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THE ELASTIC-PLASTIC RESPONSE OF HADFIELD STEEL UNDER INDENTATION TEST

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1. INTRODUCTION

Austenitic manganese steel, known as Hadfield steel, is specially employed for the casting of railway crossings, because of exceptional work hardening capacity and fracture toughness, proved by many experimental works [3] Depending on the loading conditions, a rapid deterioration of parts can occurs if wear is faster than work hardening. Explosive hardening is therefore prospective way to improve the service life [1]

In presented study, the rolling contact fatigue (RCF) resistance of Hadfield steel was tested at two states, with and without explosive hardening. Experimental loading was adjusted to real operational ratio between the normal loading and longitudinal slip. Strengthening effect of surface layer was monitored at chosen loading stages and verification of experimentally induced degradation process was based on structural analyses of operational induced process. Instrumented indentation test was employed for evaluation of elastic-plastic capacity under influence of hardening in compared states of Hadfield steel.

2. METHOD OF EXPERIMENT

In service, railway crossings are submitted to rolling stresses and heavy impact loads resulting from the change of train wheels from the wing rail to the nose rail. These repeated contact stresses will harden the top surface layer of the crossings. Therefore, Hadfield steel railway crossings exhibit excellent wear resistance. In this study, Rolling contact test was performed. Sample from rolling contact test was cut out and applied several indentation test by using 2 types of indenter.

Sample for analyses of real degradation mechanisms was cut out from railway switch, cross section was 40mm in width of contact track, i.e. In position typical by high dynamic operation loading. Chemical composition of tested Hadfield steel was in full accordance with the standard EN 15689.

The degradation process was simulated by specialized wheel-test rig, which enables the rolling contact loading at defined ratio of the contact pressure and longitudinal slip. The contact is induced between the wheel with 920mm in diameter and special sample holder - disk 136mm in diameter. The principle of the test is displayed in Fig.1. The tested samples may be pull-out from the holder during the test and can be subjected to complex material analyses in chosen stages of the fatigue test. Presented test was focused on the degradation mechanism in defined state of rolling-contact loading, so the evaluation consisted of following parameters: surface hardening (in HV10 values), depth of the plastic zone, character and depth of surface damage (i.e. the slope and depth of surface microcracks) and wear rate, measured by weight loos between defined steps of loading. The test was performed at contact pressure P_{max}= 1140MPa, relative longitudinal slip s = 1%. Dynamic response of Hadfield steel was evaluated in two conditions - after typical process of fabrication vs. after explosive hardening process. The influence of explosive hardening at degradation mechanisms was estimated within this experiment.

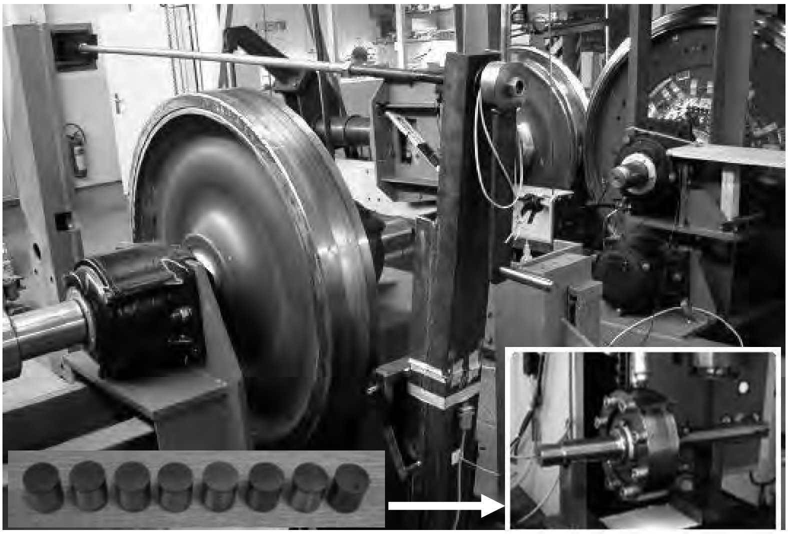

Figure 1 Rolling-contact fatigue testing equipment, detail on holder for set of tested samples

The structural analyses were performed in the final state of examination, i.e. after 1mil. loading cycles. Intensive dislocation hardening up to depth of 700 μm was observed by metallographic analysis in cross sections directed according to rolling contact in Fig.2. White etching layer (WEL) is a phenomenon that occurs on the surface of rail when it is in service due to the action of wheels. Its name arises from its resistance to etching by acids during metallographic preparation and its white featureless appearance under the optical microscope. It is commonly found in patches, approximately 20–100 μm deep, on the surface of rail after it has been in service for several months [4]

