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Explosive Hardening and Its Application in Production of Railroad Switch Frogs

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Abstract

The peculiarities of explosive hardening (**EH**) associated with the impact of the shock wave on the metal are considered. Mechanical properties of Hadfield steel after EH are given. It is shown that intermediate layer of dry sand between explosive charge and treated metal provides amplification of the shock wave. This enables EH with the use of powdered explosives with low density and detonation velocity. The industrial technology of EH of railroad switch frogs is described. EH increases the service life of these parts by 20–30 %.

Keywords

Explosive hardening; shock wave; Hadfield steel; railroad switch frog; mechanical properties; hardness.

Introduction

The first patent on explosive hardening (**EH**) of high-manganese steel was issued in 1955 [1]. Since then R&D works has continued in the US, in 1960s they had begun in the former USSR and later in Japan, China and other countries [2–10]. It was found, that strong shock wave generated by explosion can heat the substance up to the melting point, induce phase transitions and twinning (Neumann bands), change microstructure and mechanical properties, such as hardness, plasticity and strength. The effect of EH is associated with an impact of the shock wave on the metal. Strain rates in a shock wave front moving in metal are greater than 10^3 s^{-1} [5]. For a noticeable hardening, the shock wave must be rather strong, i.e. to have an amplitude exceeding the elastic limit of the material. For example, elastic limits of aluminum alloy 2024, deformed (50 %) copper, nickel, structural steel 1020 and titanium are equal to 529, 617, 980, 1215 and 1813 MPa, respectively [5].

Though it has been more than 50 years since research works on EH have started, the interest in this phenomenon still exists and research is ongoing, for example in the search for new explosives suitable for EH [11]. This paper is focused on the description of explosive hardening of Hadfield steel and use of this technology in production of railroad switch frogs at Novosibirsk Railroad Switch Plant.

Experimental

The first series of experiments was carried out using the direct explosive loading (see Fig. 1*a*) of samples made of Hadfield steel with different initial mechanical properties. Plasticized explosive GP-87 used for hardening has had a detonation velocity of 7.2 km/s and a density of 1.6 g/cm^3. The thickness of explosive charge varied from 6 to 15 mm. Table 1 shows the results of experiments, the initial properties of samples are given in the second column.

The second series of experiments was carried out using the indirect explosive loading with an intermediate layer of dry sand between the explosive charge and treated sample (Fig. 1*b*). The objective was to compare the degree of hardening obtained by direct and indirect loading using both plasticized and powdered explosives. These experiments were stimulated by theoretical considerations stated in [12], where it was shown that the pressure in the shock wave reflected from a substrate in a porous layer is greater than the pressure of shock wave generated in direct contact of the same explosive with the same substrate.

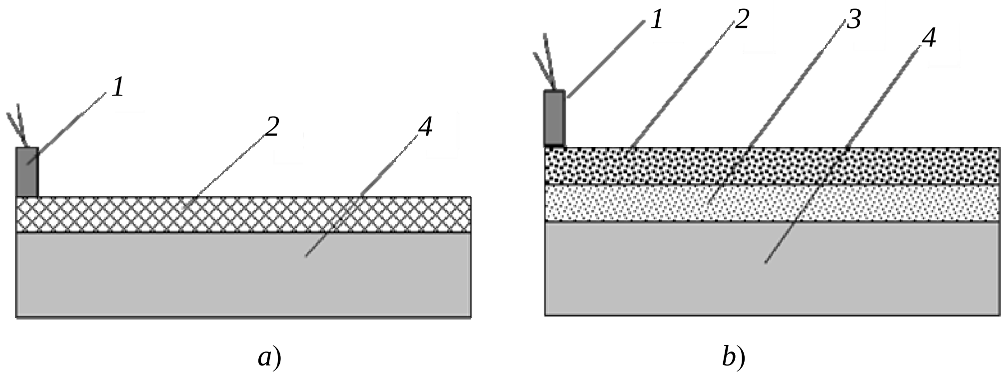


Fig. 1. Hardening by a contact explosive charge (*a*) and through an intermediate porous layer (*b*):
1 – detonator; *2* – high explosive; *3* – porous layer (dry sand); *4* – sample under treatment

Table 1

Properties of Hadfield steel after explosive hardening

Thickness of GP-87 layer, mm	0	6	9	12	15
Surface hardness, HB	210	321	345	365	375
Tensile strength, MPa	684	832	1008	830	1004
	785	932	1043	1035	1104
	887	997	1117	1079	1174
	964	1078	1181	1133	1238
Yield strength, MPa	432	719	844	814	965
	439	757	856	883	947
	439	773	882	902	981
	452	766	894	941	985
Elongation, %	27	13	11	6	4
	33	15	12	8	7
	42	21	19	14	13
	48	31	23	18	17
Narrowing, %	26	17	17	12	7
	28	21	17	13	12
	33	24	20	16	15
	37	27	26	21	20

This amplification effect has been later confirmed experimentally, and the new method of explosive hardening has been patented [13]. Fig. 2 shows the results of experiments.

