# The welding of "Roxor" high tensile steel

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Objekttyp: **Article**

Zeitschrift: **IABSE congress report = Rapport du congrès AIPC = IVBH Kongressbericht**

Band (Jahr): **2 (1936)**

PDF erstellt am: **06.08.2024**

Persistenter Link: https://doi.org/10.5169/seals-3267

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## The Welding of „Roxor" High Tensile Steel.

## Das Schweißen von hochwertiger Stahlbewehrung „Roxor".

## Le soudage de l'acier à haute résistance „Roxor".

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The introduction of the "Roxor"[1] high tensile steel represents a great advance in reinforced concrete construction, and its use as reinforcement for high strength concrete has made it possible to erect reinforced concrete structures of so large a span that the usual length of the bars has frequently to be exceeded. It follows, therefore, that in any large structure of this kind a large number of joints have to be provided in the reinforcing bars.

Hitherto it has been customary to make such joints by the simple process of allowing the bars to overlap over a certain length, but if a joint of that kind is to be made completely effective it is essential that the bars should be completely embedded in concrete, which entails an increased distance between them with the result that the width of the beam has to be increased accordingly. According to the official specifications it is not permissible to allow bars to overlap of more than 32 mm diam., and this places a limit on the span of the structures which can be built.

Hence the necessity to find some other type of joint which would allow of the ends of the two bars being completely bonded together over the whole of their cross sections without any weakening, and the only satisfactory solution to this important problem is that of welding the bars. Most of the existing regulations for welded work apply only to ordinary qualities of steel, and as no regulations were available for the welding of high tensile steels such as "Roxor" the problem had to be studied from first principles.

"Roxor" high tensile steel is made by slightly increasing the carbon content above that of the ordinary steel C 37 (maximum 0.22 % C), which is done by introducing certain elements such as silicon (maximum 0.90 % Si), manganese (maximum 0.50 % Mn) and copper (maximum 0.50 % Cu). The amounts of sulphur and phosphorus remain the same. The following are the mechanical properties of "Roxor" steel produced in this way.

| | |
|---|---|
| Minimum yield point | 38 kg/mm² |
| Minimum tensile strength | 50 kg/mm² |
| Minimum elongation | 20 %. |

[1] Preliminary Publication, page 240.

In the welding of "Roxor" steel, the choice of electrodes plays a very important part, as it is necessary that the weld metal should be of the same quality as the parent metal. To ensure this, "Arcos-Superend" electrodes were adopted, the yield point, tensile strength, elongation and tenacity of these having been determined in accordance with the special regulations for the welding of metal bridges issued by the Ministry of Public Works. The results of these tests are given in Table I:

Table I.

*Tests of weld metal deposited by "Arcos-Superend" electrodes.*

| | Minimum | Average | Maximum |
|---|---|---|---|
| Yield point | 40.7 | 49.7 | 56.4 kg/mm² |
| Tensile strength | 50.7 | 57.0 | 63.3 kg/mm² |
| Elongation (gauge length = 5 diameters | 18.0 | 19.5 | 20.4 % |
| Reduction in area | 29.9 | 39.2 | 50.1 % |
| Tenacity (Mesnager) | 5.0 | 6.6 | 7.9 mkg/cm² |

