

КВАЛИТЕТ ЕКСПЛОЗИВНО ЗАВАРЕНИХ ЧЕЛИЧНИХ ПЛОЧА КОРИШЋЕЊЕМ ЕКСПЛОЗИВА DEMEX

QUALITY OF EXPLOSIVELY WELDED STEEL PLATES USING DEMEX EXPLOSIVE

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Заваривање експлозивом се често користи када конвенционалне методе заваривања не могу да обезбеде заварени спој два различита материјала, али и када треба заварити неку специфичну геометрију или велике површине металних плоча. Остваривање споја код заваривања експлозивом се заснива на динамичком дејству великог притиска створеног експлозијом. У ту сврху најчешће се користе индустријски експлозиви ниских параметара детонације, а један од њих је DEMEX, произвођача TRAYAL, из Србије. У овом истраживању DEMEX је примењен за заваривање плоча две различите врсте челика. Пре експерименталног поступка заваривања одабраних металних плоча, експлозив добијен од произвођача је подвргнут улазној контроли квалитета: мерењу његове насипне густине и брзине детонације, коришћењем оптичких сонди и фотодетектора повезаног са електронским бројачем. Експериментална поставка за заваривање била је следећа: експлозив DEMEX у прашкастом стању нанесен је у равномерном слоју преко горње челичне плоче, која је хоризонтално постављена преко доње плоче од друге врсте челика, у паралелном положају, са малим дрвеним дистанцерима ивично постављеним између њих. Активација је извршена електродетонирајућом капислом и малим бустером од пластичног експлозива. Заварени спој је испитан применом метода ултразвучне дефектоскопије, течним пенетрантима и микроструктурне анализе завареног споја. Микроструктурне анализе попречног пресека заварених плоча урађене су на стерео и оптичком микроскопу како би се анализирао зона завареног споја.

Кључне речи: заваривање експлозијом, алатни/конструкциони челик, DEMEX експлозив, заварени спој

Explosion welding is often used when conventional welding methods cannot provide welded joint of two dissimilar materials, but also when some specific geometry should be welded, or large surfaces of metal plates. The formation of a joint in explosive welding is based on the dynamic effect of the high pressure created by the explosion. For this purpose, most often some industrial explosives of low detonation parameters are used, and one of them is DEMEX, produced by TRAYAL, Serbia. In this research DEMEX was applied to weld plates of two different types of steel. Prior to the experimental procedure of welding, the selected metal plates, the explosive obtained from the producer was subjected to initial quality control: measurement of its bulk density and detonation velocity, using optical probes and a photodetector connected with an electronic counter. The experimental setup for welding was as follows: explosive DEMEX in powdery state was applied in a uniform layer over the upper plate, which was horizontally placed over the lower plate, in parallel position, with small wooden spacers, marginally placed between them. Activation was performed by an electro-detonating cap and a small booster of plastic explosive. The welded joint was examined using methods of ultrasonic defectoscopy, liquid penetrants testing and microstructural analysis of the welded joint. Cross-sectional microstructural analyses of the welded plates were performed using a stereo and optical microscope to analyze the weld zone.

Key words: explosion welding, tool/construction steel, Demex explosive, welded joint

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1 Introduction

In addition to their use in ammunition and armaments, explosives also play an important role in industrial applications such as the cladding or welding of metal plates. Explosive welding uses the energy of explosive detonation to weld together metal parts that are compatible from a metallurgical standpoint as well as those that cannot be welded using conventional techniques. [1, 2]. For this purpose, explosives with low detonation velocities are usually used to avoid severe damage to the processed metal plates. For this purpose, explosives with low values of detonation velocity are usually used to avoid severe damage to the processed metal plates.

Explosive welding is a solid-state process in which a high-speed joint is made between dissimilar metals by controlled detonation. The explosion welding process, illustrated in Figure 1, relies on the following principles [2]:

- cladder metal (flyer plate) can be placed parallel or at an angle to the base plate,
- the explosive material is spread over the top of cladder metal plate,
- after detonation, the cladder plate collides with the base plate and forms a weld,
- waves are generated so due to mechanical bonding joining takes place, and
- a single blasting cap can be used to ignite the explosive.

