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JOINING BUILDING REBARS USING COUPLINGS COMPRESSED BY EXPLOSION

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ABSTRACT

Joining building rebars is a labour-consuming critical process. Arc welding processes are of little use in the cases of application of heat-strengthened building rebars, or such which have a protective layer. It is shown that use of steel couplings, compressed by explosion, allows producing strong and reliable joints of building rebars for various applications. Coupling parameters are calculated under the condition of equal strength with rebars steel. Rupture testing revealed a higher strength of the coupling joint, compared to the strength of rebars beyond which a rupture took place. Cyclic fatigue life testing showed that fatigue resistance of coupling joints is higher than that required by normative documentation. There is experience of application of explosives in large construction sites and in operating industrial facilities.

KEYWORDS: building rebars, rebar joining, coupling, fatigue resistance, strength, explosion compression

INTRODUCTION

The methods for joining rebars in the construction of reinforced concrete objects available for today [1, 2] have a number of disadvantages. Electric arc, pool and resistance welding require the use of special equipment and powerful power sources, which complicates the works in site conditions; heating to melting point at the joining place leads to the softening of the base metal of heat-resistant building rebars (HBR); burnout of elements of a corrosion-resistant protective layer (if such deposited on rebars). Winding of rebars with steel wire leads to an axial displacement of joined rebar elements, it does not always provide equal strength of joint and base metal either, is a very labour-consuming process, especially when joining rebars of a large size. Joint rebars with the use of couplings, which are compressed by hydraulic presses, requires the use of expensive imported equipment and is a labour-consuming process with a low efficiency.

The development of high-efficient, economic and ergonomic methods for joining HBR, providing the strength properties of joints at the level of base metal is an urgent task for today.

One of such methods can be joining rebars by couplings compressed by explosion. The advantages of the explosive method are the lack of softening of the base metal and the need in using special equipment, independence from power supply sources and high efficiency.

Under the action of explosion pressure, the coupling is plastically compressed and forms a mechanical joint with the rebars by gearing the coupling metal with transverse projections of the rebars. The joint strength during tensile loading will be determined by the strength of the coupling metal and the strength of transverse projections of the rebars operating on crumbling. The calculation by these parameters, taking into account providing the equal strength of the joint and rebar metal, will ensure determination of the thickness and length of the coupling. The shear calculation of the transverse projections gives a shorter length of the coupling than the crumbling calculation. All the necessary data for the calculation is given in DSTU 3760 [3].

Schematic diagram of rebar joint by the coupling compressed by explosion is shown in Figure 1. The appearance of joining before and after the explosion is shown in Figure 2.

As an explosive substance, the detonating cord of grade DShE-12 was used, which had a bulk weight of 12 g/m, an outer diameter of 6 mm and was manufactured in industrial way [4].

As was noted above, the greatest difficulties occur when joining rebar elements of a large diameter. Therefore, to evaluate the capabilities of the explosion compression method, in research works, rebars of grade A600 DSTU 3760–98 were used [3] with a rated diameter of the rod of 25 mm, $\sigma_y = 600$ MPa, a cross-section area of the main rod of 491 mm^2, the maximum diameter of 28 mm, a cross-projection area near the base of 96

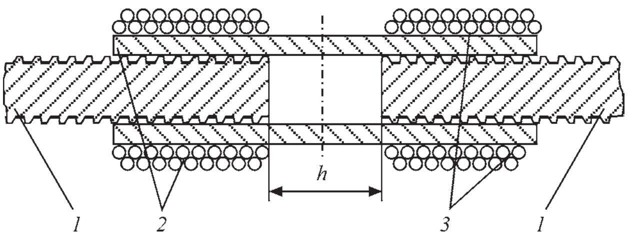

Figure 1. Schematic diagram of joining rebars by the coupling compressed by explosion: *1* — ends of joined rebars; *2* — coupling; *3* — charge from a detonating cord, wound on the coupling; *h* — adjustable gap between rebar ends