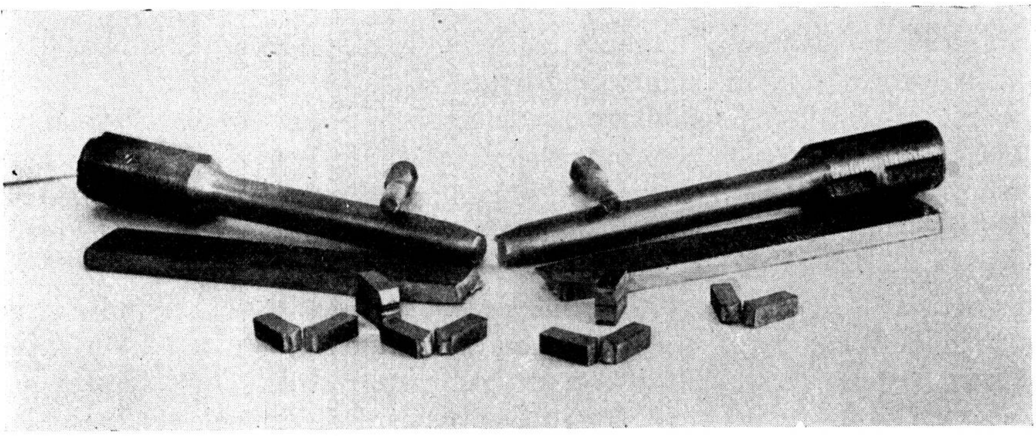


Fig. 1.
Tests of parent metal.

These figures indicate a quality of weld metal which, when deposited between two sheets of "Roxor" steel having the characteristics given in Table II below, will be the same as that of the parent metal (Fig. 1).

Table II.

*Tests on "Roxor" steel.*

| | Average | Specified |
|---|---|---|
| Yield point | 41.7 | 38 kg/mm² |
| Tensile strength | 58.5 | 50 kg/mm² |
| Elongation (gauge length = 10 diameters) | 22.6 | 20 % |
| Reduction in area | 53.7 | — % |
| Tenacity (Mesnager) | 11.0 | — mkg/cm² |

In addition to the tests on the electrodes, the tensile strength of the weld produced by them was tested on specimens consisting of two "Roxor" steel plates 12 mm thick joined by a weld at right angles to the direction of rolling (Fig. 2); the angle of folding and elongation of the extreme fibres of the weld

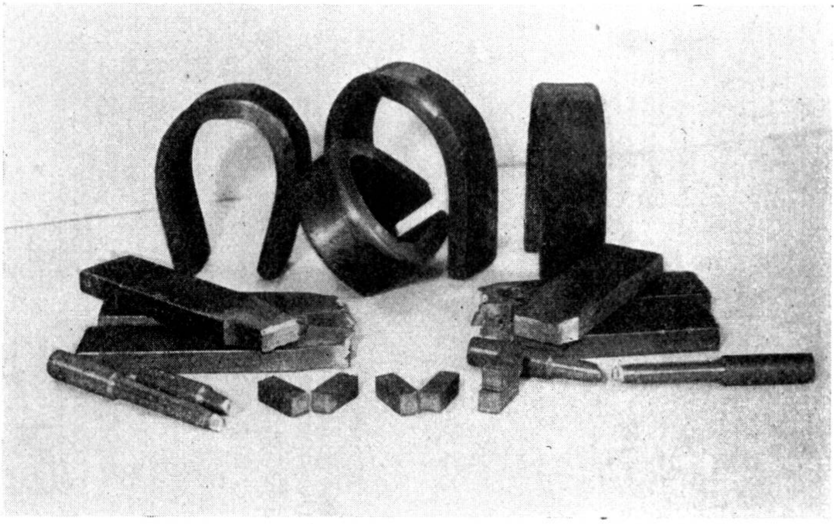


Fig. 2.
Tests of welds.

were also tested, giving results which were used as a check on the welders. The results are given in Table III:

Table III.

*Tests on welded "Roxor" plates.*

| | Minimum | Average | Maximum |
|---|---|---|---|
| Tensile strength . . . . . . . . . . . | 50.5 | 59.8 | 65.7 kg/mm$^2$ |
| Folding angle . . . . . . . . . . . . | 180$^0$ | 180$^0$ | 180$^0$ |
| Elongation of extreme fibres . . . . . . | 16.0 | 18.8 | 22.0 % |

These tests were followed by the welding of "Roxor" reinforcing bars, which are of cruciform section with ribs to improve the adhesion. The welding tests were carried out on "Roxor" bars of 60 mm diameter (circumscribed circle), which is a size frequently used in long span bridges. The ends of the bars to be joined were first bevelled, then held in a special form of clamp (Fig. 3) while being welded with a V — seam using the "Arcos-Superend" electrodes (Fig. 4).

