INFLUENCE OF EXPLOSIVE HARDENING ON WEAR OF RAILWAY CROSSINGS MADE BY HADFIELD STEEL

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Abstract

The high alloyed austenitic manganese steel, the Hadfield steel (C = 1.2 %, Mn = 12 %, Si = 0.45 %), thanks to its good wear resistance of the running surface and maintaining the high toughness of the internal material, is successfully applied for casted crossings. The crossings are the most dynamic stressed components in the railway turnouts. Thanks to low surface and sub-surface hardness the occurrence of plastic deformation and the progressive wear of the crossing running surfaces can be found since the initial stages of the crossing operational life. One possibility how to increase the surface and the sub-surface hardness and this way improve the dimensional stability and the crossing lifetime as well is to apply the explosive hardening of the crossing running surfaces. The technology mentioned above means the application of the explosives to the running surface of the crossing, when the high pressure wave acting within the extremely short period actuates the plastic deformation of the material structure. The experiments of this work describe the long - term validation, the surface hardness and wear of the running surfaces of 4 explosive hardened crossings made by Hadfield steel already installed into the Czech Railways network.

Keywords: Hadfield steel, explosive hardening, railway crossing, hardness, wear

1. INTRODUCTION

1.1. Hadfield steel and its behaviors

The English metallurgist Mr. Robert Abbott Hadfield applied in 1883 the patent, which had dealt with a steel consisting 10-14 % of manganese, proving sufficient toughness combined with a remarkable resistance against wear and abrasion (the British Patent No. 200) and then followed the U.S. Patent No. 303150 and 303151 [1]. The one of the most important behavior of this steel is its ability to harden itself under sufficiently high load or the impact application. In case the steel is stressed just in an abrasive way, i.e. without load and impact then its resistance against wear is insufficiently low. The surface hardening occurs also during machining as well, the machinability is strongly difficult [2]. The deformation hardening of the Hadfield steel was intensively studied since 1960. Since that time a number of opinion theories appear, which dealt with reasons of this deformation hardening, one of them was the transformation of austenite into epsilon, or the alpha martensite. The theory like this according to [2] and [3] and according to the reference [4] can be excluded, the cause of which is just a small amount of epsilon martensite occurrence in the plastic deformed austenitic manganese steel, less than one percent. The bigger part of these phases might be influenced by the partial loss of carbon (0.6 %) and manganese (8 %) on the surface part [5]. The chemical composition of crossings made of the Hadfield steel according to EN 15689 is stated in **Table 1**, while the Hadfield steel mechanical properties, as measured within the thesis [1], are stated in the **Table 2.**

Table 1 Hadfield steel chemical composition (wt. %) [6]

Standard	C	Mn	Si	P	S	Cr	Mo	Ni	Cu	Al
EN 15689	0.95-1.30	11.5-14.0	0.65 max.	0.05 max.	0.03 max.	0.75 max.	0.75 max.	1.75 max.	0.3 max.	0.045 max.

Table 2 Mechanical properties of Hadfield steel [1]

Rm [MPa]	Rp0.2 [MPa]	A [%]	Z [%]	HBW 2.5/187.5	KV [J]
849	368	58	40.7	200	153

1.2. Railway turnout crossings

The Hadfield steel is applied for the casted crossings of the railway turnouts manufacture thanks to its ability that its running surface can be hardened by railway vehicles axle passage through and from reason of the suitably high toughness of the crossing central part. The railway turnout **Figure 1a** makes possible the railway vehicle running in the required direction. The crossing has a special way of design making possible the mutual intersection of the rails and the final separation of both directions - the main line and the branch line of the turnout, i.e. the passage of the railway axle from the turnout one direction into other one. The crossing is extremely stressed by means of dynamic impacts and by means of load and impact stress caused by the railway vehicles axles. The crossing is the most stressed component of the turnout [1]. The crossing installed into railway turnout is in **Figure 1**. Most used type is the cast mono-block crossing made from Hadfield steel.

