PECULIARITIES OF EXPLOSION WELDING OF STEEL WITH CAST IRON

I.V. DENISOV and **L.B. PERVUKHIN**
Institute of Structural Macrokinetics and Materials Science, RAS
8 Acad. Osipyan Str., 142432, Chernogolovka, RF. E-mail: isman@ism.ac.ru

Products of cast iron find a wide spreading in modern machine building, in particular for manufacture of friction discs, in which the plates of cast iron are fastened by bolts to steel or copper plates. According to hypothesis about formation of impact-compressed gas (ICG) and its thermal ionization at the interface with the formation of thin layers of low-temperature («cold») plasma in a welding gap during explosion welding, the conditions of formation of carbon steel–low-alloy cast iron joint were determined. Conditions of explosion welding and heat treatment were set for producing full-strength joint and prevention of defects in the form of cracks and spallings along the entire line of contact between the steel and cast iron. The carried out evaluation calculations of parameters of ICG with account for super-speed flowing of surface being welded by it showed that change in rate of contact spot from 2400 up to 4000 m/s leads to increase in temperature and decrease of length of ICG region, as well as time of plasma effect. 6 Ref., 1 Table, 1 Figure.

Keywords: *explosion welding, welding gap, impact-compressed gas, gas parameters, cleaning, contact spot*

In manufacture of friction discs the cast iron plates are fastened to steel or copper ones using bolts. Replacement of the bolted joint by strong welded joint along the entire surface of the cast iron disc will allow increasing the strength of the product, its manufacturability, making possible to apply welding in manufacture of cast iron products. However, the bolted joint does not guarantee the dense contact along the entire surface, thus deteriorating the heat removal from the cast iron disc and contributing to its non-uniform heating. The presence of local zones of preheating leads to cracking and pouring out of cast iron.

The main drawbacks of cast iron as a structural material are its low ductility and poor weldability by all the methods of welding, including explosion welding. The experience of previous works on producing of steel + cast iron bimetal by explosion welding showed that due to a low ductility the defects in the form of cracks, spallings, delaminations are formed in the process of welding [1].

During development of the technology of explosion welding of cast iron with steel it is necessary to solve the following main tasks:

• producing of strong joint over the entire surface;

• prevention of formation of cracks and fractures of cast iron during welding;

• investigation of mechanical properties and structure of produced joints, as well as effect of postweld heat treatment on them.

To solve the put tasks, the following methodology was developed, which provided on the basis of published data and experience of production of bimetals by explosion welding:

• evaluation of feasibility of explosion welding of steel with cast iron;

• working out of technological solutions, reducing the probability of formation of cracks and fractures of cast iron during welding;

• development of pilot technology of producing steel + cast iron bimetal and investigation of produced joints.

At present, a large experimental and theoretical information was accumulated on the problem of formation of joints in explosion welding, which was generalized in works [2, 3]. Some hypotheses were made, explaining the formation of joints from different points of view. In the zone of collision in explosion welding the high pressures are developed, an intensive plastic deformation is going on, accompanied by significant increase in temperature of metals in the collision zone.

The explosion welding is characteristic of three stages of process for formation of strong bonds between the atoms of metals being joined, realizing in the following sequence: cleaning and activation of contact surfaces, formation of physical contact, and volume interaction. The quality of explosion welding is defined, first of all, by the processes, proceeding in a welding gap ahead of the contact spot [4], i.e. by cleaning and activation of surfaces being joined.

© I.V. DENISOV and L.B. PERVUKHIN, 2013

Evaluation of parameters of impact-compressed gas (ICG) in the welding gap was made by procedure [4] for the following explosion welding mode parameters: rate of contact spot v_c is varied from 2400 up to 4000 m/s, ratio of mass of explosive to mass of flyer plate — from 1.2 to 0.7, welding gap — from 8 to 1 mm, Mach number is varied from 7 up to 11.6. The calculations showed that the ICG parameters in welding gap in this case are varied in the following limits: pressure — from 7 up to 13.7 MPa, temperature — from 2500 up to 5000 K.

The carried out evaluation calculation by the procedure [4] showed that increase in rate of contact spot improves the conditions of cleaning and activation of surfaces being welded due to increase in rate and temperature of ICG in welding gap and parameters of plasma at the interface between the ICG and surfaces being welded. Time of plasma effect t can be determined by formula $t = l/v_c$, where l is the length of ICG region, determined by procedure [4]. With increase in rate of contact spot from 2400 up to 4000 m/s, the time of plasma effect is decreased from $2.4\cdot10^{-5}$ to $1.12\cdot10^{-5}$ s.