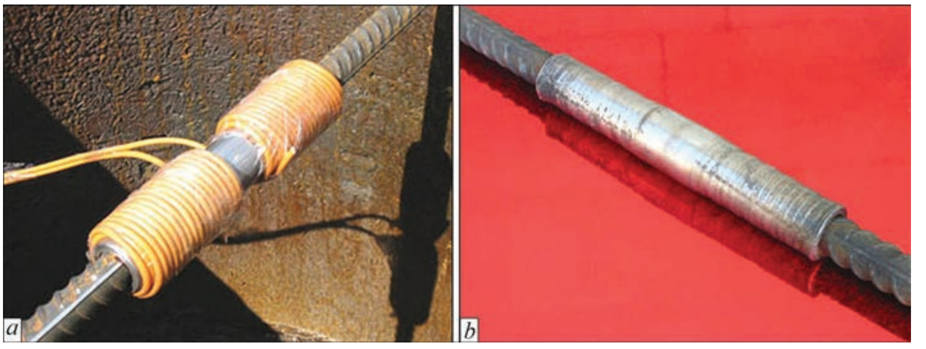

Figure 2. Coupling joint of rebars, prepared before compression explosion (*a*) and coupling joint after explosion (*b*)

mm^2 and an average input number of cross projections (taking into account manufacture defects of rebars in the form of lack of projections) of 114 pcs/m.

Couplings (tubes) were manufactured of steel 06G2B, σ_y = 440 MPa, outer diameter is 44 mm, wall thickness is 6 mm, length is 235 and 255 mm. The cross-section area of the coupling was selected in such a way that its tensile strength was slightly higher than the strength of rebars, i.e., the force at which the yield strength of 315 and 300 kN is respectively reached.

Three specimens of rebar joints were manufactured, whose couplings were compressed by charges consisting of one, two and three layers of DShE-12.

One layer was not sufficient for a reliable compression of the coupling. Two and three layers formed a dense joint of the coupling with rebars.

Additionally, two samples were manufactured with the coupling compression by two layers of the detonating cord with a gap between the rebar ends of 20 and 40 mm, respectively, the length of the coupling was 235 and 255 mm, the lengths of the compressed areas were maintained constant.

During tensile tests of the samples, the fracture occurred on the base metal of the rebars (Figure 3).

The stressed state of the coupling metal in the butt zone is largely determined by the gap between the rebar ends. In the samples with a zero gap during tension, which creates axial stresses close to the yield strength, in the cross-section of the coupling, passing through the butt of the rebar ends, a volumetric stressed state will be created. In this case, the rupture force should increase, and the fracture of the coupling wall should have a brittle nature. As the gap increases, the main stresses in the circumferential direction and across the thickness will decrease, the stressed state will approach the linear state, the overall rupture strength of the coupling metal should reduce and the nature of the fracture will be more tough.

To check the impact of the gap on the strength of joint and the nature of fracture, a series of experiments on the rebars samples of grade A400C of steel 25G2C with d_r = 28 mm was carried out. The coupling metal is steel 20. The inner diameter of the couplings is 32 mm, the calculated outer diameter of the couplings is 43.5 mm. For the purpose of fracture of the joint over the coupling metal, the outer diameter is taken equal to 43 mm, the thickness of the coupling wall was 5.5 mm.

The compression of the couplings was carried out using DShE-12, wound on the couplings in two layers. The samples with a gap between the rebar ends inside the coupling were only compressed on the side of the coupling that was above the rebars. The test results are given in Table 1.

Figure 4 shows the appearance of the cross-section of the couplings after the fracture of the samples with a different gap. It should be noted that the fracture of the samples occurred at stresses close to the tensile strength of the rebars.

Additionally, two series of strength tests (each for 2 samples) were conducted on the samples made

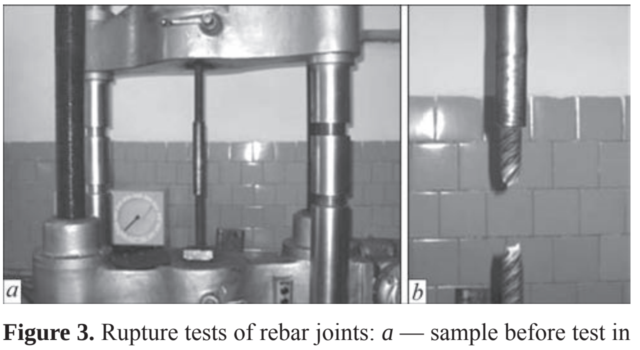

Figure 3. Rupture tests of rebar joints: *a* — sample before test in a rupture machine; *b* — sample after tests

Table 1. Test results of rebar joints with different size of gap between its ends

Number of joint	Size of gap, mm	Average rupture force, kg	Place of gap
1	0	32000	Over the coupling
2	0	36500	Over the base metal
3	0	35500	–»–
4	20	31000	Over the coupling
5	20	27750	–»–
6	20	29000	–»–
7	40	31500	–»–
8	40	33000	–»–
9	40	32750	–»–

