INFLUENCE OF THE BEAM DEFLECTION ON PROPERTIES OF THE ELECTRON BEAM HARDENED LAYER

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Abstract: *The usage of the high-energetic source of the electron beam enables a repeated surface quenching of the chosen areas of an engineering part surface. Different techniques of the electron beam deflections allow the creation of hardened layers of different shapes and above all the thicknesses. The deflection was tested at one point, six points, a line and a field on the material 42CrMo4 (1.7225). The effect of the process speed and defocusing of the electron beam was studied. The electron beam surface quenching resulted in a very fine martensitic microstructure with the hardness over 700 HV0.5. The thickness of the hardened layers depends on the type of deflection and depends directly on the process speed. The maximum observed depth was 1.49 mm. The electron beam defocusing affects the width of the hardened track and can cause an extension of the trace up to 40%. The hardness values continuously decrease from the surface to the material volume.*

Keywords: Electron beam, hardening, quenching, 42CrMo4, deflection

1. Introduction

An electron beam (EB), together with laser, is one of the most modern technologies used for the local surface heat treatment. Both of the methods have some similar characteristics; however there are clear differences predetermining which of them will be chosen. The fast beam deflection characteristic for the EB allows a different distribution of the supplied energy at an adequate programming of the quenching equipment. A deflection of the EB can be realized both in a direction perpendicular to the direction of the components movement and also in a parallel direction. [1-5]

The properties of the quenched layer can be directly controlled by process parameters. The total supplied power rate is controlled by a combination of the accelerating voltage „U_{EB}“ and the electron current „I_{EB}”. This energy is distributed to the components surface depending on the selected type of the EB deflection. The scanned area is determined by dimensions „SWX“, „SWY“ and is set together with the scanning frequency in the individual directions „FRQ“, „FRQ2“ (Fig. 1). Usually some beam defocusing „Offset“ is set up, which can be realized by a shift of the focal plane above the quenched surface (a positive value) or below the surface (a negative value). The last very important parameter is the quenched component movement rate “v_s” below the quenching beam „EB“. [6-10]

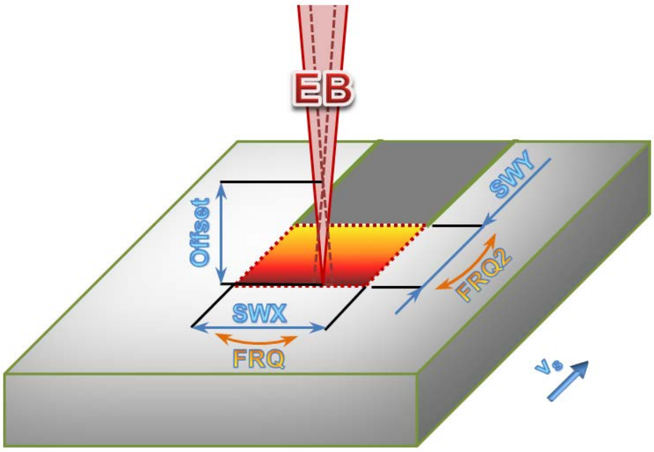

Fig. 1 *The EB surface quenching parameters scheme.*

2. Experimental material and methods

Experiments were carried out on the high grade steel 42CrMo4 (1.7225) with the chemical composition of (wt%): C 0.41, Mn 0.69, Si 0.25, Cr 1.04, Mo 0.20), which is a suitable material for the surface quenching. It finds an application where there is a requirement for an elevated strength in a combination with a defined and high level of toughness. The tested material was in a state tempered at the temperature of 600 °C with a fine sorbitic structure and an average hardness 300 HV0.5.

The surface quenching was performed on the PROBEAM K26 equipment adopting the electron beam technology with a maximum beam power of 15 kW and an accelerating voltage from 80 to 150 kV. The width of the EB hardened traces were set to SWX = 10 mm except of one point deflection. The constant accelerating voltage U_{EB} = 80 kV was used for the experiments and the electron beam current I_{EB} was subsequently optimized for each machines configuration. One point, six points, a line (consisting of 1.000 points) and a field were tested as the EB deflection modes and many more influences of a defocusing degree and a movement rate in each mode on the quality of the hardened layer were observed. A common “Offset” values for each mode were 50, 100, 200 and 300 mA and common v_s were 5, 10, 15, 20 and 25 mm·s^{-1}.

The field deflection mode was programmed to allow a local energetic density increase within a given area. This is used for an intense heating at the surface of a treated material during the progressive quenching. The rest of the area, with the lower beam intensity, contributes to the heating of the material deeper to the volume. The length of the field SWY was determined for each movement rate based on the change of a temperature across the affected area on the sample measured with a pyrometer.

