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Method of controlling reactive stresses when joining reinforced concrete constructions with pool welding due to forcedly formed weld

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Abstract. The paper deals with a method of controlling stretching reactive stresses in reinforced concrete constructions. These deformations are caused by pool welding with forced weld formation in fabricated forms. This method does not require precise measuring and labour-intensive preparatory efforts and experiments. Reactive stresses are experimentally determined after welding the protruding bars of rigid reinforced constructions. The concentrator is used outside the heat-affected area (i.e. far from the welded joint). Reactive strains are determined on the basis of the calculated connection between the level of reactive stresses σ_w and the limiting cut depth l_c. This method is used to determine the level of reactive stresses in the protruding bars of reinforced concrete constructions after certain modes of welding and to establish the optimum welding conditions to obtain the required values of reactive stresses σ_w.

1. Introduction

Currently, prefabricated reinforced concrete constructions and frameworks are more and more used to increase significantly the level of engineering and building, but cause a number of problems. The most urgent one is improving the reliability of welded joints. Therefore, one of the most common methods of welding for reinforced concrete constructions is pool welding with forced weld formation in fabricated forms [1-4]. Framed constructions are also known to have stretching reactive stresses, with their level largely determining the reliability of welded joints [5-7]. The choice of optimal welding modes is an important point when developing technologies. It provides the required degree of tensile reactive stresses in the installation of reinforced concrete.

At present, there are many variety methods used to estimate the level of residual stresses in welded joints [8-14]. For example, some methods are based on the release of welded joints from ties. These methods are carried out by turning the surface of the reinforcement and are accompanied by the redistribution of residual stresses. They require the mandatory subsequent measurement of deformations in the field of mechanical action. This process is very labour-intensive and requires careful preparation of experiments, recalculations of deformations caused by reactive stresses and is associated with significant errors. The slotted hole method is more promising. It is used for measuring the level of reactive stresses based on the data about redistribution local deformations and stresses near the cut slot. However, this method requires precise measuring equipment and carefully prepared surfaces of protruding bars to apply gages. This method cannot be used for estimating reactive stresses in reinforcement bars with deformed sections. In addition, physical methods with complex technical devices and equipment (magnetic resistive flaw detectors, magnetic anisotropic scanning flaw detectors, etc.) are widely used requiring large material costs for testing. In this connection, recently developed relatively simple and reliable methods for controlling reactive stresses in reinforced construction joints are of great importance.

2. Theoretical background and research tasks

The paper deals with a calculation technique for experimental quick controlling of reactive stresses in the joints of protruding bars of reinforced constructions. It does not require precise measurements and labour-intensive preparatory efforts and experiments.

In accordance with the proposed approach, calculations and experimental determinations of reactive stresses are carried out after welding the protruding bars of reinforced constructions in a rigid frame and applying the concentrator outside the heat-affected area (i.e. far from the welded joint) (figure 1). The latter is applied at a depth of $l=lc$ to ensure the spontaneous destruction of reinforcement bars caused by the action of reactive stresses σ_c.

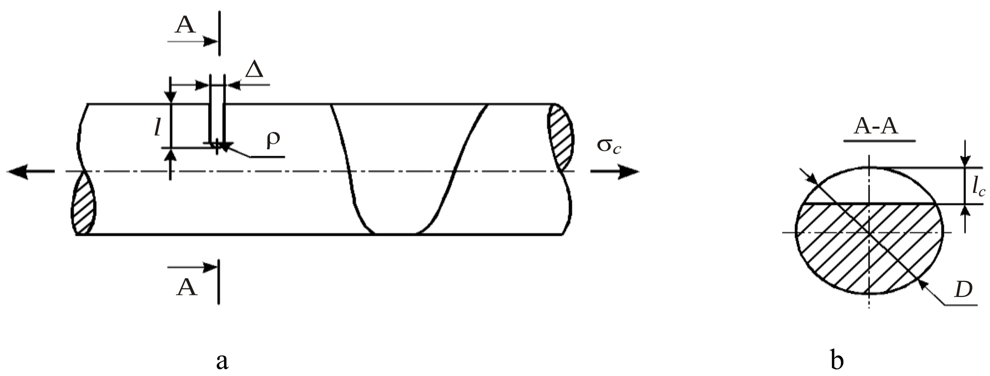

Figure 1. Welded joint of reinforcement bars with a concentrator applied for estimating reactive stresses σ_c.

The analysis of the state of maximum equilibrium was carried out using the approaches and criteria of brittle fracture mechanics. This allowed us to obtain the basic relations between reactive stresses σ_c and cutting depth l_c. A cylindrical body weakened by a segment concentrator was used as an object of analysis. The geometrical parameters of the concentrator (figure 1): Δ is the width of the cut, and lc is the depth of the cut, leading to the destruction of the reinforcing bars [15-18].