The results of all the tests carried out on welded "Roxor" bars are shown graphically in Fig. 5. It should be noticed that the welds were not machined. The average values obtained in the tests, together with the maxima and minima, are given in Table IV. In every case breakage of the bar took place outside the weld.

Table IV.

*Tests on welded "Roxor" bars.*

| | Minimum | Average | Maximum |
|---|---|---|---|
| Yield point | 39.4 | 40.1 | 40.6 kg/mm² |
| Tensile strength | 55.7 | 57.4 | 58.5 kg/mm² |
| Elongation (gauge length $= 11.3\sqrt{A}$ [A = area]) | 22.8 | 26.1 | 28.5 % |
| Reduction in area | 33.8 | 47.9 | 51.4 % |
| Folding angle | 180° | 180° | 180° |
| Elongation of the extreme fibres | 6.2 | 10.3 | 12.1 % |

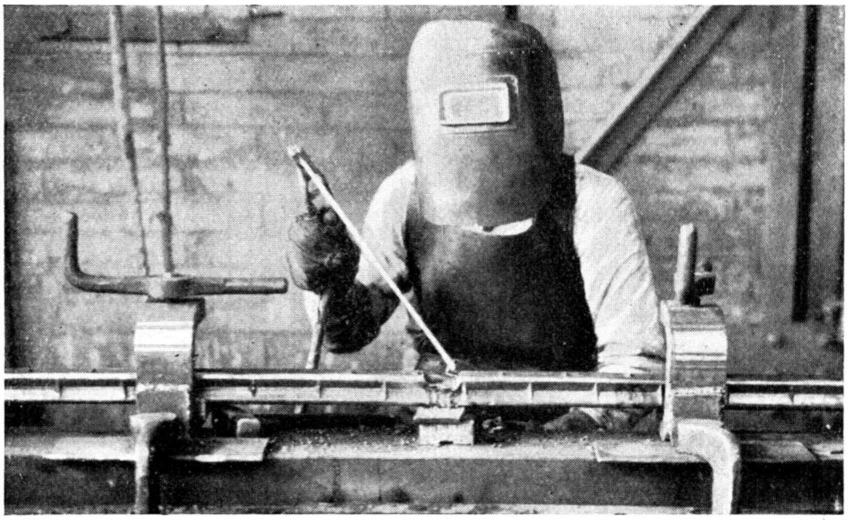


Fig. 3. "Roxor" bar ready for welding.

Test bars measuring $2 \times 1.25 = 2.50$ m in length were adopted in order that when the "Roxor" bars were applied in an actual job the heat should not spread

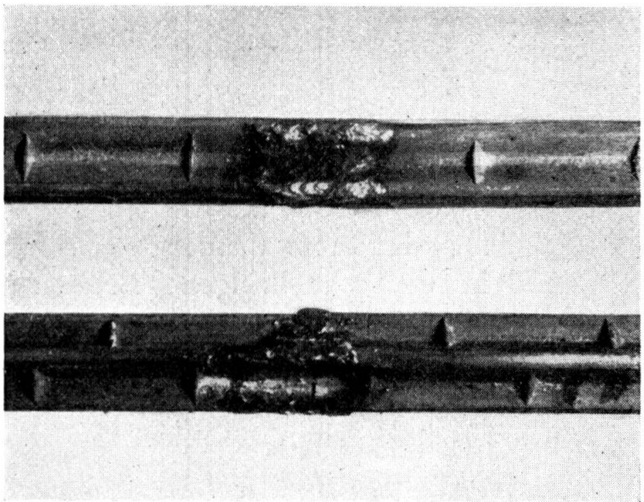


Fig. 4. Welded "Roxor" bars.

more rapidly than in the tests, as would have been the case if the usual small sized specimens had been used. It was ascertained, in the course of welding, that the heating of the bars did not extend beyond 0.50 m from the weld, a result which may be attributed to the large cross section of the specimens (17.34 $cm^2$).