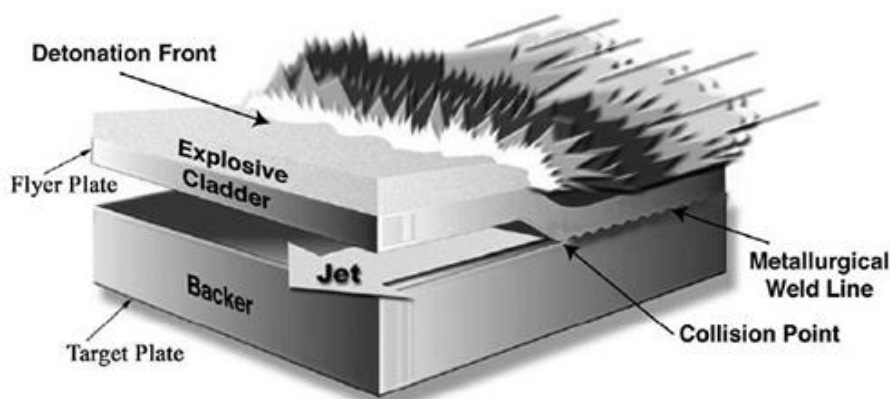


Figure 1. Schematic view of explosion welding process [2]

Explosive welding has a number of benefits over traditional welding methods, including the ability to weld dissimilar metals together, high bond strength, preservation of original metal properties, ability to weld over large areas, and practically there is no heat-affected zone. There are also some disadvantages, such as the fact that the metal pieces to be welded must have high enough impact resistance and ductility, their geometry must be simple - flat, cylindrical or conical, and the fact that this technique produces noise and carries certain risks and hazards due to manipulation with explosive.

The aim of this study was to investigate the possibility of using the industrial explosive Demex, which belongs to a group of explosives with low detonation velocity, for welding metallic materials - plates of highly wear resistant alloy steel X160CrMoV121 and low-carbon steel S355J2. These two types of steel were selected as a combination with potential application for specialized cutting tools.

2 Materials and methods

2.1 Steel plates and Demex explosive

In the experimental part of this study, two different metal materials were selected for welding: X160CrMoV121 and S355J2 steel. The chemical composition of these two metal materials is listed in Table 1 and their main properties in Table 2.

Table 1. Chemical composition of the used steels

Content	Element, wt. %													
	C	Si	Mn	P	S	Cr	Ni	Mo	Cu	N	Ti	Nb	V	Al
X160CrMoV121	1.58	0.26	0.32	0.01	0.01	12.0	-	0.9	-	-	-	-	0.7	-
S355J2	0.16	0.033	1.38	0.013	0.005	0.027	0.028	<0.001	0.029	0.007	0.008	0.029	0.004	0.038

Table 2. Properties of the used steel plates

	HV,f, HV,p – Vickers hardness	ρ_f, ρ_p – density, kg/m^3	h, thickness, mm
X160CrMoV121	$2.30 \cdot 10^9$	$7.80 \cdot 10^3$	3
S355J2	$1.84 \cdot 10^9$	$7.85 \cdot 10^3$	10

The industrial explosive Demex manufactured by TRAYAL Corporation was used for welding. Demex consists of ammonium nitrate (~95.5%) and TNT (2%) as energetic components, and other inert constituents. It is in a form of powder that can be easily spread in a desired layer over the metal plates to be welded. Detonation velocity declared by the producer was 2600-2650 m/s, and bulk density 0.75 g/cm^3 . Before the experiment, quality control was performed to check the main properties of Demex. Bulk density was determined using a brass vessel of the volume of 100 cm^3 and the detonation velocity was measured according to an internal procedure of Military Technical Institute [3], using optical probes and a photodetector in conjunction with a high-precision time counter. The powder explosive was poured into a PVC pipe 200 mm long, with an inner diameter of 50 mm. Two holes were drilled on the PVC pipe for placing the optical probes. The first hole is 75 mm away from the initiation point, while the second hole is 175 mm away from the initiation point. Photodetector was used to register the arrival of the detonation wave on *start* and on *stop* probe, and transfer it to the time counter. In this setup, three detonation velocity measurements were made. Figure 2 shows the sample with built-in probes, ready for measuring the detonation velocity of Demex.