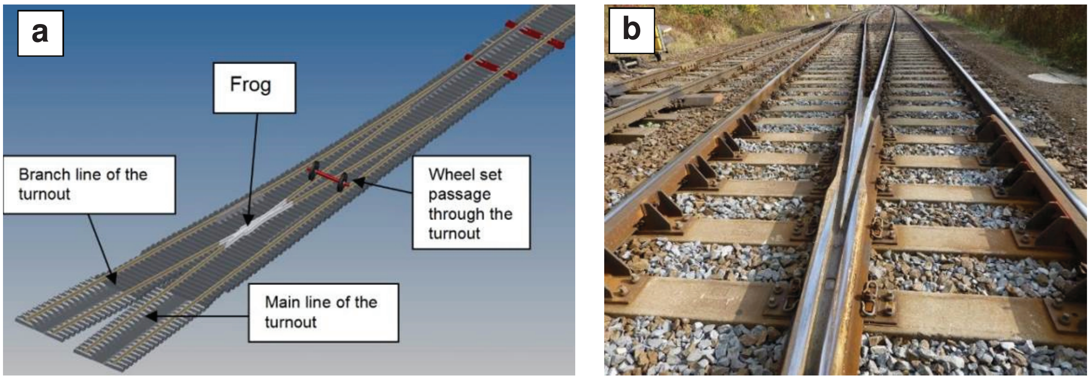


Figure 1 Railway turnout main parts (a) [1], crossing installed in the track (b)

1.3. History and application of explosive hardening used for railway crossing

The technology of a manganese steel hardening by means of explosion via high speed impact wave was invented in the USA and covered by patent on 1st March 1955 as a patent No. US 2703297 A, inventor Mr. Norman A. MacLeod. In 1956 the US chemical factory *E. I. du Pont de Nemours and Company* under cooperation with Norman A. MacLeod developed a new type of plastic explosive of uniform thickness, which could be simply cut into required shape and this way it was easy possible to cover the surface of intricate shape and fasten it via special glue. Mentioned plastic explosive is made on basis of pentaerythritol tetranitrate (PENT) and known under trade name as the DETASHEET. The commonly used explosive for hardening across Europe is the SEMTEX 10-SE stuff developed in 1987 by company Synthesia (now Explosia, a.s.) in Semtín, Pardubice, Czech republic. The name Semtex is a conjunction of two words: ***SEMT****ín* and ***EX****plosive* = *SEMTEX*. The thickness of this explosive layer equals to 2 mm. The explosive Primasheet 2000 with thickness 3 mm [1] is also used worldwide.

The explosive hardening is applied on railway crossings with aim to eliminate the significant wear of the crossing within the initial phases of its operation in the track and increase the operational life of the crossing and reduce the maintenance cost in the track. The principles of technology called the explosive hardening of crossings and influence of explosive hardening towards the structure, features and the wear of the Hadfield steel are described in detail in the doctoral thesis [1], including the practical application in [7-9]. Crossings explosive hardened are sometimes labeled like EDH (explosive depth hardened).

2. EXPERIMENT

The experimental part deals with work [9] and it incorporates results of the long-lasting measurement of the surface hardness and the running surface wear concerning the four explosive hardened crossings (marked as C1 till C4) and installed into Czech railway network. The explosive hardening was carried out according to standard EN 15689, the applied explosive was Semtex 10-SE. From reason to compare the characteristics of crossings as hardened and as non-hardened, we applied the same method when monitoring the explosive non-hardened crossing (marked as R). The crossings parameters are stated in **Table 3.** The time-table for the monitored crossings measurement was set with respect to the possibility to carry out the assessment within the same applied wheel load category, which is stated in million gross tons (mgt). The speed of passage through the crossing panel equaled to 140 km·h^{-1}.