Increase in rate of explosive detonation will lead to the increase in speed and energy of collision of flyer plate with the base. This, in turn, will increase the plastic deformation of the base sheet and probability of appearance of cracks and fractures in it. It is possible to control the speed of plate flying by changing the welding gap. The procedures of calculation of collision speed, described in works [2, 3, 5], does not take into account the value of welding gap and it was only suggested in work [6] to determine the angle of collision and speed of flying v_0 with account for value of the welding gap:

for mixed explosives

$$v_0 = 2D \sin \frac{0.49r}{r + 2.71 + 0.184/h}; \quad (4)$$

for ammonite

$$v_0 = 2D \sin \frac{0.416r}{r + 2.71 + 0.184/h}, \quad (5)$$

where D is the detonation rate of explosive; r is the dimensionless parameter equal to ratio of explosive mass to mass of the flyer plate; h is the gap height.

Calculation of flying speed and angle of collision by these formulas for the above-given explosion welding conditions and at varying the welding gap from 1 up to 8 mm showed that flying speed at decrease of welding gap from 8 to 1 mm is 2 times reduced. This will allow 4 times decreasing the collision energy and, as a consequence, decreasing the probability of appearance of cracks and fractures in cast iron.

Thus, to guarantee the strong joints in explosion welding of cast iron with steel, the process should be performed under conditions with increased rate of detonation of 3500–4000 m/s and 2–1 mm welding gap to prevent the formation of cracks and fractures of cast iron.

As initial material in conductance of experimental investigations, the sheet of steel of 08kp grade (killed) of 4 × 300 × 500 mm sizes and cast plates of ferrite-pearlite low-alloy cast iron with a lath graphite (further — cast iron) of 8 × 180 × × 350 mm sizes were used. A parallel scheme of explosion welding was applied. Two explosion welding conditions were used:

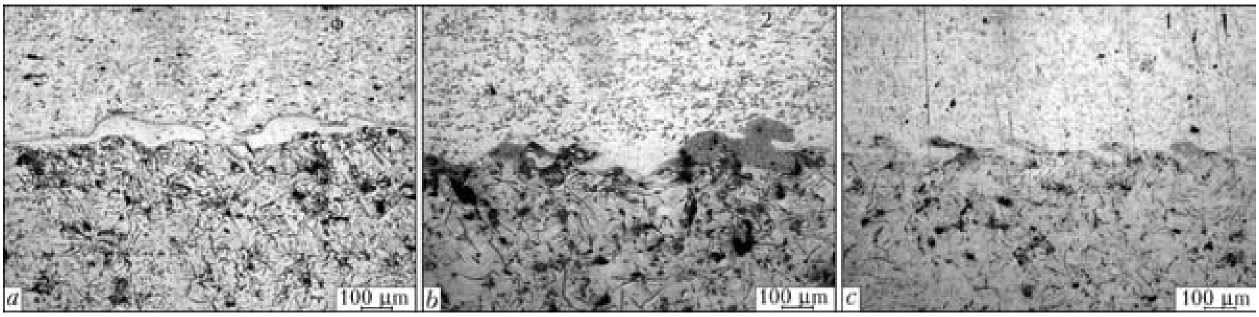
- rate of detonation of explosive D = 2400–2500 m/s; dimensionless parameter r = 1.2; welding gap is 8 mm that provides the flying speed of 500–550 m/s; calculation angle of collision is 8–9°;
- D = 3500–3700 m/s; r = 0.7; welding gap is 1.8 mm that provides the flying speed of 340–400 m/s; calculation angle of collision is 2–3°.

It was found as a result of experiments that in welding using the first variant the cutting of overhanging of steel plate, significant deformation of plate of cast iron with its partial fracture and full absence of the joint over the entire surface of cladding with prints of relief of mechanical treatment of cast iron plate are observed. The absence of adhesion spots on the surfaces being welded indicates that the preset condition of explosion welding did not provide cleaning and activation of cast iron surface ahead of contact spot.