The metallographic specimens prepared by standard procedures were analyzed by the optical and the scanning electron microscopy. LECO LM 247 AT microhardness tester was used to analyze the hardness HV0.5 changes (a hardness profile) from the surface to the volume in the quenching trace axis. For the microstructural characterization, the scanning electron microscope (SEM) ULTRA PLUS, Carl Zeiss GmbH, Germany, equipped with dispersive X-ray spectrometer (EDS) X-MAX, Oxford Instruments, England, was used. For the surface analysis, the detector of the secondary electrons (SE) type Everhar-Thornley and the four-quadrant silicon detector of back scattered electrons (BSE) were used.

3. Results

Traces heaving width of 10 mm were processed by a surface quenching on the 42CrMo4 high grade steel. Basic experiments were optimized from the point of view of the used electron beam current I_{EB}. The optimal energy density conditions were estimated only based on the observation of the occurrence of melted areas on a specimen surface. The melted areas were brighter than the quenched ones. A slightly molten surface could not be identified by observing the microstructure because it was also a fine martensitic structure. The maximum hardness of the quenched and the molten material was the same and therefore it could not be used to determine the optimal EB current for hardening.

The length of the field deflection was determined by a pyrometric measurement of the temperature profile within the irradiated area. Too long SWY caused a significant drop in a temperature, while too short one did not exploit all the potential of the technology. An optimized parameter SWY for an individual tested movement rate are given in the Table 1.

Table 1: *Optimal length SWY of the field resulted from temperature profile.*

Movement rate	$mm \cdot s^{-1}$	5	10	15	20	25
Field length	mm	5	8	12	18	25

From the macroscopic point of view, a constant width of traces was observed in the beam movement direction. A continuous quenching depth decrease to the trace edge was observed in the direction perpendicular to the beam movement (Fig. 2). The microstructure in the surface quenched area of all the traces consisted of a fine martensite (Fig. 3). The finest martensite was obtained at the one point deflection and the coarsest at the field one. A continuous change of the fine martensitic structure to the basic material created by a tempered martensitic structure with complex carbides was observed in the transition area (Fig. 4).

Fig. 2 *The macrostructure of the surface hardened area in a perpendicular direction - field deflection.*

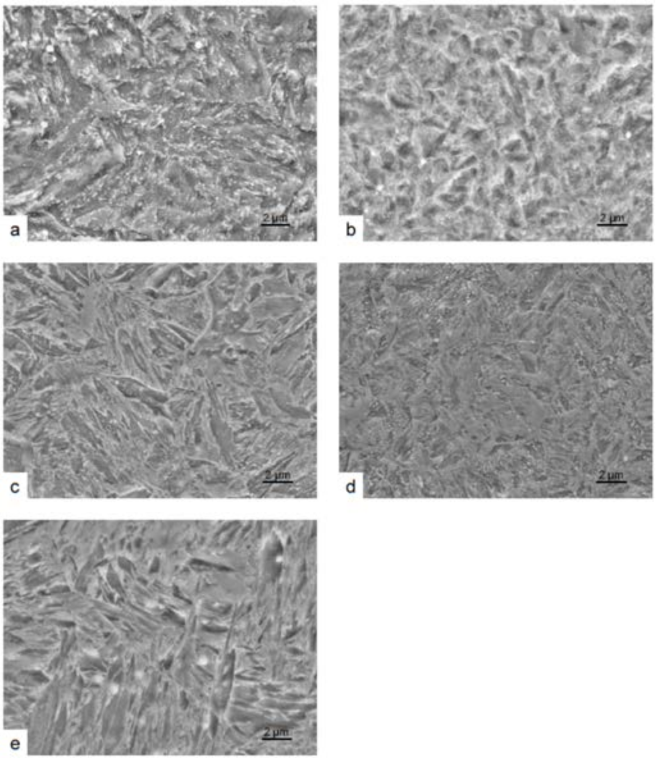

Fig. 3 *The microstructure (SE) of (a) basic material, and hardened layers, (b) one point, (c) six points, (d) line, and (e) field deflection regimes respectivelly.*