On the basis of the works [19] the following relation was obtained for describing the limiting equilibrium state of a cylindrical rod weakened by a segmentary concentrator of the mathematically cut type with zero thickness ($\Delta \to 0$) determining the initiation moment of brittle fracture, with fracture being initiated at the concentrator top:

$$K_{Ic} = \frac{\sigma_c \pi R^2}{2\sqrt{\pi(R-l_c)}}\sqrt{\frac{l_c}{R-0,8(R-l_c)}} \quad (1)$$

where σ_c is the level of reactive stresses leading to the brittle fracture of the rod weakened by the concentrator of the depth l_c; K_{Ic} is the critical strain intensity factor (the material characteristic); *R is* the rod radius.

It should be noted that the use of (1) to estimate the brittle fracture initiation moment of joints of reinforcement bars with a cut of a width Δ is possible only when the solution is corrected according to the concentrator sharpness (ρ=Δ/2). The latter can be performed in accordance with the approach outlined in [16, 18] by correcting the concentrator sharpness K_{Ic} in the following form:

$$K_{Ic(\rho)} = K_{Ic}\sqrt{\frac{\rho}{\rho_0}} \quad (2)$$

where ρ_0 is some effective value of the radius at the concentrator top equivalent in its effect to the fatigue crack.

The value ρ_0 is a characteristic of the material and can be approximately determined, with the recommendations [18] being taken into account.

$$\rho_0 \cong 0{,}1\left[\frac{1}{2\pi}\left(\frac{K_{Ic}}{R_e}\right)^2\right] \quad (3)$$

where R_e is the limit of stretching strain of the material.

Omitting the intermediate transformations, the expression (1) with (2) and (3) to be also considered can be represented in the following form:

$$\sigma_c = 2R_e\sqrt{\frac{2\Delta}{l_c}\left(1-\frac{2l_c}{D}\right)^3\left(1+\frac{8l_c}{D}\right)}. \quad (4)$$

3. Research results

According to the found reinforcement geometrical parameters (*D* is the rod diameter) and the cut (Δ and l_c), the obtained expression (4) makes it possible to determine the level of reactive stresses in the protruding bars of reinforced concrete constructions in certain welding conditions. In addition, the obtained relation can be used to determine the optimum conditions for pool welding of protruding bars of reinforced concrete constructions to obtain the required values of reactive stresses σ_c.

To check if the relation (4) is true, a series of welded samples was prepared from a reinforced construction with the diameter *D* = 36 mm (35GS steel). The samples were pool welded horizontally to form a rigid frame. After welding, concentrators were cut into the samples (mechanically, with an angle grinder equipped for making horizontal cuts).

The level of residual reactive stresses σ_c in these compounds was determined by the relation (4), by measured widths (Δ), cutting depths $l_c=l_{max}$ (l_{max} corresponds to the initiation stage of brittle fracture of reinforcement bars) and the known characteristic of the reinforcement material (σ_m = 400 MPa). The strain gauges were glued before welding onto the studied fittings far from the heat-affected zone and the welded joint to check the obtained values of σ_c. The experimental values of reactive stresses $\sigma_{c(ex)}$ were determined using strain gauging (table 1).

The difference in the results obtained is within 10...15 %. Thus, the proposed calculation and experimental method for estimating the level of reactive stresses in reinforced concrete constructions was proved to be appropriate.

Table 1. Comparison of calculated σ_c and experimental $\sigma_{c(ex)}$ values of reactive residual stresses.

No. sample	Δ mm	$l_c = l_{max}$ mm	$2\Delta / l_{max}$	σ_c MPa	$\sigma_{c(ex)}$ MPa	δ %
1	2.05	9.80	0.418	283.7	285.6	0.67
2	2.03	9.93	0.409	274.9	275.0	0.04
3	2.05	10.0	0.410	272.2	281.3	3.23
4	2.00	10.3	0.388	316.2	320.0	1.20
5	2.10	9.85	0.422	292.3	305.3	4.26
6	2.05	9.98	0.411	274.1	302.2	9.63
7	2.03	9.82	0.413	280.5	288.4	6.08
8	2.08	9.90	0.420	280.1	290.0	3.41
9	2.06	9.98	0.413	274.5	278.0	4.40
10	2.06	10.14	0.406	265.0	290.4	8.75
11	2.05	10.12	0.405	265.9	277.2	4.08
12	2.03	10.16	0.400	262.2	265.9	1.39
13	2.10	10.3	0.392	260.0	305.7	14.95
14	2.05	10.2	0.402	262.2	300.5	12.75
15	2.00	10.0	0.400	268.7	279.6	3.90
16	2.06	9.92	0.415	264.9	285.0	7.05

4. Conclusion

According to the obtained relation describing the limiting equilibrium state of a cylindrical rod weakened by a segmentary concentrator of the cut type with a width Δ, a calculation technique for quick experimental controlling of reactive stresses in the joints of reinforced concrete constructions is proposed. It does not require precise measurements and labour-intensive preparatory efforts and experiments.

This calculation technique for quick experimental controlling of reactive stresses was tested with reinforcement samples with the diameter D=36 mm (35GS steel), horizontally pool welded in a rigid frame. The results of estimating the level of residual reactive stresses $\sigma_{c(ex)}$ were compared with the experimental data obtained with strain gauging.

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