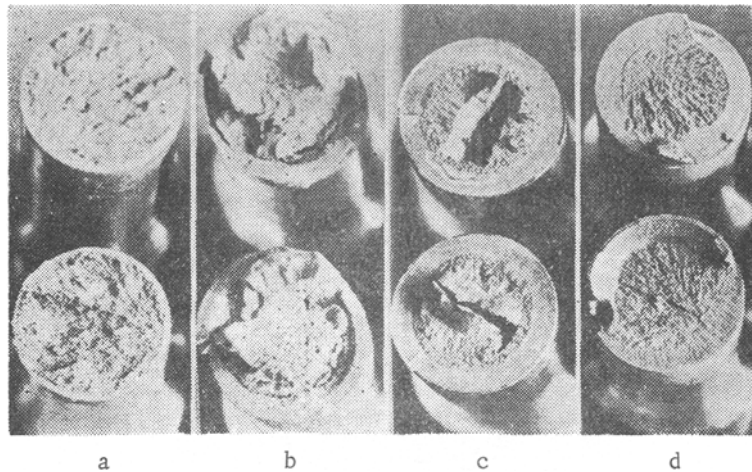


Fig. 5. The appearance of fracture surfaces of surface-hardened specimens of steel 40Kh with the following initial structures: a, b) pearlito-ferritic; c) troostitic; d) martensitic.

When surface-hardened specimens of steel with an initial pearlito-ferritic structure are stress-corrosion tested, numerous closely situated cracks are formed on their surface; due to the self-relieving effect [5] these cracks produce a smaller reduction in the conditional static corrosion-fatigue limit than that produced by a single crack\* (Fig. 2, curves 3, 4).

The fracture surface of these specimens is clearly divided into two zones: a zone of the propagation of a corrosion crack through the surface-hardened layer, and the zone of ultimate fracture in the specimen core (Fig. 5a). In isolated cases a brittle fracture took place as a result of simultaneous propagation of several cracks, as a result of which a step-like fracture surface was produced (Fig. 5b).

In the case of surface-hardened specimens with initial sorbitic, troostitic (Fig. 5c) and martensitic (Fig. 5d) structures, the fracture took place along the path of the first crack formed; metallographic examination revealed no other cracks in specimens of this kind.

\*The formation of a single crack was ensured by painting the specimen gauge portion with a bakelite varnish and then making a circular incision in the varnish coating to expose a very narrow band of specimen surface.

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