FLASH-BUTT WELDING OF REINFORCEMENT BARS OF A400S–A600S CLASSES IN CONSTRUCTION OF STRUCTURES OF MONOLITHIC REINFORCED CONCRETE

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The application of flash-butt welding of reinforcement bars in civil engineering under site and semi-stationary conditions in construction of monolithic reinforced concrete structures is considered. This method is characterized by a high stability of characteristics of quality of concrete reinforcement being welded and absence of auxiliary consumables. The main technological parameters of the process were determined, basic technologies were developed, providing the increase in service life of reinforced concrete structures, improvement of their reliability and guarantee of high service life.

Keywords: *flash-butt welding, reinforcement bars, welded joints, site conditions, monolithic reinforced concrete*

In construction and repair of reinforced concrete constructions and structures the different methods of arc welding of concrete reinforcement are used. The manual and semi-automatic electric arc welding, bath-arc welding and others have found the widest spreading. It should be noted that at plants and industrial groups of as-assembled reinforced concrete a flash-butt welding with a continuous flashing is widely used, except the above-mentioned methods. Now, it is one of main methods of producing the butt joints of concrete reinforcement under the shop conditions.

The flash-butt welding is characterized by a high stable quality of welded joints, almost equal in strength to the parent metal that makes it possible to increase greatly the reliability and service life of reinforced concrete structures and to provide the high productivity. The process of welding is performed in the automatic conditions, combines the assembly and welding operations in a single cycle, does not require application of auxiliary consumables (electrodes, welding wire, fluxes, gases, etc.). Moreover, special requirements to the welder's qualification are not specified. At the present time, this method is not used in site, first of all, due to the absence of special technologies and equipment.

The existing experience in the development of technologies and specialized equipment of the flash-butt welding in the field conditions of railway rails and pipes allows applying this method for joining the reinforcement bars of concrete under site and semi-stationary conditions. For this purpose, it is necessary to define the technological features of the process and requirements to the specialized equipment, which depend mainly on the conditions of its service. The equipment should be mobile, compact, have available a minimum possible electric power and maximum protection from the environment effect.

As a rule, the concrete reinforcement bars of up to 22 mm are joined by the flash-butt welding with a continuous flashing, and the large-diameter bars are joined by using a flashing with a preliminary resistance preheating. The latter is characterized by a wide instable HAZ. The flash-butt welding with a pulsed flashing allows joining all the assortment of reinforced bars and has advantages over the above-mentioned methods.

In construction of monolithic reinforced concrete structures the reinforcement of A400S–A600S classes of steels St3Gps (semi-killed), 25G2S and 35GS in hot-rolled or heat-hardened state are most widely used in accordance with recommendations [1]. Technological investigations and development of a basic technology were made using this concrete reinforcement. Mechanical characteristics of these steels in hot-rolled state are given in Table 1, and chemical composition is given in Table 2.

The carried out technological investigations of welding the hot-rolled reinforcement bars made it possible to establish the values of main parameters of welding conditions: adjusting length L_{adj}, tolerances for flashing L_{flash} and upsetting L_{upset}, open-circuit secondary voltage $U_{2o.-c}$, rates of flashing v_{flash} and upsetting v_{upset}, time of welding t_w and time of upsetting under current $t_{upset I}$ (Table 3). The values of tolerances, necessary for attaining the required heating of the zone of plastic deformation of metal in upsetting with account for beveling the parts being

Table 1. Mechanical characteristics of bar reinforcing steels

Steel grade	$\sigma_{0.2}$, MPa	σ_t, MPa	δ, %
35GS	370–500	610–670	18–30
25G2S	380–400	590–620	23–31
St3Gps	235	370–490	25

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Table 2. Chemical composition of bar reinforcing steels, wt.%