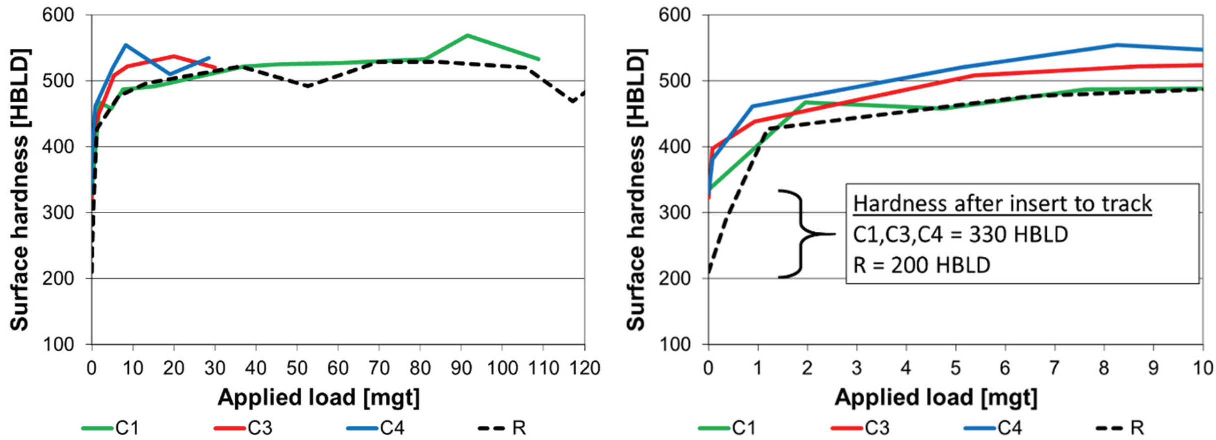
Table 3 Monitored crossings parameters

Crossing designation	Explosion hardened	Crossing geometry	In railway network since	Annual wheel load
C1	YES	1:12-500	2012	34 mgt
C2	YES		2014	35 mgt
C3	YES		2015	31 mgt
C4	YES		2015	30 mgt
R	NO		2010	34 gt

2.1. Surface hardness measurement results

The surface hardness was checked prior the installation on the railway network (crossings C1, C3 and C4 explosive hardened) via hardness tester Proceq Equotip, probe type D, the assessment expressed in HBLD units. The further measurement was carried out at the crossing running surface in the track. The results of the surface hardness measurement carried out at the crossing nose at section thickness 40 mm are represented in **Figure 2a,** and under load of 10 mgt then in **Figure 2b** in detail.

We can see in **Figure 2** that the most significant increase of the surface hardness was measured within the first month after installation on track, which corresponds approximately with applied load 2 mgt. The surface hardness of the nose of crossing R reached the initial surface hardness of the explosive hardened crossing (330 HBLD) after one week under operation and under applied load of 0.8 mgt. How already proved by the experiments stated in the doctoral thesis [1], the benefits of the manganese crossings explosive hardening is increase of the surface hardness and mainly of the sub-surface hardness, which means the crossing higher resistance against wear and the stabilization of the crossing dimensions as well.



a) course of hardness b) in detail

Figure 2 Monitored crossings nose surface hardness in dependency with applied load

2.2. Crossings wear measurement results

The wear was determined as a decrease of material volume coming from the crossing upper running surfaces. The monitored crossing running surfaces were scanned via 3D scanning device HandyScan 3D EXAscan and HandySCAN 700 prior installation on the track and moreover in the track. Measurement was carried out in track under the full extent of the railway operation. The crossing monitoring intervals were set in a shorter period within the first weeks since the crossings installation in track to enable more frequent measurement, and the longer time intervals were applied since the third month of the installation in track. The reason of different intervals application was the possibility to carry out the more detailed measurement of the deformation hardening (and to check the increase of the surface hardness and the wear as well) of the crossing running surface immediately after crossing installation in the track. In **Figure 3** we can see the outputs of the 3D scanning of crossings C1 - C4 (**Figure 3a - d**) and the crossing R (**Figure 3e**). In **Figure 4** we can see the graphical image of the monitored crossings wear in dependency with applied load and the results are finally summarized in **Table 4**. The wear measurement results say that the crossings explosive hardened (C1 till C4) prove the lower wear of the running surfaces in comparison with referenced non-hardened crossing R and saved material concerning the C1 crossing equals to 2 mm approximately.