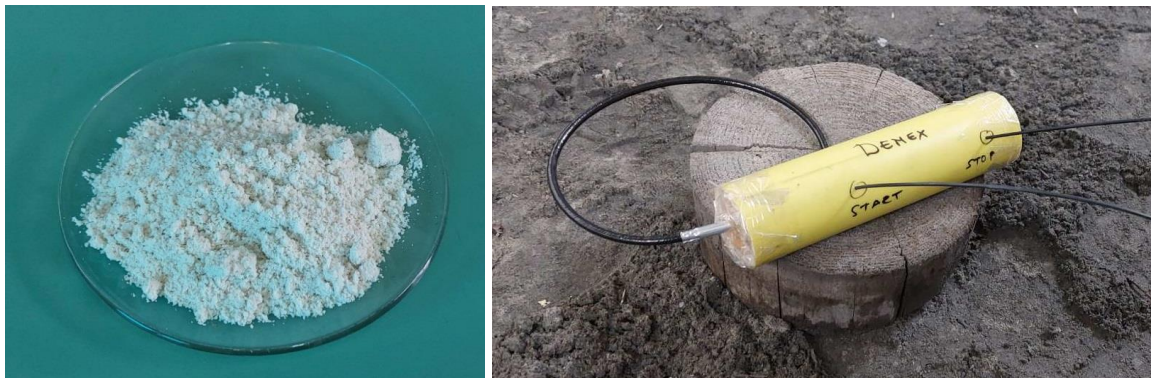


Figure 1. Left: Demex powder explosive; right: sample for measuring detonation velocity

2.2 Set-up for explosion welding

Steel plates were placed in a parallel configuration, with a distance between them 4 mm, achieved using small holders – wooden spacers positioned at the corners. Two sets of plates were prepared for welding. Demex explosive was evenly poured over the flyer plates of sets labeled with 1 and 2, in quantities of 540 and 640 g, respectively. The mass of the explosive was calculated according to theoretical approach, to meet the criteria of a quality welded joint [4-9].

Wooden frame was placed over the plates to hold the explosive in place, since it has a powdery consistency. Detonation cap/blasting cap DK8 was used for activation of Demex. The experimental set-up for the explosion welding is shown in Figure 3.



Figure 3. Experimental set-up for explosion welding, left: steel plates in parallel configuration with wooden spacers; right: wooden frame placed over the plates with DEMEX explosive and blasting cap placed in a holder

2.3 Welded joint quality inspection

The quality of the obtained welded joint was examined using methods of ultrasonic defectoscopy, liquid penetrants testing and microstructural analysis of the welded joint.

The welded steel plates were ultrasonically tested with the "Phasor XS" device / ultrasonic probe over the entire surface, by the pulse-echo method.

In order to prepare the samples for metallographic examination, the welded plate was cut with a water jet, with the following working parameters: the speed of the jet was 50 mm/min, pressure 3800 bar, and consumption of abrasive material 250 g/min and 1.5 l/min of water.

After grinding and polishing of metallographic samples, cross-sectional microstructural analyses of the welded plates were performed using a stereo microscope Leica equipped with a DFC 295 camera.

Testing with liquid penetrants of the explosively welded steel plate was performed with the penetrant system IIEd according to the standard SRPS EN ISO 3452-1 [10]. The test temperature was 23°C, while the illumination of the test surface was 750 lx. Before testing with liquid penetrants, the surface of the samples was cleaned and dried. After that, penetrant was applied to the test surface and left to penetrate into the open surface irregularities. After the time required for penetration, the excess penetrant was removed from the surface and then a developer was applied, which has a role to absorb the penetrant left in the irregularities and to give a visible indication.

3 Results and discussion

3.1 Quality of Demex explosive

For the performed measurements of detonation velocity and bulk density of Demex, the results are given in Table 3, as mean values obtained from three measurements and their standard deviations.

