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Explosive Surface hardening of the Austenitic Steel

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Abstract

The research focuses on the presentation and analysis of explosive welding and hardening processes. In practice, the direct method is used for explosive hardening, in which the explosive is placed on the surface of the metal to be hardened. The indirect method is not yet common in practice. In the indirect process, similar to explosive cladding, there is a gap between the explosive and the surface of the metal to be hardened. We conducted experiments on two different steel grades (X120Mn12, X5CrNi1810) using the same quantity and quality of explosive. Following direct and indirect hardening, the hardness measurement results showed that the hardness achievable with direct hardening (238 HV for X120Mn12, 263 HV for X5CrNi1810) was lower than that achieved by indirect hardening (472 HV for X120Mn12, 322 HV for X5CrNi1810) using a 1.5 mm gap distance.

Keywords: *explosive welding, plastic deformation, dislocation, cohesive bonding.*

1. Introduction

Explosive forming and welding technologies began to be developed and applied after World War I. The physical basis of the technology is the plastic deformation effect, which is aided by the heat generated by friction caused by deformation in the crystal structure of the metal **[1]**. The high-pressure gas shock wave generated from the explosion can join the metal surfaces at high speed during explosive welding. The forming speed in this case differs significantly from the forming speed used in cold metal forming. The deformation caused by the explosion is a high-speed dynamic effect that causes deformation and phase transformation in the face centered cubic crystal structure steels **[1]**. Typically, this process is used for austenitic Hadfield steel hardening, as this type of steel is prone to work hardening through phase transformation. The austenitic microstructure steel phase transformation can also be observed as a result of cold working, Strain-Induced Martensitic Transformation (SIMT). In practice this hardening process is not used in the case of the austenitic stainless steels.

The shock wave established by the explosion causes an increase in hardness of metals, but the parameters of this phenomenon have not yet been fully described in scientific terms. The analysis of the effect of deformation rate on the γ-α' transformation in austenitic steel has long been a subject of interest to researchers. Early studies simply noted that as the explosion pulse duration (Δt) increased, the amount of martensite also increased and the hardness of the steel increased (**Fig. 1**) **[2]**.

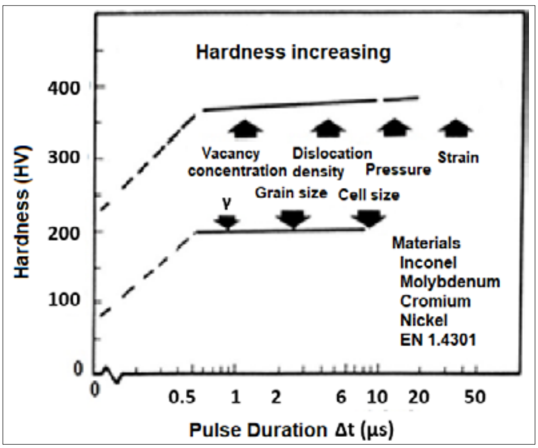

Fig. 1. *Hardening as a function on the explosion impulse time.* **[2]**

The traditional hardening mechanism of Hadfield steel mainly involves dislocation, twinning, and dynamic deformation ageing [3]. Although explosion-hardened Hadfield steel frogs are widely used on railways around the world, the deformation mechanism that occurs during the explosion hardening of this steel is not yet fulyly understood [4]. The explosive hardening of Hadfield steel railroad frogs is a widely used technology worldwide that allows for increasing the surface and subsurface hardness of crossings [2, 4, 5]. Fig. 2 shows a typical application of a casted Hadfield steel at the tip of a railroad frog

References in the literature indicate that, as a result of plastic deformation caused by high-speed forming, Hadfield steel undergoes Strain-Induced transformation triggered by deformation, and γ austenite transforms into α ferrite or ε martensite. It has been shown that the transformation from γ austenite to ε martensite depends on the deformation rate [6]. Explosive hardening technology can also increase the hardness and wear resistance of ausustenitic stainless steel [7, 8]. Austenitic stainless steel has high formability, low hardness, and very good corrosion resistance. Heat treatment cannot be used to increase its hardness. Of course, there are stainless steels that can be hardened exceptionally well, but their chemical composition differs from that of the widely used austenitic stainless steels [9, 10].