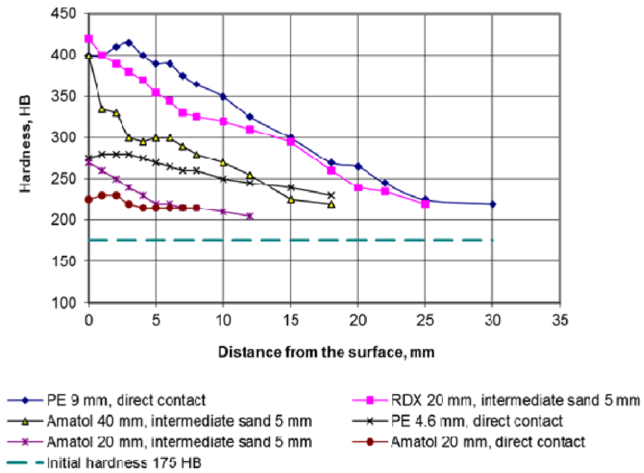


Fig. 2. Dependence of hardness on a distance from the sample surface in explosively hardened high-manganese steel. PE is a plasticized explosive GP-87

Results and discussion

Table 1 shows that Hadfield steel loses plasticity significantly during explosive hardening. For example, when it is hardened to a hardness of 365 HB, a ductility of samples with initial elongation δ = 25–35 % drops to δ = 8 %, and that of samples with initial δ = 45–50 % drops to 18 %. In general, explosive hardening of cast high-manganese steel parts intended for operation on the railroad is reasonable, when their initial ductility exceeds 30% in order to avoid the loss of plasticity after hardening and caused by this cracking and chipping of metal during part operation.

In Fig. 2 we can see that explosive hardening using powdery amatol and RDX with the charge thickness of 40 and 20 mm correspondingly, and with an intermediate layer of dry sand (see Fig. 1*b*), provides the same surface hardness as the treatment with 9 mm thick plasticized explosive GP-87 placed in direct contact with the sample (see Fig. 1*a*). Table 2 contains detonation characteristics of above explosives and of plasticized explosive LVV-11-1 used presently in industrial explosive hardening technology. It is obvious that not only high explosives with high density and detonation velocity are suitable for EH, but low-density powdery explosives as well, if to apply a porous interlayer between the explosive charge and treated sample.

Table 2

Detonation characteristics of explosives used for hardening

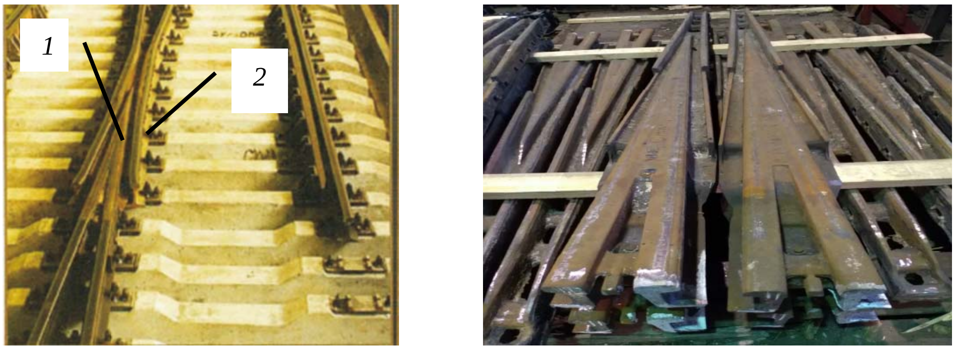
Explosive	Density, g/cm^3	Detonation velocity, km/s	Detonation pressure, GPa
GP-87	1.60	7.2	21.0
RDX	1.00	6.2	10.0
Amatol	1.00	4.2	5.0
LVV-11-1	1.42	7.4	19.4

Industrial application of explosive hardening

The first steps to the full-scale industrial application of EH were taken in 1960s, when Administration of Novosibirsk Railroad Switch Plant has applied to Lavrentyev Institute of Hydrodynamics with the problem of increasing the service life of the railroad switch frog. The most wear places are on the frog guardrails and frog core wedge (Fig. 3).

Over decades, Lavrentyev Institute of Hydrodynamics, Ural Branch of All-Russian Institute of Railway Transport and Novosibirsk Railroad Switch Plant have conducted the research works, developed the technology, and designed and manufactured explosion chambers. Service tests of hardened frogs were carried out and it has been proven that EH increases their lifetime by at least 20–30 %. Finally, in 1979 the special shop for EH of switch frogs has started working in Novosibirsk Railroad Switch Plant. Subsequently the developed technology was patented [14–16].

Fig. 4 shows the implementation of EH process in explosion chamber. EH increases the surface hardness from 200 HB to 350–380 HB, the depth of a hardened material amounts to 30–35 mm. This prevents the initial crushing of the frog core and guardrails in the operation and therefore its lifetime grows.



a) *b*)

Fig. 3. Railroad switch frog on the railway track (*a*) and switch frog castings before explosive hardening (*b*):
1 – frog core wedge; *2* – guardrail

a) *b*)

Fig. 4. Explosive chamber in the open state (*a*) and the switch frog on the working table with explosive charge on the hardened surfaces (*b*)

Conclusion

Based on R&D works conducted in Lavrentyev Institute of Hydrodynamics and Ural Branch of All-Russian Institute of Railway Transport, a full-scale production of hardened railway switch frogs was organized at Novosibirsk Railroad Switch Plant. Since 1979, the hardening shop at the Plant has produced more than 350 thousand switch frogs. Presently, the production volume of the said Plant is 10–12 thousand hardened pieces per year. More than 90% of produced R65 frogs (grades 1/11 and 1/9) are explosively hardened. Explosive hardening increases the lifetime of frogs by 20–30 %.

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