Figure 4. Nature of fracture of samples during tensile tests: *a* — sample with a zero gap; *b* — sample with a gap of 20 mm; *c* — sample with a gap of 40 mm

Table 2. Results of fatigue tests of coupling joints

Sample number	Load, tf		Stresses, MPa		Number of cycles
	max	min	max	min	*N*
1	25.1	10.1	306.16	122.50	287840
2	25.0	10.0	304.94	122.0	323390
3	19.0	7.6	231.76	97.70	837680
4	28.0	11.2	341.50	136.60	289150
5	22.0	8.8	268.35	107.30	529030
6	13.1	5.3	160.0	64.0	2290430 not fractured

from the rebars of grade A500C with d_r = 32 mm. The couplings were made of a low carbon steel with σ_y = = 270 MPa and with σ_y = 400 MPa, the wall thickness was 10.5 and 8 mm, respectively. In all cases, the fracture occurred on the base metal of the rebars.

Bridges and similar reinforced concrete structures undergo variable loads from transport moving across them.

In DBN B.2.3-14 [5], the formulas for calculation of the fatigue strength of the rebars during tensile tests are shown. DSTU 3760 [3] regulates carrying out cyclic tests in such a way: "Reinforced rolled metal of grades A400, A500, A600, A600C, A600K, A800, A800K and A1000 should withstand 2 mln load cycles at a maximum stress, which amounts to 6 0 % of the normalized tensile yield strength without the fracture. In this case, the range of stresses should amount to 180 N/mm^2".

The fatigue tests were performed in the laboratory conditions of the PWI on a soft mode of axial harmonic tension in a multicyclic area of fatigue life with a frequency of 5 Hz and the cycle asymmetry coefficient ρ = 0.4. The studies were performed on the rebars of grade A500 (A IV) with a diameter of 32 mm of a total length of 800 mm, σ_y = 500 MPa, σ_{max} = = 300 MPa, σ_{min} = 120 MPa.

The criterion for completion of the tests was a complete fracture of the sample. The samples were fractured inside the coupling at a distance of 10–35 mm from its edge. The results of the studies are presented in Table 2, as well as in a graphic form in Figure 5.

The results of the experimental studies allow determining the fatigue resistance of the coupling joints of the rebars of grade A500C of 32 mm diameter at an asymmetric cycle of axial tension ρ = 0.4 in the whole multicyclic region of an alternating load. The fatigue strength of such joints on the base of $2\cdot10^6$ cycles is 165 MPa.

In DBN B.2.3-14 [5], the value of the coefficient characterizing the serviceability of rebar joint of grade A500 (A IV) at cyclic tests with an asymmetry coefficient 0.4, is taken equal to 0.75. The value of the coefficient obtained experimentally is equal to 0.87, which is higher than the normative and fully satisfies the requirements of DBN B.2.3-14. Such joints neither in strength nor in fatigue resistance are not inferior to the joints, produced by other methods widely used in industry.

It should be noted that for explosion compression of the couplings, the charges of a low power are used, simultaneously up to 10 charges can be initiated, the safe

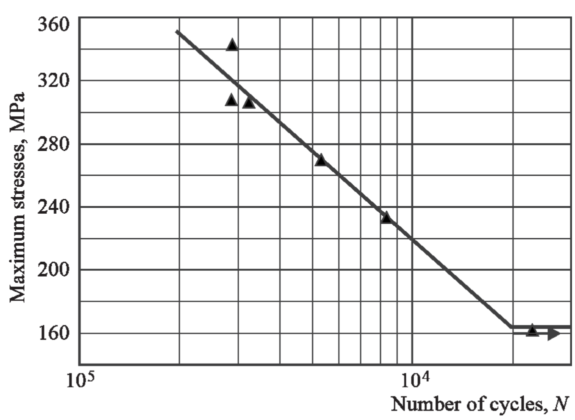

Figure 5. Diagram of fatigue resistance of coupling joints

distance from explosion to the location of a human behind the action of a shock wave is 30 m [6], during a working shift, a team of 7 persons can produce 50–100 butts. The experience of using explosion at operating enterprises [7] indicates the possibility of industrial use of this method on large construction sites.

CONCLUSIONS

1. The use of steel couplings compressed by explosion allows producing joining of HBR, which meet the building standards of Ukraine, which in terms of strength and cyclic fatigue life are not inferior to those produced by traditional methods.

2. Using the method of coupling explosion compression is possible at operating enterprises and large construction sites.

3. The method proposed in this work has a higher efficiency than traditional methods.

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CONFLICT OF INTEREST

The Authors declare no conflict of interest

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