Cost reduction opportunities in induction surface hardening processes for smaller diameter cylindrical loads

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Abstract-This article focuses on the possibilities of improving the efficiency of induction surface hardening (ISH) processes using a specialized spray-quench device. This quench is fabricated using 3D printing, and the load is cooled by a quenching spray tangentially fed to its surface. Furthermore, the paper presents the results of several specific experiments which show how the tangential spray-quench device can influence the quenching phase of the ISH process. It is shown that the influence of the surface temperature of the load can be realized not only by the amount and type of quenching medium but also in what way the quenching medium is fed to the surface of the load.

Keywords-induction surface hardening, tangential spray-quench device, 3D print

I. Introduction

The induction surface hardening (ISH) process aims to achieve the load's desired surface hardness and strength. The load is usually a stressed machine part that must be heated during the first phase of ISH according to the appropriate temperature transformation austenitization diagram (TTA). The load is then quenched according to the (CTT) or (CCT) austenite decay diagram, depending on the specific steel and the desired final hardness during the subsequent ISH phase.

ISH usually involves a low-temperature tempering process to reduce the stresses created within the load in the ISH process. By significantly eliminating the stresses in the load, the tempering process reduces the risk of possible cracks on the load's surface. The tempering process may consist of volumetric heating of the load in the furnace to its tempering temperature or repeated induction heating. This usually results in a reduction in micro-creep and a decrease in the resulting hardness of the load depending on the temperature selected. [1, 2, 3]

II. Load

A. Formation of internal tension

A closer look at the ISH shows that the stresses in the load occur when the surface temperature of the load is lowered below the martensitic start temperature of about 300 °C. Since the transformation of the starting austenite to the martensite is the so-called athermal, no intensive cooling of the load is necessary below this temperature. Therefore, it is advisable and often used in this final stage to reduce the load's cooling rate and thus limit the formation of stresses in the load. It is also possible to take advantage of the internal heat in the load to reduce the stress level and, to some extent, to use the so-called self-tempering. If the cooling rate in the final stage of the ISH process is appropriately controlled, the subsequent tempering process can be omitted.

B. Elimination of tension

When using a conventional spray-quench device in ISH processes (such as in Fig. 1), the load is usually cooled to the temperature of the quenching medium, which is usually water, during quenching. By adding polymers to the water, a favorable modification of the load quenching process in the final stage of ISH can be achieved [4].

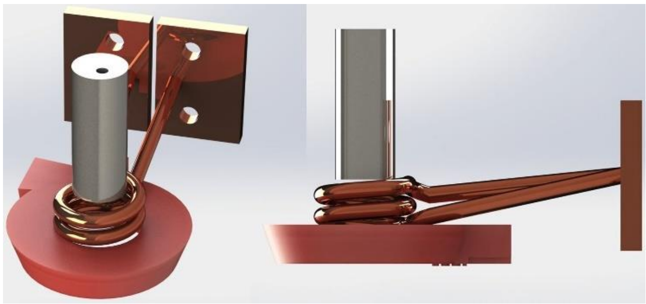

Fig. 1 Standard arrangement of components in ISH process, inductor, load, spray-quench device. [4]

In practice, solutions of polymers based on PAG (polyvinyl alkylene glycol) are most commonly used in the ISH process. Usually in the concentration range of 6% to 20%. However, this solution increases the price of the ISH process and requires higher investment costs for specialized management of quenching media. Quenching bath with polymers must be constantly checked, refilled, swirled, etc. The aerosols released during the ISH process condense on the surrounding surfaces. This phenomenon can subsequently lead to failures of electrical and mechanical components of induction systems. The danger for personnel was that the additives previously used in polymers were considered to be carcinogenic substances. In general, this solution worsens the quality of the environment.

III. Experiments

After several experiments carried out using a specialized spray quenching device made by 3D printing (FFF) and a specific method of quenching the load, it turns out that the ISH process can be controlled in the desired way even if the hardening medium is pure water.

The experiments aimed to define the influence of tangential spraying of the deposit on its final temperature after the hardening process, depending on the direction of rotation of the load with respect to the quenching spray and the distance of the spray from the tangent with its surface.