In addition to the tensile tests the "Roxor" welded bars were subjected in cold bending tests (Fig. 6), and the results of these were found to be in accordance with the specifications. To determine the elongation of the extreme fibres, and the effectiveness of the bond with the parent metal, a few of the bars were machined in the neighbourhood of the weld before testing, and the results so obtained are included in Table IV. The internal diameter of the bend is equal to five times (or occasionally six times) the diameter of the "Roxor" bar.

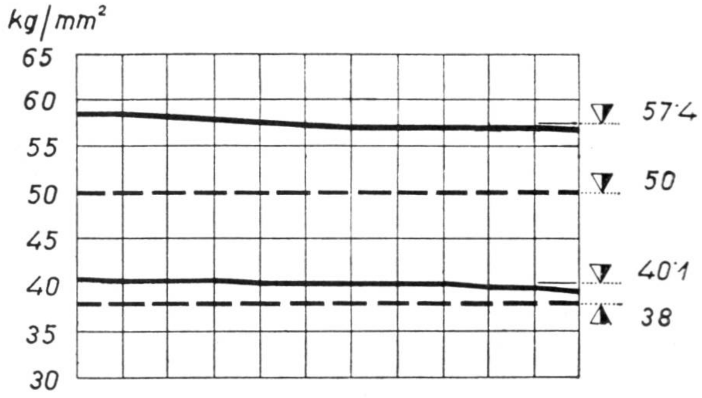



Fig. 5.

Results of tensile tests on welded "Roxor" bars, showing tensile strength and apparent elastic limit in kg/mm.

Figs. 7 and 8 are macroscopic and microscopic views of the longitudinal sections of a 60 mm "Roxor" welded bar. Fig. 7 shows part of the band of

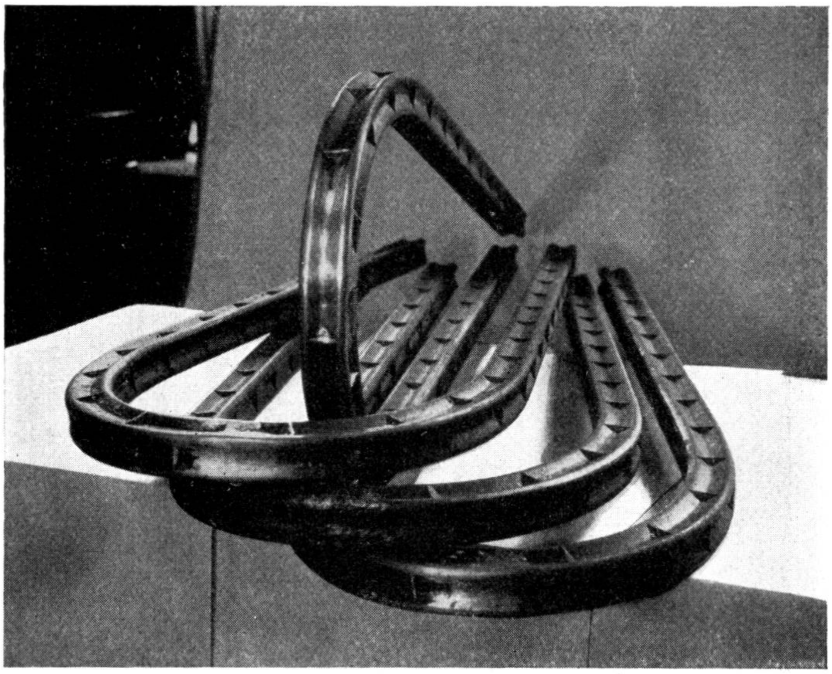


Fig. 6.

Bending tests of "Roxor" bars.

recrystallised metal between the weld metal and the parent metal. The crystals of sulphur and phosphorus are uniformly distributed in the parent metal without forming a coagulation, and the weld itself is completely free from such crystals.