Table 3. Demex detonation velocity and bulk density

Property	Mean value	Standard deviation
Bulk density (g/dm ³)	0.5610	0.72
Detonation velocity, D (m/s)	2803.7	39.5

As it may be observed, the standard deviations are relatively small, so the measurements gave reproducible, relevant results. The obtained results are somewhat higher than the properties declared by the producer, which is good for future use of the selected explosive.

3.2 Ultrasonic defectoscopy results

The resulting welded area registered by ultrasonic defectoscopy is depicted in Figure 4. The area on the welded plates presented with white lines, is the area where the material was successfully welded. The welding attempt outside of this region was unsuccessful. The explosive activation was carried out in the locations designated by the numbers 1 and 2. It may be observed that in these areas the joint was not achieved, because there still was no stable detonation process developed. Also, in the marginal area of the plates, the weld was not achieved due to presence of the spacers. The area of the welded joint is similar for both the samples.



Figure 4. Explosively welded plates 1 and 2: area of weld, registered by ultrasonic method

3.3 Chemical penetrants test results

The cleaned samples were sprayed with colored penetrants and after a penetration time of 20 min. excess penetrant was removed from the surface with a cloth (Figure 5) and the samples were allowed to dry in ambient air before applying the liquid developer.

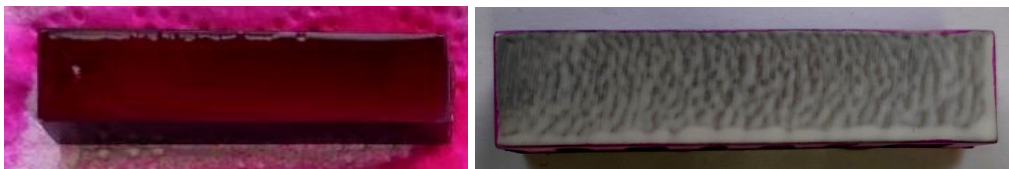


Figure 5. The appearance of the samples after the application of the chemical penetrants (left) and after their removal (right), sample 1

As seen from Figure 5, the penetrant did not show any irregularity along the welded joint, so the procedure of explosive welding may be considered successfully performed.

3.4 Microstructure of the welded joints

The observed microstructure in the zone of the welded joint is shown in Figures 6 - 8.