Two quenching media, water and 8% water-polymer (SERVISCOL 98SK-F1) solution were used during the experiments. A high-speed camera was used to study how the water spray behaves on the surface of the load. It captured the ISH processes taking place on the surface of the load as it was being focused. At the same time, the surface temperature after the quenching process was captured by the thermal imaging camera. Subsequently, the maximum, minimum, and average surface temperatures were evaluated to assess the cooling efficiency of the different spraying methods. The following Fig. 2 shows the relative arrangement of the spray-quench device and the load, while the green arrows in the figure show how their manipulation was implemented during the experiments.

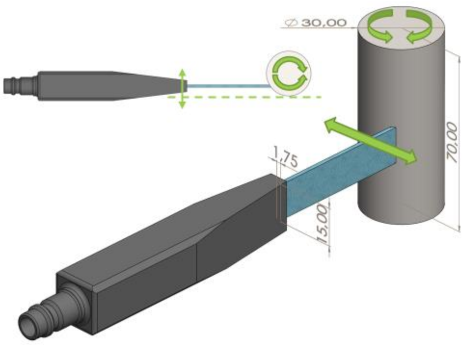

Fig. 2 3D model showing the relative arrangement of the spray quench and the inlet during tangential spraying. All dimensions are in mm.

During the experiments described above, the parameters affecting the ISH process were set identically. The main parameters are listed in TABLE 1.

TABLE 1 ISH process parameters, which are the same for all experiments

Load				Generator		Transformer	S-quench device
steel	*diameter (mm)*	*height (mm)*	*moving speed (mm/s)*	*I (A)*	*fr (kHz)*	*Conversion (-)*	*flow rate (kg/m)*
EN 34CrAlNi7	30	70	2	85	28	16:1	11

IV. Results

Next, Fig 3. shows the temperature field distribution captured by the IR camera on the load's surface after the ISH process. The spray direction in Fig. 3 is opposite to the direction of the rotating load. Spray dimensions 1.75 x 15 mm. The green arrow in Fig. 3 shows the rotation direction of the load. The blue arrow in Fig. 3 shows the spray direction. The situation in Fig. 3 corresponds with the point/variant "W OD" in Fig 4.

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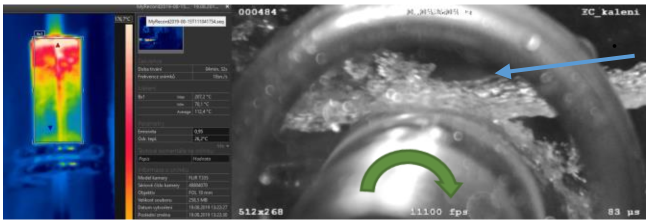

Fig. 3 The left side of the figure shows the temperature distribution in the load surface after the ISH process (front view). Min. temperature on the load surface is, in this case, 70 °C and the max. temperature is 207 °C. Generally higher differences between min. and max. were in cases when pure water was used. The right side shows a figure from a slow-motion camera during the ISH process (top view).

In summary, the Fig. 4 shows results of the eleven implemented ISH experiments and demonstrates the indicating symbols near the measurement results. The results show the average temperature of the load surface as a function of the distance of the quenching spray from the tangent to its surface.

Fig. 4 Experiments results, W means water, P8 means water solution with 8% polymers, SD means the load is rotating in the same direction to the water stream, OD means the load is rotating in the opposite direction to the water stream.

Discussion of Results

As presented in Fig. 4, the best cooling effect of the quenching medium was found in the case where the distance of the quenching spray was about 2 mm from the tangent with the surface of the load. In this instance, the average surface temperature of the load was the lowest of all experiments. Except for the case where the resulting average surface temperature of the load after ISH process was around 400 °C, all other samples reached the minimum hardness defined in the technical delivery conditions of the respective steel. From the results of the experiments carried out, it is clear that by a suitable configuration of the tangential spray-quench device in relation to the load, the desired load temperature can be achieved after the ISH process. Current experience show that it should be also possible to quench other steels by this ISH method. Further study will confirm these assumptions. A corresponding numerical model is also in preparation.

References

[1] Valery, R., and George, E. T., eds. 2014, *Induction Heating and Heat Treatment 4c*, ASM International.

[2] Rudnev, V., Loveless, D., and Cook, R., 2017, *Handbook of Induction Heating*, Routledge.

[3] Totten, G. E., 2002, *Handbook of Residual Stress and Deformation of Steel*, ASM international.

[4] Hájek, J., Rot, D., and Jiřinec, J., 2019, "Distortion in Induction-Hardened CylindricalPart," *Defect and Diffusion Forum*, Trans Tech Publ, pp. 30-44.