The white crystals appearing in Fig. 8 practically all consist of pure iron (ferrite) and the dark spots around them are perlite (ferrite plus cementite, $F_{e3}$ C). The

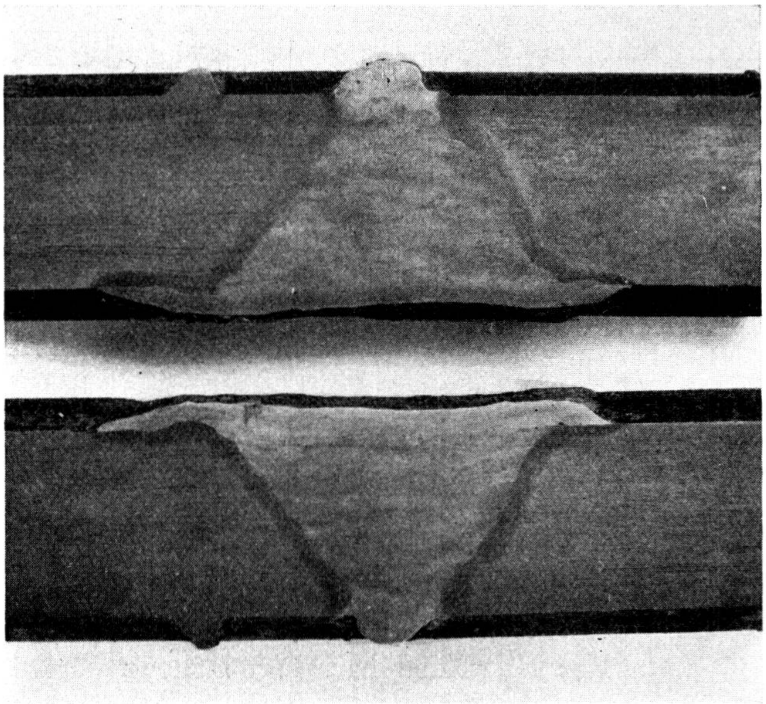
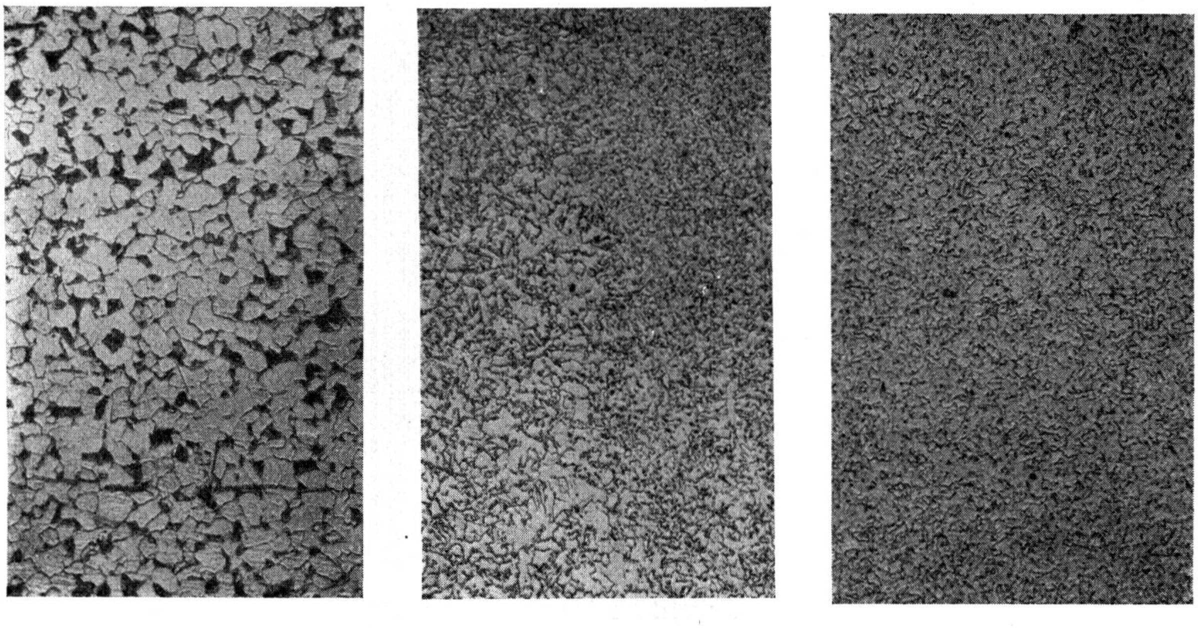


Fig. 7.
Etched and polished longitudinal section through a welded "Roxor" bar.

structure of "Roxor" steel is characterised by the presence of small uniform grains of ferrite, and the good mechanical properties are a consequence of this.



