EXPERIENCE WITH EXPLOSIVE HARDENING OF RAILWAY FROGS FROM HADFIELD STEEL

Petr HAVLÍČEK a, Kateřina BUŠOVÁ b

a DT-Výhybkárna a strojírna, a. s., Dolní 100, 797 11 Prostějov, havlicekp@dtvm.cz
b Univerzita Tomáše Bati ve Zlíně, nám. T. G. Masaryka 5555, 760 01 Zlín, k.busova@seznam.cz

Abstract

A railway turnout is a special construction allowing a ride of a railway vehicle in a given direction. A part of each turnout is a frog (alternatively - crossing), it allows to cross rails and a definitive tracks separation of two different directions. The most suitable material for a production of extremely stressed railway turnouts frogs is austenitic highly alloyed manganese steel – Hadfield steel. This steel, with chemical composition of carbon (1,2%), mangan (12%), silicon (0,45%) and austenitic structure, is able to harden its working surface (i.e. to increase its surface hardness) under a sufficient pressure and shock loading because of railway wheels shocks during the train passage through the turnout. But the hardening of Mn frog running surfaces can be done before its inserting into the track using a special technology – explosive hardening. This special Mn frogs hardening technology uses world’s leading manufacturers of railway turnouts. DT-Výhybkárna a strojírna, company registers recently great interest, especially from foreign customers, in railway turnouts contain Mn frogs with explosive hardened running surfaces. Foreign customers requirements vary depending on internal regulations, standards and norms of the country where the turnout will be installed. This article shows Hadfield steel explosive hardening tests, which had to be made because of fulfillment with requirements of existing and future explosive hardened Mn frogs customers.

Keywords:
railway turnout, Hadfield steel, frog, explosive hardening, surface hardness

1. INTRODUCTION

Explosive hardening of railway frogs from Hadfield steel (Mn steel) is a common technology in the world, which allows to increase a surface and subsurface hardness of frog. This increase of hardness causes an improvement of wear resistance of running surfaces and a reduction of more frequent frog running surfaces maintenance - a grinding or a welding. The hardness of the surface (running) non-hardened frog areas ready to an inserting in to a track is about 200 HBW, and the hardness decrease to a depth of a material. This non-hardened frog wears down very quickly in first weeks from inserting in to the track, the wear is about 3 mm. The explosive hardening of frog running surfaces, which is applied before the frog installation into the track, influences surface layers hardness increase up to 400 HBW. Explosive hardening increases a subsurface hardness up to depth of 20 mm from running surfaces too [2]. In this article are described two different explosive hardening experiments, specifically on three Mn rail profiles and on a Mn frog. Because this experiments we have very interesting results, which are possible to apply during a serial use of the explosive hardening railway turnout Mn frogs technology.

1.1. Railway turnout frogs

The railway single turnout is shown at Fig. 1. The most dynamic stressed part of the turnout is a frog – Fig.2, which is the part (mostly Hadfield steel casting), which allows the rails intersection and the definitive separation of two different track directions - a main and a branch line of the turnout. The frog is extremely
loaded with dynamic stresses and with pressure and impact stresses coming from the railway vehicles wheel sets.

1.2. Explosive hardening of railway turnout frogs in the world

Railway frogs made from the austenitic high manganese Hadfield steel are inserted into railway turnouts around the whole world, in the non-hardened or the explosive hardened condition. Using this type of the material is logical: Hadfield steel has a high wear resistance with sufficient pressure and shock loading. High wear resistance is because of an ability of Hadfield steel to strengthen the work surface. On frog running surfaces occurs deformation hardening, which results in formation of deformation lines in a material structure. In detail is the deformation hardening principle together with the explosive hardening principle described in [1, 2].

The world’s leading manufacturers insert into railway turnouts Mn frogs, where is a running surface (areas with railway wheel contact) strengthened by a special technology of explosive hardening. This technology is used in the world commonly, approximately 60 years, especially in North America, Europe, Asia and Australia too. Foreign customer requirements vary depending on internal regulations, standards and norms of the country where the turnout will be installed. Differences is possible to find especially in requirements - a surface hardness, a range of hardening areas, an explosive application depth and a hardness test locations after explosive hardening. Table 1 and Fig.3 shows a summary of Mn frogs requirement according different regulations and norms, together with a chemical composition requirements. A turnout purchaser can (for example in a case of a high load turnout) require a higher surface hardness after explosive hardening than surface hardness in a appropriate standard.