Steel grade	C	Mn	Si	Cr	Ni	S	P	Cu
25G2S	0.20–0.29	1.20–1.60	0.60–0.90	<0.30	<0.30	<0.045	<0.040	<0.30
35GS	0.30–0.37	0.80–1.20	0.60–0.90	<0.30	<0.30	<0.045	<0.040	<0.30
St3Gps	0.14–0.22	0.80–1.10	<0.15	<0.30	<0.30	<0.050	<0.040	<0.30

Table 3. Parameters of conditions of welding the hot-rolled concrete reinforcement of A240S–A500S classes

D, mm	$U_{2o.-c}$, V	L_{flash}, mm	L_{upset}, mm	t_w, s
12–18	5.5–6.0	10–12	3	8–10
20–28	5.5–6.0	11–15	4–5	15–20
32–40	6.0–6.5	13–17	5–6	Up to 30

Table 4. Results of mechanical tests of welded joints of hot-rolled concrete reinforcement of A400S class of stell 35GS

D, mm	σ_y, MPa	σ_t, MPa
16	$\frac{432.7–472.4}{457.9}$	$\frac{721.2–731.1}{726.1}$
18	$\frac{361.4–402.6}{387.9}$	$\frac{628.8–660.2}{647.6}$
20	$\frac{394.7–451.2}{418.0}$	$\frac{652.5–719.4}{699.4}$
22	$\frac{356.6–394.4}{372.2}$	$\frac{639.3–684.0}{657.7}$
25	$\frac{399.2–482.8}{432.9}$	$\frac{652.5–754.4}{678.7}$
28	$\frac{455.1–513.0}{490.0}$	$\frac{674.8–754.4}{724.8}$
32	$\frac{456.2–565.8}{505.9}$	$\frac{684.4–719.4}{697.1}$
36	$\frac{469.4–517.3}{498.1}$	$\frac{646.2–757.6}{708.8}$

welded, were determined experimentally. It was found that the rate of flashing at the beginning of the process is 0.4–0.5 mm/s, and it is increased up to 2.0–2.5 mm/s directly before upsetting. The open-circuit secondary voltage, which provides a stable proceeding of heating process in flashing, should be minimum [2].

Mechanical testing of full-scale specimens of joints of a hot-rolled reinforcement bars of steel 35GS, welded by a continuous flashing at optimum conditions, were performed in accordance with requirements [3]. Their results are given in Table 4. Fracture of all specimens occurred in the parent metal at a large distance from the welded joint and HAZ (Figure 1).

Similar results were obtained also on steels St3Gps and 25G2S in a hot-rolled state. Macrosection of the joint and distribution of microhardness are shown in Figure 2, microstructure of zone of joint and parent metal is given in Figure 3.

Preliminary thermal hardening of reinforcing steel increases greatly the requirements to the selection of its heating condition in welding, guaranteeing the formation of welded joint equal in strength to the parent metal.

In welding of heat-hardened reinforcement bars using a continuous flashing at soft conditions or flashing with a preliminary resistance preheating the reduction of tensile strength to the level of tensile strength of steel, which was not subjected to preliminary heat treatment, is observed in HAZ metal. As main varied parameters of the welding condition, the values L_{adj}, L_{flash} and t_{upsetI} were selected.

It was determined during investigations and development of the technology of welding of heat-hardened reinforcement bars of steel 25G2S that the optimum value of an adjustable length is within the same limits as in welding of a hot-rolled reinforcement bars $(1.7–2.0)D$. The value of tolerance for flashing is also little differed and it can be taken equal to appropriate tolerance, defined for the hot-rolled reinforcement bars.

