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High Energy Rate Forming Induced Phase Transition in Austenitic Steel

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Abstract. In this study, the effects of explosion hardening on the microstructure and the hardness of austenitic stainless steel have been studied. The optimum explosion hardening technology of austenitic stainless steel was researched. In case of the explosive hardening used new idea means indirect hardening setup. Austenitic stainless steels have high plasticity and can be cold formed easily. However, during cold processing the hardening phenomena always occurs. Upon the explosion impact, the deformation mechanism indicates a plastic deformation and this deformation induces a phase transformation (martensite). The explosion hardening enhances the mechanical properties of the material, includes the wear resistance and hardness [1]. In case of indirect hardening as function of the setup parameters specifically the flayer plate position the hardening increased differently. It was find a relationship between the explosion hardening setup and the hardening level.

1. Introduction

Shock hardening is a very useful and common technology. Explosive hardening of railway frogs from Hadfield steel (Mn steel) is a common technology in the world, which allows to increases a surface and subsurface hardness of frog [2]. This hardening technology is also able to increase the hardening and wear resistance of the austenitic stainless steel too. This steel has a great ductility, low hardness and very good corrosion resistance. It can’t increase the hardness by the way of simple heat treating.

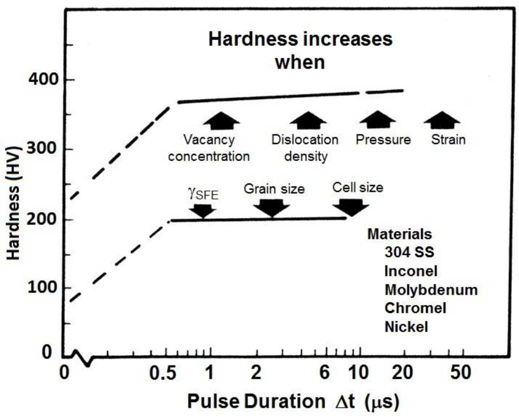

Figure 1. Hardness increasing [4]

Cold working and aging heat treatment involve hardening in case of this steel. That static strain aging is well-known phenomenon frequently observed in bcc metals and alloys [3].
It is known the explosion caused shock also occurs a hardness rising but the parameters of this process has not been well understood yet. The effect of strain rate on the ϒ-α' transformation in stainless steels has been of interest for a number of years. The early work simply noted that an increase in rate decreased the amount of martensite [4].

The aim of this study is to report the results of the hardness improving of an austenitic stainless steel treated using explosive treatment. Among the treatments intended to improve the surface properties of materials, shocks are known to induce an important hardening, either by flyer plate impact [5, 6].

2. Materials and explosive hardening setup

2.1. Used materials

In case of our tests we used austenitic stainless steel (X5CrNi1810, EN 1.4301, AISI 304) and like flayer plate an unalloyed low carbon steel the chemical composition of them is given in Table 1. The flayer plate material was unalloyed low carbon steel (S235JR, EN 1.0037). The Table 1. shows the basic parameters of the studied metals.

Table 1. Chemical composition of the used steels (at.%)

DIN;	C	Si	Mn	Cr	Ni	N_{max}	P_{max}	S_{max}	Al	Cu
X5CrNi1810	0.07	1	2	18.25	9.25	0.11	0.045	0.015		
S235J2	≤0.2	≤0.6	≤1.4	≤0.3	≤0.4		≤0.045	≤0.045	≤0.1	≤0.3

Table 2. Basic performance of the steels

	Sign by DIN	Thickness	Size	HV_{30}	Yield stress (MPa)
Flayer plate	S235J2	1.5 mm	80×80 mm	300 HV	235
Base plate	X5CrNi1810	40 mm	D80 mm	215 HV	220

2.2. Explosive hardening parameters

A new setup of explosive hardening technology was used. The base plate and the flayer plate are parallel and the explosive find directly on the surface of the flayer plate without buffer see Figure 2. [5]. In case of this setup the flayer plate worked like hammer. The surface of the austenitic steel had thin plastic coating, to prevent the joining of the flayer plate and the base plate.

