IMPROVEMENT OF IMPACT TOUGHNESS OF STEEL WELDED JOINTS BY EXPLOSION TREATMENT

V.G. PETUSHKOV, Yu.I. FADEENKO, E.Ya. LOKSHINA,
S.N. SMIRNOVA, A.I. GRISHAENKO and I.E. TITOVA
E.O. Paton Electric Welding Institute,
Academy of Sciences of Ukraine
11 Bozhenko St., 252650, Kiev, Ukraine

ABSTRACT

The paper presents review of the results obtained by the authors on the effect of explosion treatment on impact toughness of welded joints in various structural metals. It is shown, that explosion treatment alone and, especially, in combination with heat treatment can provide an essential increase in impact toughness of welded joints. However, the application of this method in practice is difficult due to the formation of the so-called "prespalling damages" the elimination of which is labour-consuming and expensive.

KEYWORDS

Explosion treatment, metal welded joints, embrittlement, impact toughness.

The welded joint zone is, as a rule, an element of welded structures most susceptible to brittle fracture. Hence, there arises the question about possible accompanying changes in impact toughness under various explosion treatments (e.g. in order to decrease postwelding residual stresses or to repair the shape defects of welded structures), as well as about methods for improvement of impact toughness of welded joints by explosion treatment (ExT), combined explosion treatment "ExT + heat treatment" ("explosion heat treatment" , "ExHT") and preliminary ExT for welding of edges ("explosion-welding treatment", ExWT).

Changes in impact toughness a_H of a welded joint as a result of conventional ExT are in complex dependence on pressure in a compression wave induced in metal by explosion and on other parameters characterizing the treatment and specimen testing conditions (Petushkov, 1986). Under low pressures of loading, when the amplitude of tensile stresses does not exceed much the value of dynamic yield stress of metal (for structural steels - under pressures up to 200-300 MPa), usually no essential changes in impact toughness are observed. This enables to use a number of the ExT technologies without any arrangements for elimination of embrittlement of metal treated. However, loading with the higher pressures can be accompanied by the drastic changes in impact toughness. There is a contradiction in data available in literature on this matter. Some works note the possible increase in impact toughness of low-carbon and low-alloy steels, some - high embrittlement of these steels, and the comparative estimation is difficult because investigations were conducted with steels of different grades (Dieter, 1965; Leslie, 1962).

To clear out the question we conducted special studies, where specimens of low-carbon steel Ст08кп (0.08 %) were loaded to different pressures with a flyer plate and then impact toughness tested. Only one of the parameters characterizing the treatment and test conditions (pressure and duration of loading pulse, ambient temperature, etc.) was varied in each series of the experiments conducted. As a result it was found, that the determining factors in this case were the specimen fitting conditions. Table 1 gives the comparative data of mechanical tests of three specimens: 1) in initial state, 2) after the 10 GPa pressure treatment with the untreated surface fitted to the base having acoustic impedance lower than that of steel Ст08кп, 3) after the 10 GPa treatment with the polished surface fitted to the massive base of low-carbon steel. The difference between the latter two operations lies in the fact that specimen 3 (except for the zone of the edge effects) is subjected only to the influence of compression stresses; while the complex wave pattern forms in specimen 2 after it collides against the metal plate, there appearing the high tensile stresses which, according to the kinetic fracture theory, for a short period of time can reach the values several times higher than the material ultimate strength determined by mechanical tests under conventional conditions.

Table 1. Effect of fitting conditions of specimen on its impact toughness.

State of specimen	σ_T, MPa	σ_B, MPa	δ, %	ψ, %	KCU, J/cm2
1	256	409	35	66	259
2	274	420	34	65	65
3	303	433	31	65	228

Here: σ_T is the yield stress, σ_B is the ultimate strength, δ and ψ are elongation and necking before fracture, KCU is the impact toughness of the specimen with the U-shaped notch.

It can be seen from the Table 1, that the main factor determining embrittlement of steel in ExT is the kinetic accumulation of prespalling damages and that embrittlement in ExT can be avoided by using the antispalling protection. However, setting up of the antispalling protection is a simple technological operation only for treatment of flat sheet metal with the sufficiently smooth surface, but ExT of welded sheet structures is difficult because surfaces are curvilinear and the weld foot is projecting. Here, the labour consumed for setting up of the protection and control of the final results is so high that in practice ExT of welded structures is usually used without any antispalling protection and only under sufficiently low pressures, when embrittlement is not yet a problem. But when the purpose of the explosion treatment is the increase in impact toughness, then ExHT and ExWT are used, rather than conventional ExT. And here, the desirable effect is achieved mainly due to the fact that impact cold working promotes complete or partial recrystallization of metal in subsequent heating during heat treatment (ExHT) or welding (ExWT). In the process of optimization of the technology the explosion and heat treatment conditions are selected so that recrystallization is accompanied by refining of grains and by increase in toughness of metal, first of all, in the most critical zone of a welded joint near the fusion surface.