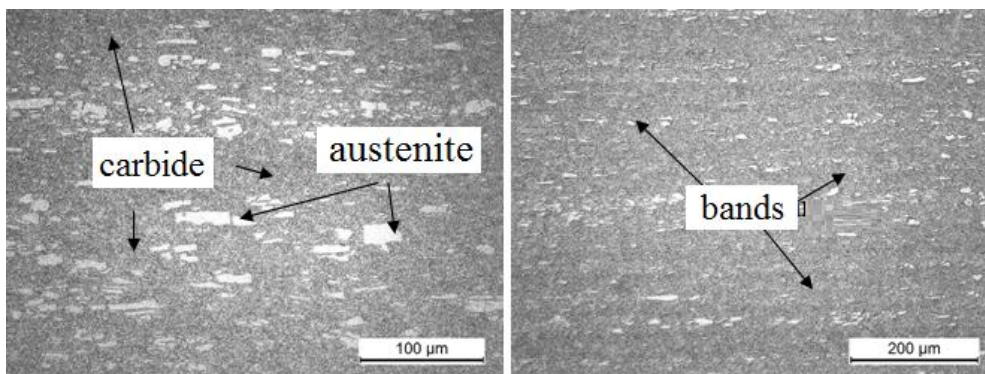


Figure 6. Microstructure of the steel X160CrMoV121

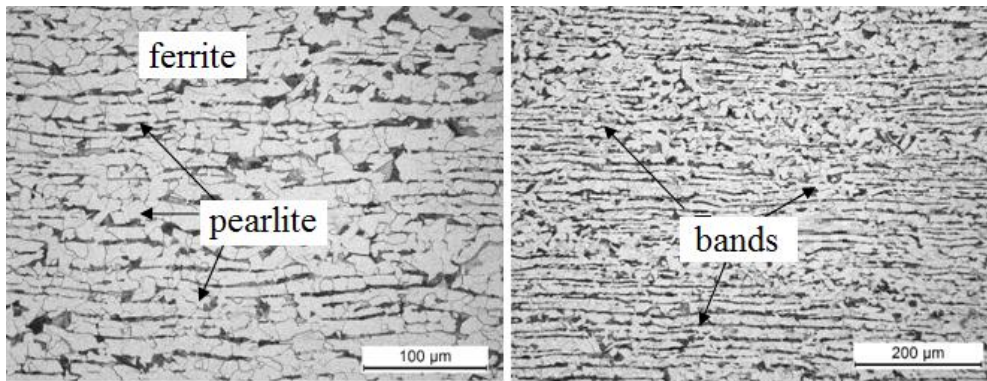


Figure 7. Microstructure of the steel S355J2

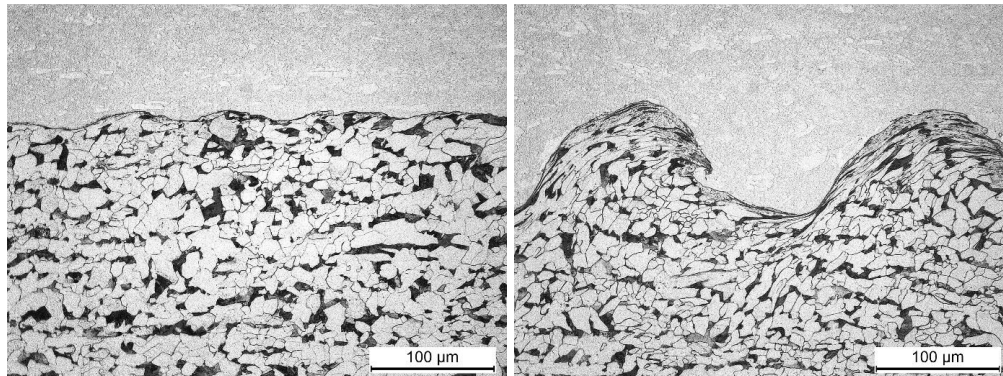


Figure 8. Microstructure of the welded joints 1 (left) and 2 (right)

In all the examined samples, the microstructure of the X160CrMoV121 steel consists of the base of carbide (cementite) particles in globular form and austenite (Figure 6). X160CrMoV121 steel is characterized by a grain structure of medium size in the range of 1 to 5 μm for carbide and 10-40 μm for austenite. The microstructure of S355J2 steel consists of a ferrite-pearlite structure (Figure 7). The S355J2 steel is in a state characterized by a uniform grain structure of medium size in the range of 5-10 μm for pearlite and 10-20 μm for ferrite. Pearlite grains are in the form of ribbon-like fine structures. The appearance of banded structure is a consequence of steel production technology, i.e. it is typical for materials subjected to hot forming [11, 12]. A secondary linear structure, i.e. pronounced bands, was observed in all samples. From Figure 8 it may be observed that welded joint 1 does not have pronounced characteristic wave-like shape, but the joint 2 does, thus having significantly bigger joining area between the two welded metal plates. This might mean that the quantity of 540 g of Demex, chosen for welding 1, maybe is on the lower limit of explosive quantity which will provide the welded joint.

4 Conclusions

The use of Demex explosive for explosion welding of plates made of the high-alloy steel X160CrMoV121 and the low-carbon steel S355J2 was investigated for potential usage in cutting tools. Prior to welding process, the explosive was examined and it was found that its bulk density and detonation velocity exceeded the minimum specified parameters provided by the manufacturer. Quantities of 540 and 640 g of Demex were used in experiment, and the quality of the welded joints was examined by ultrasonic defectoscopy, liquid penetrants, and microstructural analyses. Ultrasonic method has revealed that there are unwelded zones in the area of explosive initiation, as well as on the margins of the plates as a consequence of the wooden spacers. Liquid penetrant testing have shown good quality of the welded joint. Microstructural analysis, however, has revealed that sample which was welded with higher amount of Demex, has larger areas of the welded joint connecting the plates and more noticeable waves along the weld line typical for explosion welding.

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