Parent metal — Transition zone — Weld metal

Fig. 8. Structure of welded "Roxor" bar, × 100.

In the transition zone, the structure varies uniformly and changes into a completely regular fine-grained ferrite structure, the transition from the parent metal to the weld metal being imperceptible. The modification undergone by the parent metal as a result of welding was determined by the Brinell test, using a ball of 10 mm diameter under a pressure of 3000 kg (Fig. 9), which gave the following results.

Diameter of indentation $< 4.80$ mm : $P = 0.345\ H$

Diameter of indentation $> 4.80$ mm : $P = 0.342\ H$

where P is the tensile strength in kg/mm² and H is the Brinell hardness in kg/mm². It may be seen from Table V, which gives the results of these experiments, that the hardness of the unmodified parent metal corresponds to its tensile strength as determined in the breaking tests, whereas in the transition zones an increase in the hardness of the metal in relation to the change of structure is observed, this being brought about by the heat developed by the electric arc. The hardness of the metal increases as the structure of the weld becomes finer. This explains the small elongation of the weld (average 10.3 %) by comparison with that of the bars (average 26.1 %).

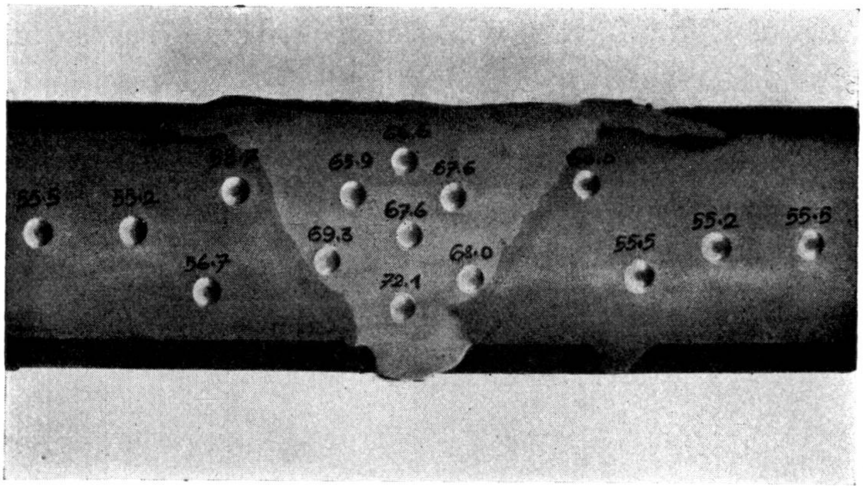



Fig. 9.
Brinell test on a welded "Roxor" bar.

Table V.

*Effect of welding on "Roxor" steel.*

Tensile strength —

Of the parent metal (kg/mm²):

55.5 55.2 56.7 55.5 55.2 55.5 Average 55.7

Of the metal in the transition zone (kg/mm²):

58.7 69.3 68.0 60.0 Average 65.9

Of the weld metal (kg/mm²):

65.9 66.6 72.1 67.6 67.6 Average 67.0

These favourable test results justify acceptance of the principle that welded joints may be formed in the "Roxor" bars without detriment to the factor of safety prescribed for unjointed bars, and for the purpose of calculation the cross section of a welded "Roxor" bar may be taken as unimpaired even in the neighbourhood of the joint.

The welding of "Roxor" bars must be carried out only by officially authorised welders and only by the use of "Arcos-Superend" electrodes as adopted in the tests; new tests would be necessary before other electrodes could be used. In order to avoid distortion of the welded bars as a result of the great shrinkage which takes place at the surface of the V-seam, it is recommended that a slight clearance should be allowed when fixing the bars in the clamp.

An incidental outcome of these tests was the acquisition of knowledge regarding the behaviour of other high tensile steels when welded, as, for instance, steel C 52.