Consider the efficiency of this technology for particular problems and materials of different grades.

LOW-ALLOY STEELS.

Table 2 gives the data on the effect of various ExHT conditions on impact toughness of low-alloy manganese steel 09Г2С.

Table 2. Effect of ExHT on impact toughness of low-alloy steel

Pressure of preliminary ExT, GPa	Impact toughness, J/cm2, after heat treatment at temperature, °C, for 1 h.			
	0	900	1000	1100
P = 0	101	75	148	140
P = 1.5	256	360	316	360
P = 10	160	272	340	254

Here, noticeable is the unusually high growth of impact toughness both in the ExT and ExHT conditions, this being associated with the peculiarities of the experimental design. Plates of the metal investigated whose thicknesses were much higher than thicknesses of the superposed explosive charges (5...10 mm) were subjected to the pressure of the sliding detonation wave induced by these superposed charges. Specimens for measuring impact tougness were cut out of the upper layer of the metal and the notch for the measurements was made directly at the surface subjected to the effect of explosion, whereas accumulation of prespalling damages took place in the layer, having the thickness of the order of the explosive charge thickness, adjacent to the back surface of the plate and removed when preparing the specimen.

Thus, the data of Table 2 confirm once more the determining effect of "prespalling damages" on embrittlement in ExT and the possibility in principle for the drastic increase in

impact toughness in conventional ExT.
We studied also the effect of low-temperature explosion treatment of welded joints in low-alloy steels 09Г2С and 10ХСНД produced after preliminary explosion treatment of the joint edges by the ExWT method. Measured were impact toughnesses of specimens with the U-shaped notch at -40°C and specimens with the the V-shaped notch at -10 ° C. The data obtained are given in Table 3.

Table 3. Effect of ExWT on Impact Toughness of Welded Joints in Structural Steels

Steel grade	Pressure, GPa	Impact toughness, J/cm2 -40 ° C	-10 ° C
09Г2С	P=0	32.0	17.6
	P=1.5	50.4	23.1
10ХСНД	P=0	65.0	33.4
	P=1.5	75.6	43.4

WELDED JOINTS IN PIPELINE.

Петушков и др. (1988) conducted investigations of the efficiency of ExHT on pipe steel joints welded using the cheap low-alloy welding consumables. The result of using these consumables may be such that the ductile-brittle transition temperature of the joints is higher than the lower limit of the service temperatures. The required level of mechanical properties of the X70 steel joints (KCU = 50 J/cm2, bend angle = 180 degrees) can be achieved by long heat treatment at high temperatures. But here, capacity of the heat treatment equipment turns out low, while the energy consumption is high. The possibility for decrease the temperature of heat treatment and for shortening its duration due to preliminary ExT of welded joint was studied in (1988). The positive result was obtained when the detonating cord charges were applied along the fusion line on the both sides of a weld and when the postexplosion heat treatment was used for 40 min within the temperature range from Ac1 to Ac3. Unlike the initial metal, the metal subjected to ExT is sensitive to heat treatment at low temperatures. Some changes in mechanical properties are observed already at the temperatures below Ac1 both in the HAZ and, particularly, in the weld metal. In the Ac1 to Ac3 range there occurs recrystallization of metal accompanied by a drop of yield stress and growth of impact toughness, and ExT prevents the too fast loss of strength after heat treatment in this temperature range, which is peculiar to the initial metal.

HIGH-MANGANESE STEELS.

Steels with high manganese content, the Г13Л and 110Г13Л grade steels in particular, are rather sensitive to explosion cold

working and the products of these steels are often subjected to ExT to improve their hardness, especially in the cases when it is necessary to have high impact and abrasive resistance (railway switch-points, mining equipment components). However, impact toughness of these steels drops after ExT from the initial level KCU = 170 ...175 J/cm2 down to 50...80 J/cm2. We established that after ExT the impact toughness can be partially recovered (up to 80...130 J/cm2) without a loss of hardness due to holding for 1 h at temperature 200 C with subsequent air cooling. Supposedly, the physical mechanism of the phenomenon consists in decrease in second-kind internal stresses, transformation of the chaotic dislocation structure into the arranged one and in growth of the phase precipitates; however, this matter is not completely clear yet.
As to the aspect under consideration, steels Г13Л and 11013Л are interesting in that the behaviour of the cast metal is similar to the behaviour of the weld metal.