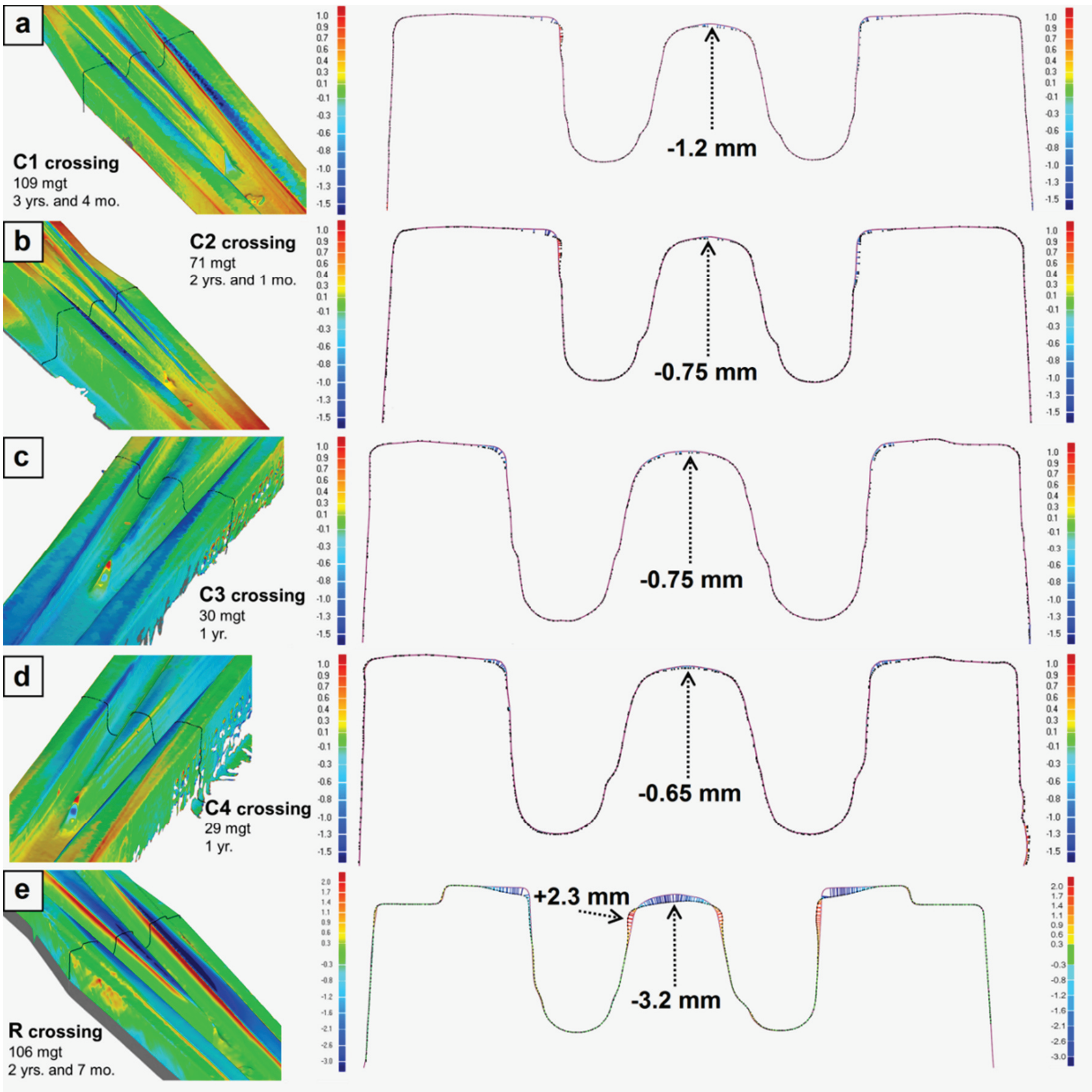


Figure 3 Wear of crossings running surfaces (cross section in nose thickness of 40 mm) - 3D scan output