<table>
<thead>
<tr>
<th>Table 1 Mn frog requirements comparing</th>
</tr>
</thead>
<tbody>
<tr>
<td>The validity of the standard</td>
</tr>
<tr>
<td>----------------------------------</td>
</tr>
<tr>
<td>EN 85889:2011</td>
</tr>
<tr>
<td>Switzerland</td>
</tr>
<tr>
<td>North America</td>
</tr>
<tr>
<td>Australia</td>
</tr>
<tr>
<td>Russia</td>
</tr>
</tbody>
</table>

Fig. 1 Main parts of the railway turnout [2] Fig. 2 Wheel set passage through the frog [2]
2. EXPERIMENT

In a practical part of this article are described Hadfield steel explosive hardening tests, which have been made in DT in 2011 because a compliance of requirements of an existing and a future explosive hardening Mn frogs customers. The experiment is divided to two parts. First one, explosive hardening of three pieces of Mn rails including a surface hardness measurement, second one – a Mn frog explosive hardening test according standards EN 15689 and ETA-03-03 (Australia).

2.1 Explosive hardening of Mn rails

Three rail castings of UIC60 profile from Hadfield steel, dimensions 700x172x156 (length x height x width), were machined in DT on top surfaces and explosive hardened in 8/2011. This hardening took place in an Explosia Pardubice with an explosive Semtex 10SE, an explosive thickness 2 mm. Rails were marked A, B, C, top surfaces of rails were divided into three parts (for example – the C rail to C1, C2, C3. A number behind the rail mark symbolizes a number of explosives (for example C2 = two explosive application). 80 mm of A rail wasn’t hardened – a part of A0. A depth of explosive application was chosen Z = 13 mm - Fig.4a, 4b.

During explosive hardening was measured rails surface hardness by the portable gauge Equotip (a D-type sonde, the surrounding temperature +25°C). The resulting average values of surface hardness measurements are in Table 2 and Figure 5. The average increase of surface hardness of rails A, B, C after first explosion was +56 HBW, after second explosion was +20 HBW. It is seen that third explosion didn’t increase surface hardness, by contrast in the place B3 (3x explosion) were identified small crack defects by penetrant test. This explosive hardening test of Mn rail led to the conclusion, that third application of explosive is unnecessary.

Table 2 The increase of the surface hardness – A, B, C rails

<table>
<thead>
<tr>
<th>The rail</th>
<th>before the 1st explosion</th>
<th>after the 1st explosion</th>
<th>after the 2nd explosion</th>
<th>after the 3rd explosion</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>249</td>
<td>A1 321</td>
<td>A2 354</td>
<td>A3 357</td>
</tr>
<tr>
<td>B</td>
<td>251</td>
<td>B1 297</td>
<td>B2 327</td>
<td>B3 322</td>
</tr>
<tr>
<td>C</td>
<td>285</td>
<td>C1 337</td>
<td>C2 332</td>
<td>C3 287</td>
</tr>
</tbody>
</table>
Surface hardness results are possible to compare with requirements from Table 1. It is evident, that rails surface hardness immediately after the 1st. explosion (parts A1 - 321 HBW, C1 - 337 HBW) fulfilled the requirement 321 HBW according EN 15689 and Switzerland, the B rail (the part B2 - 327 HBW) fulfilled this requirement after the 2nd. explosion. The A rail (the part A2 - 354 HBW) fulfilled after 2nd. explosion requirements of all countries from Table 1.

It was also found, that it is important to rise slightly ends of explosive remote from a detonator during the explosive application - Fig.6 bottom left. Otherwise, a sharp transition can occur (a decrease of a material) - Fig.6 top right. This sharp transition is necessary to grind after the explosive hardening - it increases the cost of hardening component.