TITANIUM ALLOYS.

Петушков и др. (1991) developed the technology for producing the fine-grain homogeneous structure across the entire section of weldments of commercial titanium ВТ1-0 by the ExHT method. After explosion loading with pressures 1.5...10 GPa the metal was subjected to annealing for 1...6 h within the temperature range from 650 to 900 C. Under the optimum ExHT conditions the authors succeeded in recrystallization of the metal by making the HAZ grains fully equal and the weld grains - almost equal to those of the base metal (0.03...0.04 mm), except for some individual coarse nonrecrystallized grains.
At the same time, for the research purposes, the same treatments were applied to the ВТ6 alloy welded specimens which were then used for comprehensive mechanical measurements, including the measurement of the welded joint impact toughness . The base metal impact toughness was at the level of 47...50 J/cm2, whereas the welded joint impact toughness before and after ExT was 35...40 J/cm2. After heat treatment the impact toughness under some conditions decreased down to 15...25 J/cm2, but under the optimum ExHT conditions it was the same 35...40 J/cm2. It is interesting to note, that under the ExWT conditions was 40...45 J/cm2, i.e. it was close to the base metal impact toughness.

HEAT-HARDENABLE ALUMINIUM ALLOYS.

The possibility was studied for explosion strengthening of welded joints in heat-hardenable aluminium alloys 1201 and 1420. The fracture resistance characteristics were determined under the conditions of off-centre tension, i.e. under the simultaneous effect of tension and bending. Here, the force characteristic is the value of nominal fracture stress σ_p which is determined by the value of the maximum load. Besides, specific energy of crack initiation (SECI) and specific energy of crack propagation (SECP) were calculated by the coordinates of the experimental load-deformation diagram automatically recorded during the tests. The complete information about the investigations will be published separately. But some results of the measurements for base metals and welded joints are given in Table 4 (AA - artificial ageing).

Table 4. Effect of Treatment Conditions on Fracture Energy of Aluminium Alloys

Alloy	State	, MPa	SECI J/cm2	SECP J/cm2
1201	quenching + AA	345	7.5	3.3
	quenching + + explosion + AA	402	10.7	3.8
	quenching + welding	302	11.4	7.0
	quenching + explosion + + AA + welding	318	10.2	6.0
1420	quenching + AA	407	5.6	3.5
	quenching + explosion + + AA	456	7.1	3.0

The data given prove that the explosion treatments in principle can provide both the drastic increase in impact toughness of various metals and their welded joints and the improvement of a set of mechanical properties as a whole. However, the practical selection of the optimum tecnologies is, as a rule, rather a labour-consuming problem. The potentials of the explosion technologies in this line are much higher than the level of their practical application.

REFERENCES

Dieter G. E. (1962) Strengthening by Shock Waves. In: Strengthening Mechanisms in Solids (Papers pres. at a Seminar of the Amer. Soc. for Metals. Oct. 13-14, 1960). Reinhold Publ. Corp., Cleveland.

Leslie V. C. Hornbogen E., Dieter G. E. (1962) The structure of shock-hardened iron before and after annealing. Journ. Iron and Steel Inst. Vol. 200. N 8. P. 622-633.

V. G. Petushkov, Yu. I. Fadeenko, E. Ya. Lokshina, V. A. Titov, I. E. Titova, V. P. Larionov, S. P. Yakovleva, G. P. Yakovlev (1986) Change in structure and properties of welded joints as a result of explosion treatment. In: High Energy Rate Fabrication (Proc. 9th Int. Conf. on High-Energy Effects of Materials, Novosibirsk, August 18-23, 1986). P. 101-105. AN SSSR Publ. House. Novosibirsk. (In Russian).

V. G. Petushkov, Yu. I. Fadeenko, S. N. Smirnova, A. I. Grishaenko. (1988) Explosion Treatment of Welded Joints in Low-Temperature Steels Before Their Heat Treatment. - Automatic Welding. N 7. P. 68-69.

V. G. Petushkov, A. D. Shevelev, I. A. Tyapko, S. N. Smirnova (1991) Explosion Heat Treatment of EB Welded Joints in Titanium. - Automatic Welding. N 2. P. 55-58.