Strength of steel + cast iron joint and hardness of cast iron* depending on heat treatment

Heat treatment	Tensile strength of joint σ_t, MPa	Hardness of cast iron *HB*	Hardness of white phase *HB*
Without heat treatment	130–135	220	514
Heating up to 550 °C, holding from 4 up to 6 h, furnace cooling	145–150	175	322
Heating up to 700 °C for 1 h, furnace cooling	155–160	160	No white phase

*σ_t of initial cast iron is 200 MPa, hardness *HB* is 163–219, no white phase.



Microstructure of steel 08kp + alloyed cast iron joint: *a* — without heat treatment; *b* — heat treatment at 550 °C for 4–6 h, furnace cooling; *c* — same at 700 °C for 1 h, furnace cooling

Experiments using the second variant showed that the joining of steel with cast iron occurs over the entire surface with a negligible deformation of welded plates. The ultrasonic testing of some two-layer plates revealed small (2–3 cm^2) angular lacks of penetration.

Tensile tests of the joint for separation of a cladding layer were carried out on specimens without heat treatment and specimens with two different heat treatments. The first condition was a heating up to 550 °C, holding for 4–5 h and furnace cooling; the second — heating up to 700 °C for 1 h and furnace cooling (Table). The tests showed the joint strength after explosion welding was 130–135 MPa, heat treatment by the first condition increased the joint strength up to 145–150 MPa and decreased its hardness. The strength of joint of specimens, heat treated by the second condition, was 155–160 MPa.

The microstructure of joint of specimens without heat treatment showed the presence of a white phase (Figure, *a*), hardness of which was *HV* 514 (see the Table). Chemical composition of the white phase corresponds to that of cast iron. Examination of microstructure of joint of specimens after heat treatment (550 °C, 4–6 h, furnace cooling) showed the decrease in sizes and amount of the white phase (Figure, *b*), which hardness was *HV* 322. Microstructure of joint of specimens after heating to 700 °C for 1 h and furnace cooling showed the absence of the white phase (Figure, *c*), consequently, this heat treatment condition allows annealing the inclusions of the chilled cast iron (white phase) at the joint interface, thus increasing the mechanical properties of the joint.

Metallographic examination of steel 08kp + cast iron joint showed that the joint has no large regions of cast inclusions. The cast iron cracking was not revealed, which could be formed in producing bimetal, thus proving the favourable effect of small welding gaps and applying the explosive with increased rate of detonation.

The analysis of investigation of microhardness of specimens showed that hardness is levelled and strength of the joint is increased in the zone of joint at heat treatment by the condition of cast iron annealing (700 °C for 1 h and furnace cooling).

Conclusions

1. Decrease in welding gap from 8 to 1.8 mm leads to reduction in rate of collision of the flyer plate with base almost 2 times and, consequently, the collision energy is 4 times decreased.

2. Experiments on explosion welding of steel with cast iron confirmed the evaluation calculations and showed that increase in rate of contact spot with simultaneous decrease of parameter *r* and welding gap to 1.8 mm creates conditions of producing full-strength joint between the carbon steel and low-alloy cast iron having no deformations and defects (cracks) on the brittle cast iron surface.

3. Investigation of microstructure of joint of steel with cast iron before and after heat treatment showed that chemical composition of inclusions of a white phase corresponds to that of low-alloy cast iron, i.e. it is a chilled cast iron. Heat treatment in the condition of annealing provides the transformation of structure of the chilled cast iron into the initial one.

1. Alekseev, Yu.A. (1997) *Structural peculiarities of weld and their influence on metal joining quality in explosion welding with narrow gaps*: Syn. of Thesis for Cand. of Techn. Sci. Degree. Chernogolovka.
2. Lysak, V.I., Kuzmin, S.V. (2005) *Explosion welding*. Moscow: Mashinostroenie.
3. Petushkov, V.G. (2005) *Application of explosion in welding technique*. Kiev: Naukova Dumka.
4. Bondarenko, S.Yu., Rikhter, D.V., Pervukhina, O.L. et al. (2009) Determination of the parameters of shock-compressed gas in the welding gap ahead of the contact point in explosion cladding. *The Paton Welding J.*, **11**, 39–41.
5. Pervukhin, L.B., Pervukhina, O.L., Bondarenko, S.Yu. (2010) Cleaning and activation of welded surfaces during explosion welding. *Ibid*., **7**, 41–43.
6. Konon, Yu.A., Pervukhin, L.B., Chudnovsky, A.D. (1987) *Explosion welding*. Moscow: Mashinostroenie.

Received 19.02.2013