![Fig. 5 The increase of the surface hardness - A, B, C rails](image)

![Fig. 6 The formation of the sharp transition during explosive hardening - above, and it's removal - below](image)
2.2 Mn frog hardening according EN 15689 and ETA-03-03

Because of a great interest in explosive hardened Mn frogs, especially from Australian customer, was one frog from Hadfield steel in 11/2011 transported to a compound in Explosia Pardubice, where was applied a test of the explosive hardening. On a right wing rail and a tip was applied the explosive according EN 15689 (the depth of the explosive application $Z = 10$ mm), a left wing rail according ETA-03-03 ($Z = 20$ mm) - Fig.7. The explosive Semtex 10SE of 2 mm thickness was used. According the experience in author’s paper [2] was this frog machined on all running surfaces with the addition of a few tenths of millimeters - the addition to the explosion. The decrease of the frog surface layer after explosive hardening is eliminated because of this material addition.

This frog wasn’t used in the track, so it wasn’t hardened on all top surfaces - Fig.7. The surface hardness after frog machining (before 1st. explosion) moved between 167 - 228 HBW. According the experiment in [2], if is a surface hardness small after frog machining, is a surface hardness after explosive hardening low too. Immediately after the frog machining was evident, that to meet the requirement of EN 15689 (min.321 HBW), or ETA-03-03 (350 to 415 HBW) will need to apply explosive hardening in two steps. During a surface hardness evaluation has confirmed this assumption. The increase of surface hardness after 1st. explosion was between +51 HBW (a location no.1) to +113 HBW (a location no.5). The biggest hardness increase after 1st. explosion was in locations no.3, 4, 5 and 6, it means in locations with the lowest hardness after machining. It is possible to state, that if is a surface hardness small after frog machining, is the increase of surface hardness after 1st. explosion bigger. The second explosive application increased the surface hardness in locations 1 and 7 over values 350 HBW. In this two locations was achieved the requirement of ETA-03-03 standard (350 - 415 HBW).
In locations 2 and 6 was measured surface hardness above 321 HBW (the requirement of EN 15689), the hardness in this locations didn’t reach the ETA-03-03 requirement. The frog surface hardness measurement results, see the Fig.8.

During the explosive hardening (before 1st. explosion - after machining, after 1st. explosion and after 2nd.explosion) were tested hardened areas by penetration test - Fig.9. After frog machining were repaired defects on left wing rail by welding. After 1st.explosion have been shown this defects again in the same places - it was because a repair weld inhomogeneity. The conclusion of this penetration test is, that it’s better to repair some smaller defects after the frog explosive hardening, not before the explosive hardening. This will prevent the unnecessary duplication of repair welding.

![Fig. 9 Frog penetration test results - after the machining and after 1st.explosion](image)

3. CONCLUSION

Explosive hardening of railway turnout frogs from Hadfield steel is used to increase the frog wear resistance, a reduction of more frequent frog running surfaces maintenance and a the extension a frog lifetime during using it the track. In this paper were compared requirements of explosive hardened Mn frog customers. In the experiment divided into two parts, were described explosive hardening test on Mn rails and on Mn frog. The resulting surface hardness after 2nd.explosion moved between 327 - 363 HBW in both experiments. In two locations of hardened Mn frog exceeded the surface hardness of 350 HBW (the requirement of ETA-03-03 Australian standard). Other locations fulfilled EN 15689 requirements (min.321 HBW). During the measurement of surface hardness was found:

- the application of third explosion didn’t increase the surface hardness, the other way around defects were on B rail, at the B3 location,
- the smaller initial surface hardness (before 1st.explosion) means the bigger increase surface hardness after 1st.explosion and the smaller resulting hardness after 2nd.explosion.

On Mn rails was described the formation of the sharp transitions during an incorrect explosive application and the method of its improvement was described too. The explosive hardening of the Mn frog leads to the recommendation – smaller defects discovered after the frog machining by penetration test are better to repair after explosive hardening. All this knowledge will be used for the serial explosive hardening of Mn frogs in railway turnouts manufactured in DT-Výhybkárna a strojírna, a.s. company.

LITERATURE