2. Explosive machining technologies

2.1. Explosive cladding process

The purpose of explosive bonding technology is to join metals together using high-speed deformation caused by an explosion. Due to the cohesive bond that forms, this process is considered to be welding [10]. Metals do not typically melt because there is no heating during the process; the heat is generated only by the deformation and the explosion, this process belongs to the group of cold welding processes. The material science basis of the process is the deformation that occurs as a result of high-speed forming, during which the atoms of the materials being joined form bonds with each other without mixing. This process is typically used in practice for joining large surfaces, such as flat plates. This process can be used to weld together a number of different metals that cannot be welded together using fusion welding (e.g., steel and titanium) [11, 12]. In the case of the explosive welding process specification, there is the need to take account of the selection of the explosive. When selecting explosives, the critical limit value for the explosive's detonation velocity must be taken into account. The speed of sound in the material must be lower than the collision speed of the cover plate and the base plate [13, 14]. The amount of the selected explosive can be determined based on the thickness and density of the cover plate. In the case of the large plates explosive welding, the base plate and the cladding plate are placed parallel to each other, leaving a gap between them calculated from the thickness of the cover plate. The parallel setup is shown in Fig. 3.

According to empirical recommendations, the gap distance should be between 0.5 and 1.6 times the thickness of the cladding plate, which is an empirical value. The gap distance is the distance that the cover plate travels before collission with the base plate. If this distance is too large, the plates may be damaged during impact and a significant increasing in the hardness may be observed. If the distance is too small, the surfaces of the plates will not bond properly [7].

The cross-section of the explosively welded joint in the direction of the explosion is the wave line following the shock wave of the explosion. The

Fig. 2. *Austenitic manganese steel railway frog.*

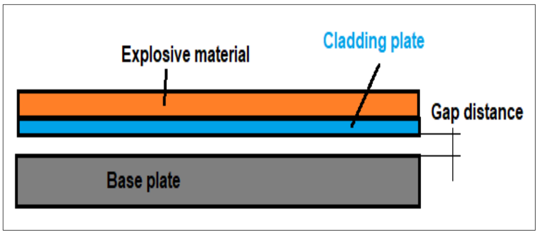

Fig. 3. *Paralell setup of the explosive welding.*

hardness on both sides of the joint increases compared to the hardness of the base metal. This can be considered the heat and deformation zone of the weld, which is a very narrow range (1-2 mm). The degree of hardening depends on the parameters of explosive cladding and the hardening coefficient of the materials used, i.e. their material characteristics.

2.2. Explosive hardening process

Explosive hardening technology is similar to explosive cladding technology in that it uses shock waves from high-pressure gas generated by explosions to increase the hardness of metal surfaces caused by plastic deformation. Different metals exhibit varying work hardening depending on their material properties. Hardness also depends on the used hardening technology. In the traditional setup, the explosive is placed directly on the metal surface for the explosive hardening process(direct hardening), while in the new setup it needs to left a gap between the metal surface and the explosive according to the explosive cladding setup (indirect hardening).

For the indirect hardening process, we used 319 g of Permont 10T explosive powder. The indirect hardening setup, which is identical to the explosive welding setup (**Fig. 3**), had a gap distance of 1.5 mm. Direct hardening was performed using the same explosive material and quantity. After hardening, Vickers hardness was measured on the surface of the steel test specimens using a load of 1.2 kgf. The results are shown in **Table 1**.

Table 1. *Results of the direct and indirect hardening*

Material	Hardness HV		
	Base metal	Direct	Indirect
X120Mn12	110	238	472
X5CrNi18-10	215	263	322

The results clearly show that indirect hardening caused greater hardening in both steel grades than direct hardening.

3. Conclusions

The results obtained from literature research and explosive hardening are in harmony. Based on the experimental results, it can be concluded that the indirect explosive hardening process results in greater hardnening than the direct process with the same explosive quality and quantity for the same steel grades.

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