The increased sensitivity to heating of heat-hardened reinforcement bars specifies the additional requirements to thermal cycles of heating in welding. As the main condition parameters of welding the hot-rolled and heat-hardened concrete reinforcement have almost similar values, the time of upsetting under current, i.e. the value of weakening, which depends

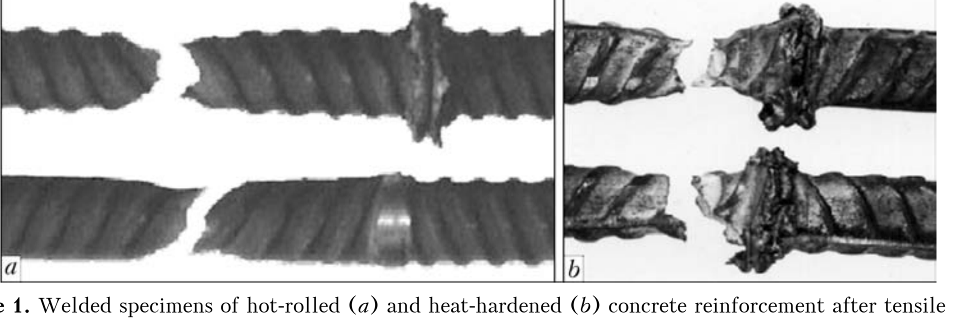


Figure 1. Welded specimens of hot-rolled (a) and heat-hardened (b) concrete reinforcement after tensile tests

Table 5. Welding condition parameters and results of mechanical tests of concrete reinforcement of A600S class of steel 25G2S

L_{adj}, mm	L_{flash}, mm	$t_{upset I}$, s	σ_t, MPa	$\sigma_{w.j}/\sigma_{p.m}$, %	Place of fracture
25	11	0.10	830–850 / 847	96.1–98.2 / 97.3	HAZ
11	4	0.10	800–825 / 816	93.7–96.6 / 95.5	In butt
7	4	0.10	870–875 / 873	93.7–102.0 / 97.9	Same
12	8	0.04	825–845 / 831	95.5–97.0 / 96.3	In butt 2 specimens
15	10	0.04	835–845 / 836	96.1–97.0 / 96.4	Same
17	12	0.04	820–850 / 838	95.0–98.2 / 96.7	In parent metal 2 specimens

greatly on additional heating in upsetting, has the highest effect on mechanical characteristics of the joint.

During investigations the time of upsetting under current varied from 0.10 up to 0.04 s. The obtained results are given in Table 5.

During the mechanical tests the first five welded specimens had a ductile fracture in HAZ with a weakening of not more than 2–4 % (see Figure 1, *b*).

In welding at conditions with smaller tolerances for flashing the brittle fracture is occurred, caused by an intensive heat dissipation into welding machine electrodes being cooled. The increase in zone of heating during flashing with a simultaneous reduction of time of upsetting under current allowed producing welded joints, being almost equal in strength to the parent metal. The weakening did not exceed 2 %. Moreover, the fracture of most specimens (about 90 %) occurred in parent metal beyond HAZ. Macrosection of such joint and distribution of hardness in it are given in Figure 4.

To prevent the occurrence of different defects of welding, it is necessary to keep strictly the recommended conditions, especially in work with heat-hardened concrete reinforcement. It was shown above that at insufficient heating of parts being welded the ductile characteristics of the concrete reinforcement are reduced greatly. During mechanical tests the brittle fracture is occurred directly in butt or HAZ. The joint overheating leads to decrease in strength characteristics of HAZ. At further increase of heating cycle up to 30–40 s the typical fracture is occurred with the presence of hot cracks in the joint plane (Figure 5, *a*), tensile strength here is not exceeding 100–140 MPa.