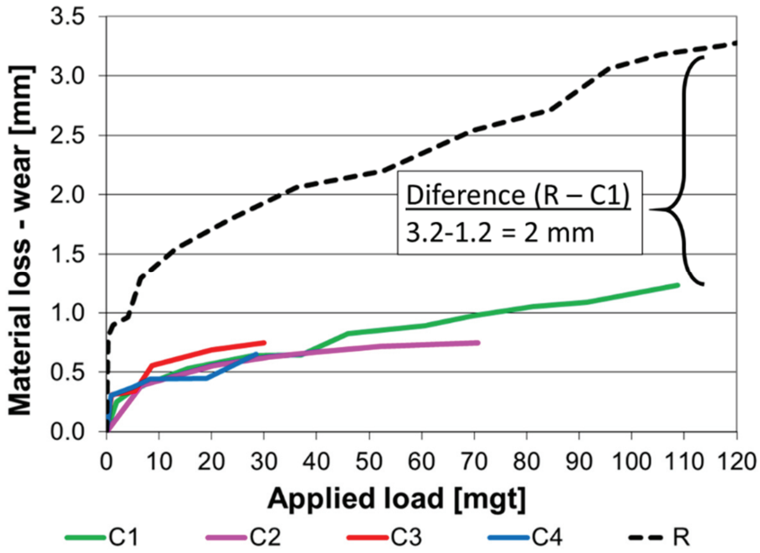


Figure 4 Monitored crossings running surface wear of crossing point in dependency with load applied

Table 4 Crossings wear measurement results

Crossing designation	Explosive hardened	Applied load [mgt]	Wear [mm]
C1	YES	109	1.2
C2	YES	71	0.75
C3	YES	30	0.75
C4	YES	29	0.65
R	NO	106	3.2

3. CONCLUSION

The experimental part of work dealt with validation of explosive hardening technology for crossings made of Hadfield steel and carried out just in railway network. The prototype crossings of geometry 1:12-500 were inserted into Czech railways network, crossings running surfaces were explosive hardened by explosive of Semtex 10-SE according to requirements of EN 15689. The surface hardness and the wear of the explosive hardened crossings (C1 - C4) were checked within the regular intervals through the whole three and a half year interval. The outcomes were compared with the explosive non-hardened crossing (R). The main conclusions are:

- The most significant grow of the surface hardness of all monitored crossings was checked within the first two months since the installation in the track, which corresponds with 1 till 2 mgt applied.
- The C1 - C4 crossings surfaces hardness were thanks to the explosive hardening at boundary of 330 HBLD and the crossing R hardness equaled to 200 HBLD. Value of 450 HBLD all crossings reached after the application of load approximately 5 mgt, which is in correspondence with two months in operation in track. Thus we are authorized to say that the surface hardness is not the most important factor when we assess behavior of explosive hardened crossings. The much more important factor is the increase of the sub-surface hardness, which occurs within the process of the explosive hardening, which is confirmed by the authors' outcome as well [1, 7].
- The benefits of the Hadfield steel crossing's explosive hardening technology was verified by measuring of the crossing wear. The outcomes from the C1 explosive hardened crossing monitoring after three and half year lasting interval and applied load of 109 mgt says, that the material saving with respect to the explosive hardening reaches the value of 2 mm (**Figure 4**), which under maximal possible wear of 3 mm

and under drive speed more than 140 km·h^{-1} and higher [11] represents significant saving of the material on crossing running surfaces That is why the explosive hardened crossing is dimensionally more stable, which after the five year monitoring validation (in 2018) should demonstrate itself as a lower maintenance cost (the grinding and built-up welding on the crossing surface) and a crossing longer service life as well. The lower wear of the explosive hardened crossings should lead to the lower dynamic impacts during the railway vehicle axle passing through the crossing and thus to the elimination of the contact fatigue damage situated at the crossing running surfaces.

- Existing results of this work show the conformance with experiment outcomes stated by the authors of the work [7], who claim that the cost of the explosive hardened crossing maintenance is halved and the explosive hardened crossings prove the service life by 70 mgt higher than the explosive non-hardened crossings.

ACKNOWLEDGEMENTS

Research reported in this paper was supported by Competence Centres program of Technology Agency of the Czech Republic (TA CR), project Centre for Effective and Sustainable Transport Infrastructure, no. TE01020168.

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