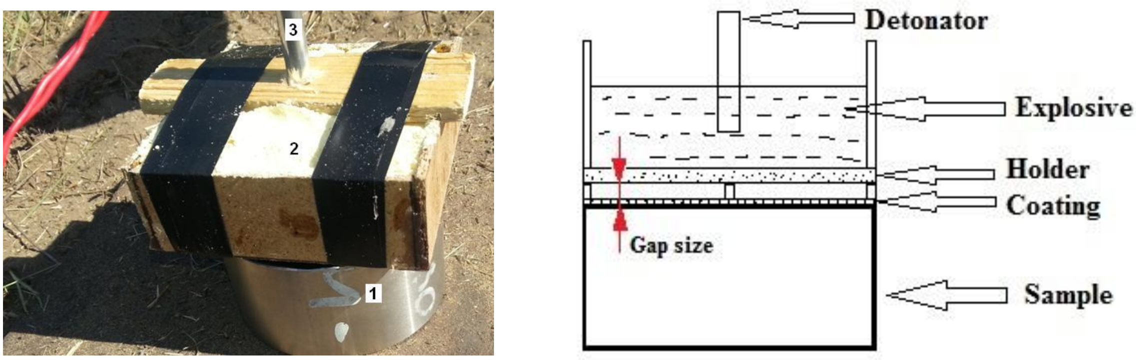

Figure 2. Setup of the indirect hardening (1 base plate, 2 explosive, 3 detonator)

Table 3. Parameters of used explosive

Explosive PERMON 10T (powder)			
Volume of the gas	928 dm^3/kg	Distance between the plates	1,5 mm
Detonation rate	3200 m/s	Thickness of the explosive	30 mm
Density	850 kg/m^3	Weight	319 g

The pressure of the nascent gases calculated by the equation (1) [7]:

$$p = {v_d}^2 \rho_0 \frac{(\rho - \rho_0)}{\rho} \tag{1}$$

Where:

- v_d: detonation velocity of explosive [m/s];
- ρ_0: density of explosive [kg/m^3];
- ρ: density of the nascent gases [kg/dm^3];
- p about 10^9 [Pa].

The explosion impact force on the surface (2) [7]:

$$J = \int p dt \tag{2}$$

Where:

- J: impulse on the surface unit [N/m^2];
- p: nascent gases pressure from the equation (1) [Pa].

The p pressure quantity depends on the parameters of explosive material and the effect time depends on the amount (thickness) of the explosive material. The velocity of the collision (v_c) must be lower than the speed of the sound (v_s)(3), that means it needs to use a low speed explosive for this technology. The interfacial pressure at the collision front also must exceed of the materials yield strength to occur a plastic deformation. This is the surface hardening under extreme pressure [6,7].

$$\frac{v_c}{v_s} < 1 \tag{3}$$

In case of the setup parameters optimization it was used some empirical parameters with the density of explosive, base plate and flayer plate (see in Figure 2). The thickness of the explosive powder was optimized on base of practice. It is known that it needs a minimal amount of explosive, that about 0.017 (g/mm^2) Permont 10T [7].

The used parameters in case of the setup posed by (2) when l_b is the thickness of the flayer plate and l_1 is the distance (gap) between the base and flayer plate. The collision velocity depends on this distance [4]. The hardness increasing depends on the pressure of the nascent gases (see Figure 3). The explosion kinetic, therefore the nascent pressure (p) is displayed as a function of time in Figure 4. It can be seen that the nascent pressure increases in the first and second period and in the third period the pressure is constant.

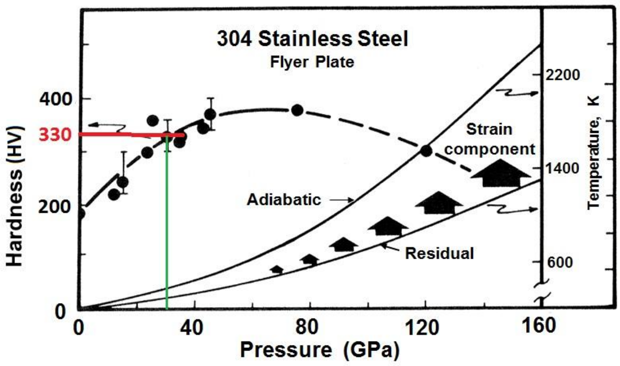

Figure 3. The hardness as function the pressure of nascent gases [6]