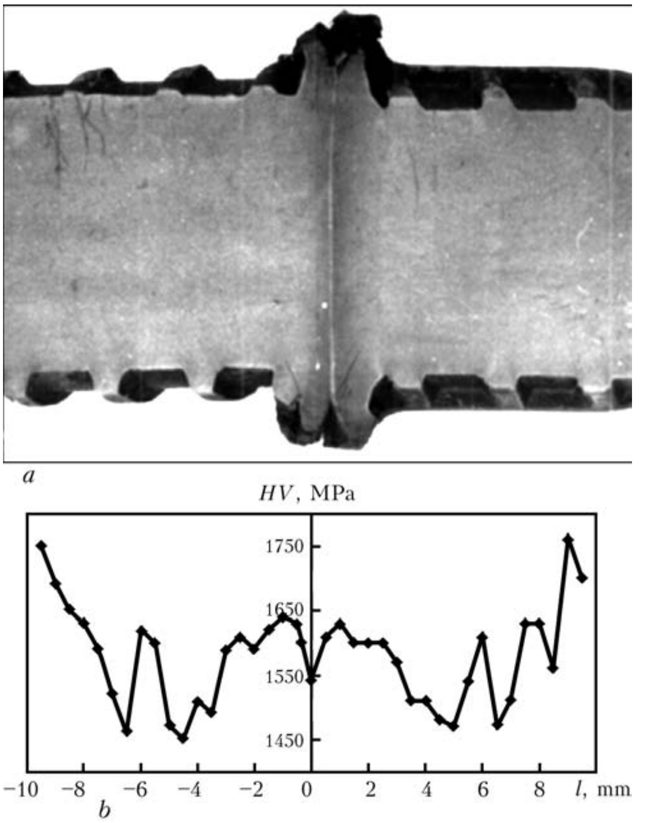


Figure 2. Macrosection (*a*) and distribution of microhardness (*b*) in the zone of welded joint of reinforcement bar of steel St3Gps

Besides, the fracture of specimens in burnt spots was observed in some cases (Figure 5, *b*). As a rule, the formation of these defects occurs at insufficient force of clamping of parts being welded or heavy contamination of current-carrying jaws. In place when the part is not tightly adjacent to the electrode the

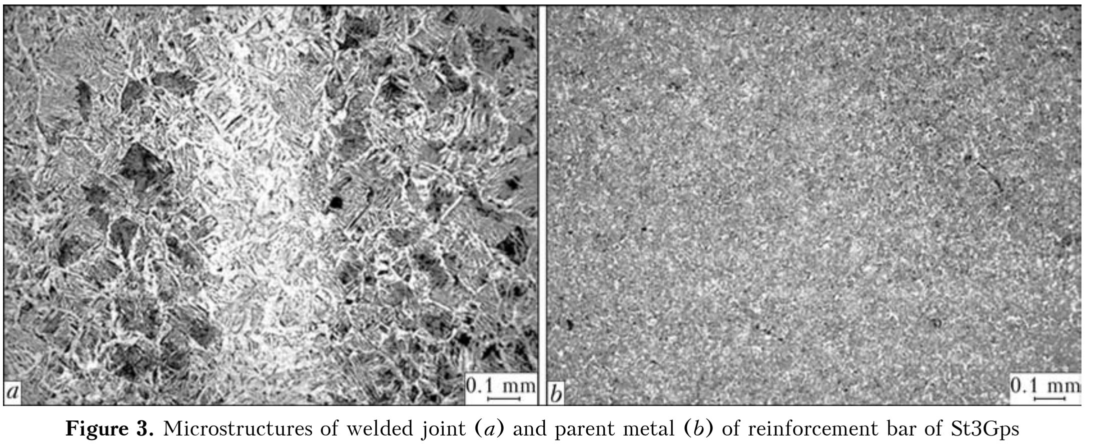
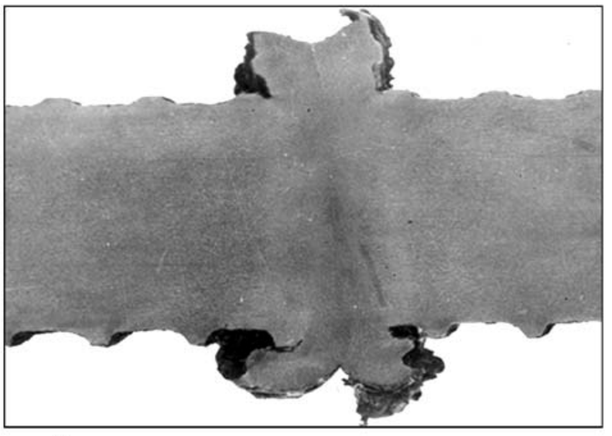
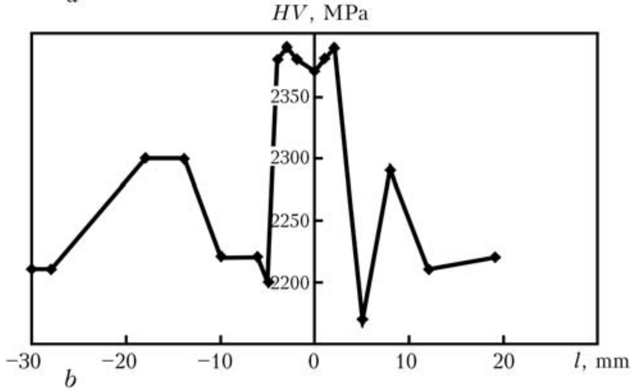