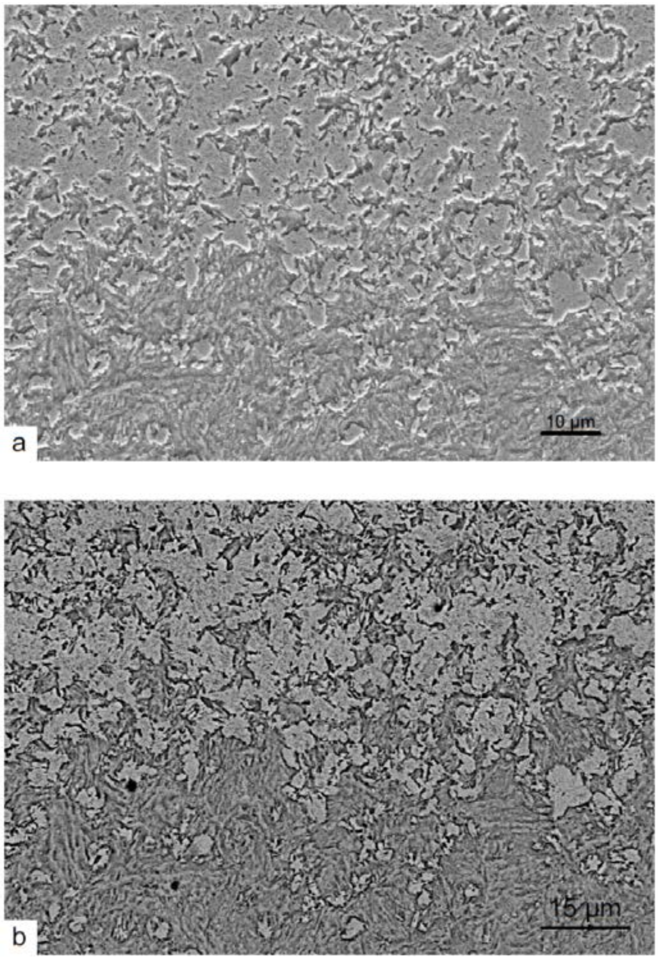

Fig. 4 *The microstructure of the transition area of field deflection sample, (a) SEM – SE mode, (b) SEM – BSE mode*

The comparison of the profiles of hardened layers made by different deflection modes shows that the lower number of deflected points forms a wider track - Fig. 5 (except one point regime). The track made by the field deflection is the deepest and the one made by the one-point deflection the shallowest one. They both have a significant curvature in the comparison to the 6 points or the line deflections that are rather parallel to the surface. Different movement rates have a negligible influence on the profile of the trace. The Offset has a significant effect on the shape of the track. As the value rises, the trace is wider and, on the contrary, too low values lead to an easier melting as well as a significant deformation of the profile of the trace - Fig. 6.

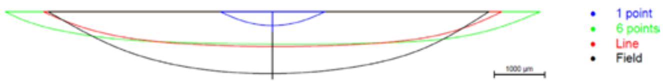

Fig. 5 *Comparison of the profiles of hardened layers*

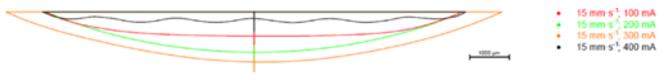

Fig. 6 *The influence of Offset on the profiles of the hardened layers –6 points deflection*

The movement rate has only a little effect on the depth of the hardened layer (Fig. 7) once applying one-point deflection and the field deflection. For the field deflection, it is the result of optimizing the field length SWY. The depth depends significantly on the movement rate for the 6 points and the line deflection. The depth gradually increases with the decreasing speed and the greatest difference can be seen between 5 and 10 $mm \cdot s^{-1}$.

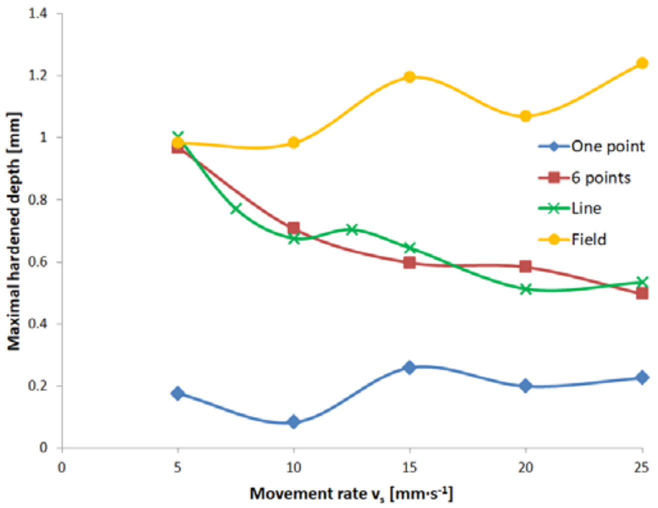

***Fig. 7** The influence of movement rate v_s on maximal hardened depth*

The increasing Offset leads to an increase of the hardened layer depth (Fig. 8). It is interesting that at higher values of the Offset there is no significant difference between deflections. The one point and the field deflection differ from the other ones with a lighter response to an Offset change.