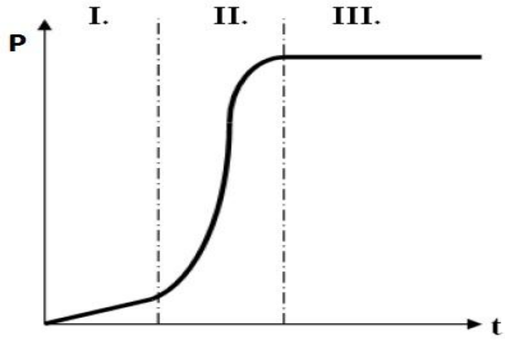

Figure 4. The kinetic of the detonation (I.: burning period, II.: explosion period, III.: detonation period) [7]

3. Results and Discussion

Hardness testing

Vickers Hardness tester (30 kg) was used to establish the hardness. Results are shown in Table 4. Cause of the plastic deformation the hardness increased. We measured hardness in case of all samples in same distance from detonator (usually in the III. detonation period shows Fig.4.).

Table 4. Hardness after explosive hardening

Gap size mm	Surface hardness HV_{30}
0	263
2	322
3	330
4	335
7	340
10	348

The Figure 5 shows the hardness in case of different gap sizes.

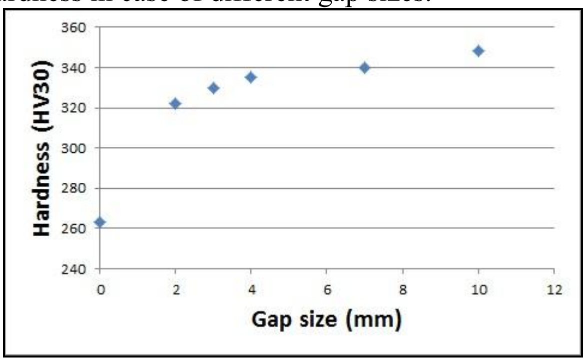

Figure 5. Hardness as function the setup (gap size)

4. Conclusion

The experimental results give new information about the optimal setup parameters of the new setup of the used explosion hardening technology.

I. The hardness increase as a function of the setup gaps sizes because the result hardness depends on the plastic deformation rate and the plastic deformation depend on the collision energy of the flayer plate.
II. In case of explosive hardening the used parameters are based on some empirical equation what are usually confidential. The literature of this process is also poor about the determination of the parameters. Based on the results in case of indirect hardening setup
III. suggestible the biggest gaps setup.

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References

[1] J.R. Davis: 2002 *Surface Hardening of Steels,* ASM International pp 1-16
[2] Petr Havlíček, Kateřina Bušová: 2012 *Experience with explosive hardening of railway frogs from hadfield steel,* Metal 2012. Brno, Czech Republic
[3] Sang Hun Lee1, Jeom Yong Choi, Won Jong Nam: 2009 *Hardening behavior of a 304 stainless steel containing deformation-induced martensite during static strain aging,* Materials Transactions, Vol. 50, No.4 The Japan Institute of Metals pp 926-929
[4] M. A. Meyers, L. E. Murr: 1980 *Shock Waves and High-Strain-Rate Phenomena in Metals,* International Conference on Metallurgical Effects of High-Strain-Rate Deformation and Fabrication, Albuquerque, N.M., pp 91-111
[5] L. Fouilland-Paill, M. Gerland, P. Violan: 1995 *Cyclic behavior of a 3 16L stainless steel hardened by an explosive Materials Science and Engineering,* A201 pp 32-39
[6] K.P. Staudhammer, C.E. Frantz and S.S. Hecker, in M.A. Meyers and L.E. Murr (eds.):1981 *Shock Waves and High Strain Rate Phenomena in Metals,* Plenum, New York, pp 91-l12
[7] Dr. Göbl Nándor – Horváth Dániel – Dr. Kovács-Coskun Tünde - Prof. Dr. Lukács László – Dr. Rácz Pál - Szalay András – Dr. Zádor István: *Nagyenergiájú Fémmegmunkálás*, Budapest 2013