Figure 3. Microstructures of welded joint (*a*) and parent metal (*b*) of reinforcement bar of St3Gps



a



b

Figure 4. Macrosection (*a*) and distribution of hardness (*b*) in the zone of welded joint of reinforcement bar of steel 25G2S

transient electric resistance is increased to the value exceeding the resistance of spark gap and the process of a local flashing along the part–electrode contact surface begins. As was noted above, the burnt spots, forming in the form of craters, decrease greatly the mechanical properties of welded joints. The formation of burnt spots is also caused by an increased electrical resistance between the profiled lateral surface of the concrete reinforcement and electrode. Therefore, the force of clamping is selected at least 2 times higher than the upsetting force.

The decrease in probability of formation and amount of burnt spots is attained by a proper selection of specific clamping force, regular cleaning of current-carrying electrodes every 5–10 welding operations and maximum possible reduction of the secondary voltage $U_{2\text{o.-c}}$.

Application of technologies of joining of hot-rolled and heat-hardened concrete reinforcement will make it possible to produce butt joints equal in strength to the parent metal under the site and semi-stationary conditions, to increase the service life of reinforced concrete structures, to increase their reliability and to guarantee the high service life.

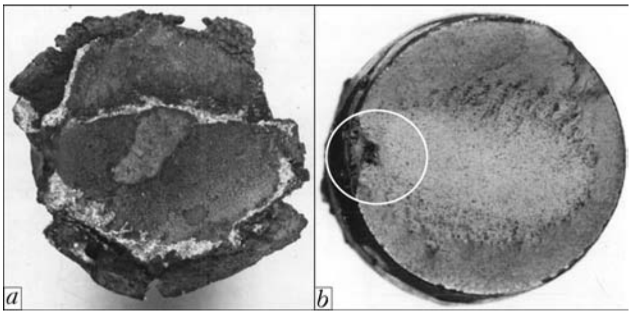


Figure 5. Fracture of reinforcement bar after tensile tests: *a* — overheating in welding; *b* — presence of a burnt spot

CONCLUSIONS

1. Application of flash-butt welding is challenging for butt welding of concrete reinforcement of high-strength steels. It is performed in automatic condition and does not require the application of auxiliary consumables. Moreover, the qualification of welders does not influence the quality of welded joints. The efficiency of the process is rather high, the time of welding of one joint does not exceed 1 min.

2. In the presence of a large amount of welded joints (for example, from hundreds of thousands up to millions of welded joints are performed on one bridge passage) the application of the flash-butt joints under site and semi-stationary conditions provide the high economic efficiency, increases the productivity of construction and reduces greatly the amount of rejected joints.

3. Distribution of temperature in a near-contact zone in welding with a continuous flashing at rigid conditions and especially using a pulsed flashing creates the most favorable conditions for plastic deformation during upsetting.

4. The application of method of flash-butt welding with a pulsed flashing provides a stable quality of welded joints of high-strength and heat-hardened reinforcing steels. In this case, the value of weakening does not exceed 2–4 %.

5. Increase in current density at pulsed flashing as compared with that of continuous flashing causes the hazard of formation of burnt spots that influences negatively the quality of welded joints.

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