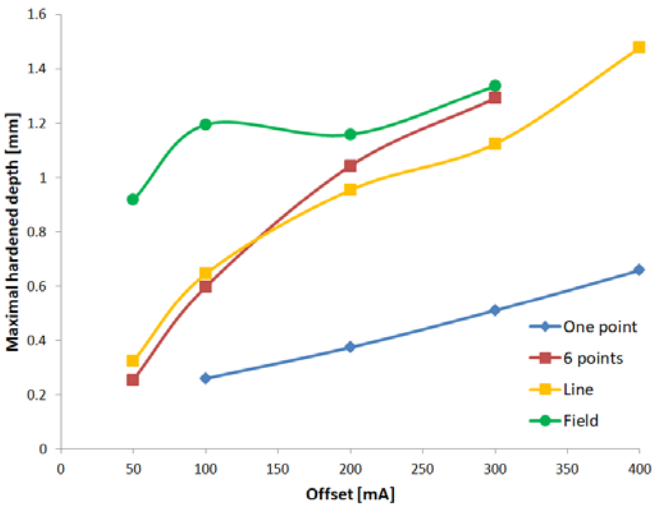

***Fig. 8** The dependence of maximal hardened depth on the defocusing Offset*

Maximal hardness values (up to 740 HV0.5) were reached by the one point deflection because the heating and especially the cooling processes are very fast. The experiments with the other deflection's modes give the hardness between 600 and 700 HV0.5. The measured values decreased from the surface to the volume. The continuous decrease of the microhardness was observed on the interface between the quenched area and the basic material. No decrease of the microhardness of the basic material was observed near the hardened traces (Fig. 9). Hardness profiles were the same in the middle of the track as closer to the edges (except the different hardening depth).

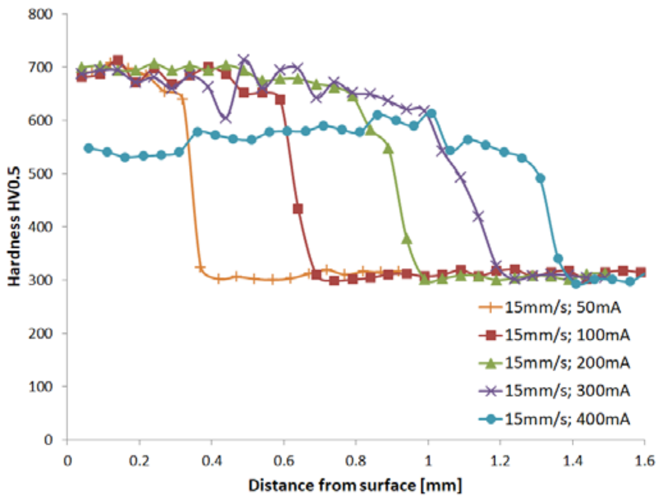

***Fig. 9** The influence of the defocusing Offset on the hardness profiles of layers*

It was not confirmed that the movement rate affects the hardness. Too high defocusing causes a total reduction in the hardness in the entire layer. The Offset value 400 mA resulted in the average hardness of 570 HV0.5 of the hardened track and it represents a 20% decrease in comparison with a sharper beam (Fig. 9).

4. Conclusion

The work was focused on effect evaluation of the type of a deflection (one point, 6-points, line, field) of the electron beam on the hardened layers. The results showed that the deflection mode can affect a number of track parameters. The martensitic structure is the finest by the one point deflection and the coarsest one is formed by the field deflection. This mode affects a little the maximum hardness. The highest hardness 740 HV0.5 has been observed by the one point deflection. For the other regime types, the maximum values are near 700 HV0.5.

The geometric profiles of the tracks in cross-sections are different for each of the applied deflection types. The 6-points and the line one are parallel to the surface and the one point together with the field one are significantly curved. The widths of the tracks were similar except of the one point regime. The depths of hardened layers were in the range 0,1-1,5 mm. The lowest depth of tracks was made by the one point deflection and the deepest one by the one point.

The movement rate affects only the depth of the hardened layer. The depth slightly increases with the speed decrease. The defocusing affects the depth more significantly. Moreover, the increasing Offset leads to wider tracks. Too low Offset can severely distort the profile of the hardened layer. Too high values again lead to an overall reduction in the hardness of the layer. The lower Offset can considerably distort the profile of the hardened layer. Too high values lead to a total hardness reduction of the layer.

Acknowledgments

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