Two different mechanism of surface microcracks initialization were involved in the wear during the rolling contact. The first one was a creation of surface layer similar to “White Etching Layers” (WEL) typically formed in pearlitic railway steels. This name was derived from its white appearance, resulting from its higher corrosion resistance against metallographic etching. Contrast phase was created by simulated contact fatigue up to depth of 30μm, typical was different level of plastic deformation inside these layers. The voids and microcracks are created directly in this layer approximately perpendicularly to the contact surface, apparently as a consequence of fragility of these microvolumes. Surface hardness in that positions, measured up to over 700 HV10, proved limited decreasing of plasticity. Microcracks, initiated at interface with bulk material or in sublayers with less intensive plastic deformation, was typically propagated along the interface with different intensity of induced transformation. Mentioned tendency is pictured in detail of Fig.2, for tested material without previous explosive hardening. Initiated microcracks propagated until a wear flakes were formed at the surface. Based on continuous contact surface observation, this stage of degradation process corresponds with the onset of increased wear rate at about 300000 cycles of experimental loading.

The different degradation process was connected with ductile shear caused by the progressive shear deformation. Surface fatigue cracks are initiated and propagated by a low cycle fatigue mechanism, driven by cyclic plastic strain. While the microcracks in the “WELL” was subjected to intensity of inhomogeneous deformation, the RCF cracks followed the plastic flow. In the operational conditions, the surface cracks due to RCF, well known as a “Head check”, are perpendicular to the running direction of the wheel.

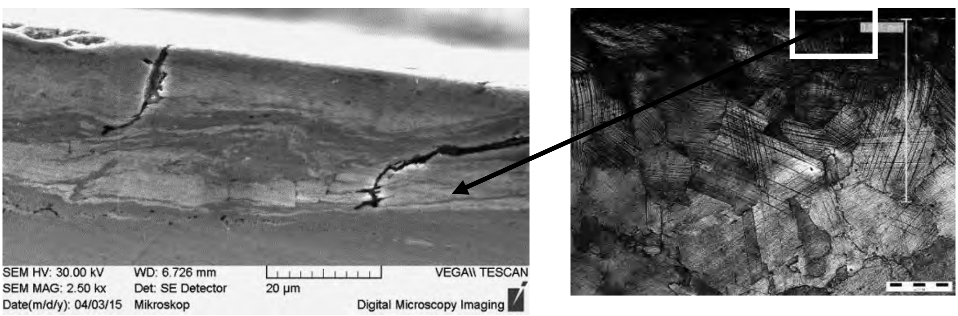

Figure 2 Creation of the well and microcracks.

Metallography analysis of Hadfield was explained before. Several types of indentation test were applied to observe rolling contact test effect and explosive hardening effect. In the first stage, Vickers indenter according the standard ISO 14577-1 was used.The depth of contact–fatigue strengthening was necessary to determine for reliable measurements of surface layer state. The gradient of experimentally induced surface changes was measured by hardness changes directed perpendicular from loading surface towards to the axis of samples. Hardness test was applied by 200 micrometer interval. Fig.3. presents the differences in intensity and depth of strengthening for compared stages of tested steel – with vs. without explosive hardening.

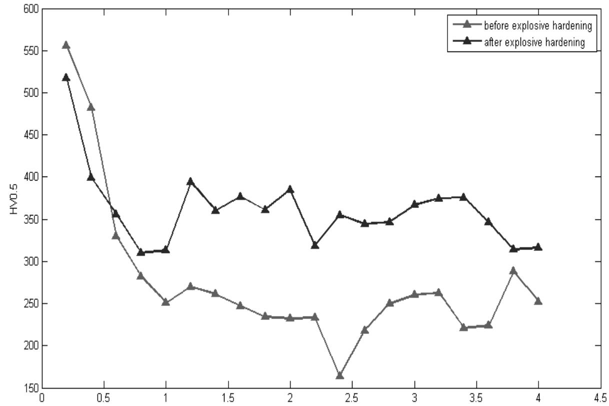

Figure 3 Record of instrumented test by Vickers indenter from surface

In second stage, comparative yield stress CYS [N/mm^2] was determined by using 1.2 mm cylindrical indenter which was applied to obtain indentation depth corresponding to linear force. HM (N/mm2) was found bellow. As is presented in Fig.4, this curve tends to be tangential curve. Indentation depth is increasingly increasing characteristic corresponding to force until yield point (1105 N/mm^2, 930N/mm^2).

