Explosive Surface Hardening of Austenitic Stainless Steel

T Kovacs-Coskun
Obuda University, Banki Donat Faculty of Mechanical and Safety Engineering - Material Science Department - 1081 Budapest - Hungary

E-mail: kovacs.tunde@bgk.uni-obuda.hu

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 mean indirect hardening setup. Austenitic stainless steels have high plasticity and can be easily cold formed. 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. 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. 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. 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].

![Image of hardness increasing graph](image-url)
It knows that the explosion caused shock also occurs a hardness rising but the parameter of this process not well understood yet. The effect of strain rate on the Y-a' 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 flyer plate an unalloyed low carbon steel the chemical composition of them is given in Table 1. The flyer plate material was unalloyed low carbon steel (S235JR, EN 1.0037). The Table 1. shows the basic parameters of the used metals.

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

| DIN;  | C   | Si  | Mn  | Cr  | Ni  | N   | P    | S    | Al  | Cu |
|-------|-----|-----|-----|-----|-----|-----|------|------|-----|----|
| X5CrNi1810 | G,G7 | 1   | 2   | 18,25 | 9,25 | G,11 | G,G45 | G,G15 |     |    |
| S235J2   | <0,2 | <0,6 | <1,4 | <0,3 | <0,4 | <0,045 | <0,045 | <0,1 | <0,3 |

2.2. Explosive hardening parameters
The used explosive hardening technology was a new setup. The base plate and the flyer plate are parallel and the explosive find directly on the surface of the flyer plate without buffer see Figure 1. [5]. In case of this setup the flyer plate worked like hammer. The surface of the austenitic steel had thin plastic coating, to prevent the joining of the flyer plate and the base plate.

### Table 2. Basic performance of the steels

|                         | Sign by DIN | Thickness | Size       | HV30 | Yield stress (MPa) |
|-------------------------|-------------|-----------|------------|------|-------------------|
| Flayer plate            | S235J2      | 1,5 mm    | SGxSG mm   | 3GG HV 235 |       |
| Base plate              | X5CrNilS1G  | 5 mm      | DSGx4G mm  | 215 HV 220 |       |

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

### Table 3. Parameters of used explosive

| Explosive PERMON 10T (powder) | Volume of the gas | Detonation rate | Thickness of the explosive | Weight |
|-------------------------------|-------------------|-----------------|----------------------------|--------|
|                               | 92S dm³/kg        | 32GG m/s        | 3G mm                      | 319 g  |
The pressure of the nascent gases, calculated by the equation (1) [7]:

\[ p = \frac{v_d^2}{\rho_0} \frac{\rho - \rho_0}{\rho} \]  

Where:
- \( v_d \): detonation velocity of explosive [m/s];
- \( \rho_0 \): density of explosive [kg/m³];
- \( \rho \): density of the nascent gases [kg/dm³];
- \( p \approx 10^9 \) [Pa].

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

\[ J = \int \rho dt \]  

Where:
- \( J \): impulse on the surface unit [N/m²];
- \( \rho \): nascent gases pressure from the equation (1) [Pa].

The \( \rho \) 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 \( (v_c) \) (1), that means it needs to use for this technology a low speed explosive. The interfacial pressure at the collision front also must exceed the materials yield strength to occur a plastic deformation. This is the surface hardening under extreme pressure [6,7].

\[ \frac{v_c}{v_x} < 1 \]  

In case of the setup parameters optimization it was used some empirical parameters with the density of explosive, base plate and flayer plate (setup see in Figure 2). The thickness of the explosive powder was optimized on base of practice. It knows that it needs a minimal amount of explosive, that about 0,017 [g/mm²] 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 \( i! \) is the distance (hole) 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 shows the Figure 4. It can see that the nascent pressure in the first and second period increase us function the time 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

3.1. Hardness testing
The used tester was in case of experiments Vickers Hardness tester (30 kg). Results are shows Table 4. Cause of the plastic deformation the hardness increased.

| Hole size | Distance from detonator (mm) | HV |  |
|-----------|------------------------------|----|---|
|           | 0mm                         | 222|   |
| 2mm       | 10mm                        | 217,5| 234|
|           | 20mm                        | 233|   |
| 3mm       | 30mm                        | 322,5|   |
| 4mm       | 40mm                        | 330|   |

The Figure 5 and Figure 6 show the hardness in case of different setup parameters and distance from detonator.

3.2. Wear test
The wear resistance of the hardened samples were tested by a ball cratering tribometer in case of standard parameters (load, rotation per minutes, investigation time, etc.). Wear coefficient calculated by the following Archard equation (4) [8]:

$$K = \frac{C \cdot \frac{h^2}{2}}{N \cdot f} \ [m^3/\text{N}]$$

| Setup Hole size | Crater depth h (m) | Wear volume (mm$^3$) | Wear coefficient K (m$^3$/Nmp) | Wear resistance (1/K) | Hardness (HV30) |
|-----------------|--------------------|----------------------|---------------------------------|-----------------------|-----------------|
| 2 mm            | 0.22               | 8,13*10$^{-9}$       | 8.93*10$^{-20}$                 | 1,11*10+19            | 322,5           |
| 3 mm            | 0.21               | 7,54*10$^{-9}$       | 8.29*10$^{-20}$                 | 1,20*10+19            | 330             |
| 4 mm            | 0.16               | 5,76*10$^{-9}$       | 6.33*10$^{-20}$                 | 1,58*10+19            | 334,5           |

3.3. Discussion
The indirect explosive hardening technology improves the hardness of the used austenitic stainless steel. Hardness increasing depends on the setup of hardening technology and also depends on the
distance from the detonator (see Figure 5-6). The wear resistance shows good correlation with hardness and also with the holes sizes of the setup. It finds relationship between the setup, hardness and wear resistance.

![Figure 7. Wear resistance](image1)
![Figure 8. Hardness](image2)

4. Conclusion

The used explosion hardening technology results give new information even that the hardness shows good correlation with wear resistance is known.

I. The hardness increase us function of the setup holes 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. The result hardness also depends on the distance from the detonator, because during the explosion the nascent gases pressure increase by the time (in the first and second period).

III. In case of explosive hardening the used parameters base some empirical equation what are usually secret. The literature of this process is also poor about the determination of the parameters. On the base of the results in case of indirect hardening setup suggestible the biggest holes setup.

Acknowledgements

The author would like to acknowledge all members of this project and especially for Andras Szalay S-Metalltech 98 Kft., Tamas Rigo OE and Laszlo Lukacs NKE.

References

[1] J.R. Davis: 2002 Surface Hardening of Steels, ASM International pp 1-16
[2] Petr Havlícek, Katerina Busová: 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 Materials Transactions 50 (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 Materials Science and Engineering A 201 32
[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 91-112
[7] Dr. Göbl Nándor - Horváth Dániel - Dr. Kovács-Coskun Tünde - Prof. Dr. Lukács László - Dr. Rácz Pál Szalay András - Dr. Zádor István: 2013 Large energy metal processing, Budapest (in Hungarian)
[8] T. Kovács 2007 The effect of microstructure on the local wear behaviour of steels, Ph.D. Thesis, Budapest