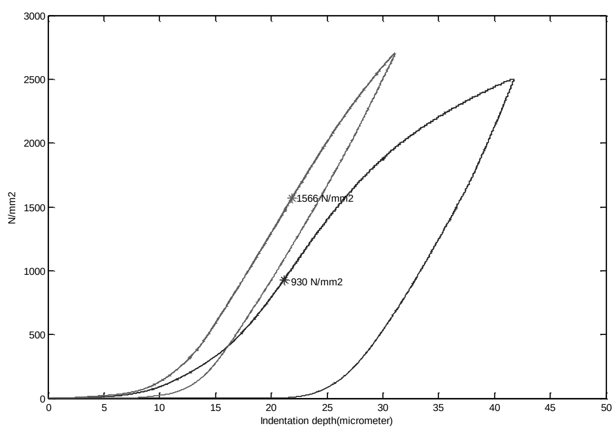

Figure 4 Finding Comparative yield stress CYS [N/mm^2] by using cylindrical indenter (red line explosive hardening, blue line without exp. hardening)

Assumed point gives us transition zone of elastic to plastic deformation. Tests were performed for two samples which is explosive and without explosive hardening. According to hypothesis [3] about behavior of the material during extrusion of a cylindrical indenter, we used the constant 2.57 as a ratio of compressive stress applied by indenter to shear yield stress.

At final stage, in order to ensure that the estimation of the measured material parameters is not affected by local surface imperfection, the evolution of HM at each point of the evaluated samples was represented as function of the indentation depth.

This stage Vickers indenter was used and observed indentation depth change corresponding to linear force increase. Fig.5 shows examples of this control. It follows that for indentation depths higher than around 5mm becomes constant. The same attitude was used by [2] for study of indenter tip imperfection.

The Martens hardness HM, is defined as the maximum applied load F_{max}, divided by contact area A_s at the load (h is indentation depth) [5]:

$$HM = \frac{F_{max}}{A_s} = \frac{F}{26,43 \cdot h^2} \ .$$

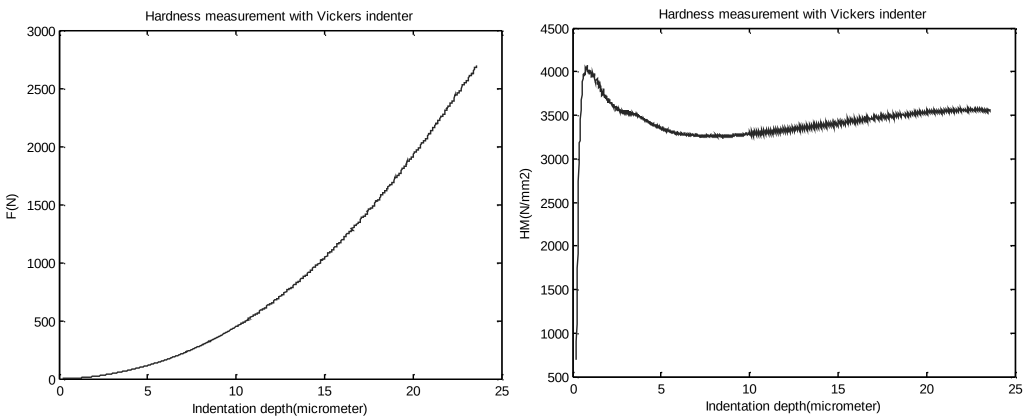

Figure 5 Physical behavior of Hadfield steel under Vickers indentation.

3. CONCLUSIONS, AIM OF THE NEXT RESEARCH

Manganese austenitic steel has some special properties that make it irreplaceable. In technical practise the hardening ability by high static or dynamic stress is used. The high hardness of face layers increases the abrasive wear resistance but because the middle part keeps good toughness, the components support high impact stress.[6]

This study present investigation of mechanical behavior of Hadfield steel under several circumstance as explosive hardened vs. unhardened stage. Several types of indentation test were performed by using Vickers and Cylindrical indenter to understand the elastic-plastic response of Hadfield steel. Different approximations were shown to find comparative yield stress CYS[N/mm^2].

In this research cylindrical and Vickers indenter was used. Finding characteristic of Hadfield steel under spherical, and smaller diameter cylindircal indenter will be next aim of reasearch. It is possible to apply extreme loading by using small diameter indenter. Comparasion of plastic-elestic reaction of Hadfield steel will be given under different type of indentation test.

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Literature

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Summary

THE ELASTIC-PLASTIC RESPONSE OF HADFIELD STEEL UNDER INDENTATION TEST

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Headfield steel is currently widely used for cast railway frogs and railway application. Because of its excellent work hardening capability, suitable strength and high toughness. Explosive hardening technique can obviously increase the hardness of metals by severe plastic deformation caused by the shock wave. A few previous research reports on the explosion hardening technique of the Hadfield manganese can be found only. Norman first reported an explosion hardening technique in 1955and got a patent for this technique. [1]

In this paper, Rolling contact test was performed for with vs without explosive hardness steel. Sample from rolling contact test was cut out and made metallographic analysis. Dislocations and white etching layer was observed. Several Indentation test were performed with cylindrical and Vickers indenter. Beside this, Martens hardness value (HM) was measured from surface to inner layer.