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Autor: Moressée, G.

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Testing and Control in the Electric Welding of Ordinary Steels.

Prüfungs- und Überwachungsverfahren für die elektrische Schweißung der gewöhnlichen Stähle.

Méthodes d'essais et de contrôle de la soudure électrique des aciers ordinaires.

G. Moressée,

Ingénieur des Constructions Civiles et Coloniales, Liége.

Electric arc welding or resistance welding of those types of steel which are normally used in the construction of bridges and building frames is no longer considered a matter of any difficulty, but the economy, facility and aesthetic advantages of these methods are leading to their continued extension, and there arises a proportionately greater need to improve the methods of testing and controlling such work.

As a rule, specifications in regard to electric welding cover only the acceptance of electrodes, the control of the operatives and the examination of the beads deposited or of the spots welded. A conscientious designer, however, is under a grave legal and moral responsibility, which requires that he should be far more severe and exhaustive in his efforts so to control the work as to ensure success.

I. Electric arc welding.

Methods of use.

In Belgium the electric arc welding of mild steels (37—44 and 42—50 kg/mm^2) and of semi-hard structural steels (St. 52, MS 60—70, C 58—65, etc.) is scarcely ever carried out otherwise than with protected electrodes of the coated or covered types. For load-bearing connections the use of bare wire electrodes has been given up on account of the brittleness and risk of oxidation of metal so deposited, which is due to the oxides and nitrides included in it (such as particles of SiO_2) or dissolved therein (FeO and nitrides up to 0,12 %).

Alternating current is generally employed in preference to direct current as the variations serve to provoke a violent agitation of the molten metal which eliminates slag and air bubbles. Its use requires that the arc should be kept short so as to ensure stability, and this produces large numbers of small drops of metal due to the concentration of the heat and the effective protection of the metal being melted. Heavy currents are especially sought after, provided the arc can be kept stable, as they allow the speed of welding to be considerably increased, thus reducing the cost and also minimising internal stresses; at the same time better penetration, and the desposition of a sound metal free from inclusions, are ensured.

Choice of electrodes.

The choice of suitable electrodes for any given job is a problem of the first importance, though too often left to the arbitrary decision of the commercial side. This choice depends on the nature of the steel to be welded, the type of connections (whether rigid, semi-elastic or elastic), the position of the stress-resisting element (butt, frontal, lateral, oblique or combined forms of weld), the position in space (horizontal, vertical or overhead seams), the place where the welding work is to be carried out (in the workshop or on the site), and even the atmospheric conditions.

The type of electrode having been decided upon, it is well to adopt the largest diameter compatible with the thickness of the pieces to be welded and the positions of the seams, for, given a suitable current density, the speed of welding increases directly with the efficiency of the materials and labour used and the internal stresses are correspondingly reduced.

Labour.

Good results depend largely on the quality and conscientiousness of the welding operators and of their supervisors. The health of the men should be checked by frequent medical inspections, and all arrangements should be made to ensure that the work is carried on under hygienic and comfortable conditions. At the beginning or end of every week, or at the most every fortnight, each welder should be required to make a sample plate (Fig. 1) which should be subjected to cold bending tests, and also cruciform specimens which must be found capable of fracture without damage to the seams, and the fracture should be examined macrographically (Fig. 2).

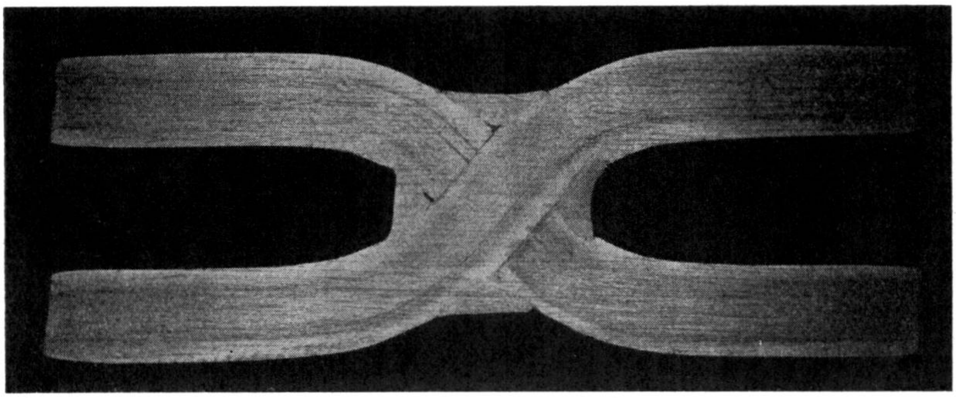
Weld metal.

The weld metal should be investigated as regards its chemical analysis (to afford a check on uniformity of quality), micrographical analysis of its structure (showing the influence of working methods on the size of grain, the penetration and presence of inclusions), macrographical analysis to show its condition of purity (inclusions, porosity, severe mechanical tests to indicate its physical characteristics (elongations at fracture being the criterion of quality, Figs. 3 and 4). See Figs. 5, 6, 7 and 8 which show an example of welding carried out on Ougrée carbon steel (58—65 kg/mm^2) using Arcos Stabilend electrodes.

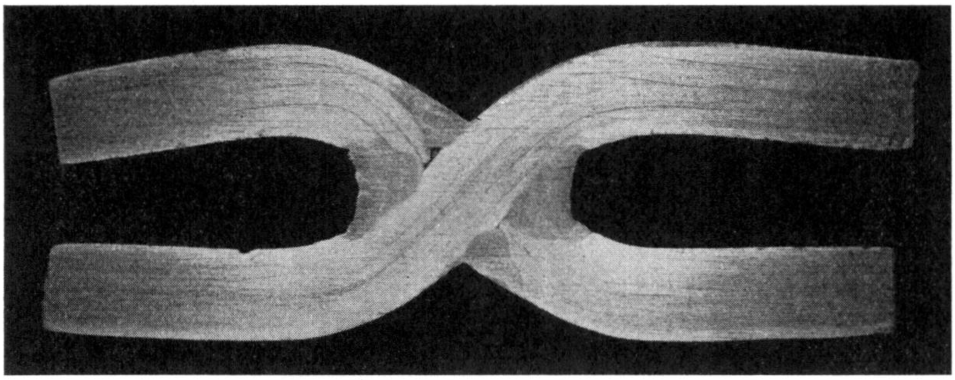
Welded connections.

The designer is concerned not only with the characteristics of the deposited metal, but also with the resistance of the welded joint as such to stress and to the corrosive agents in the atmosphere.

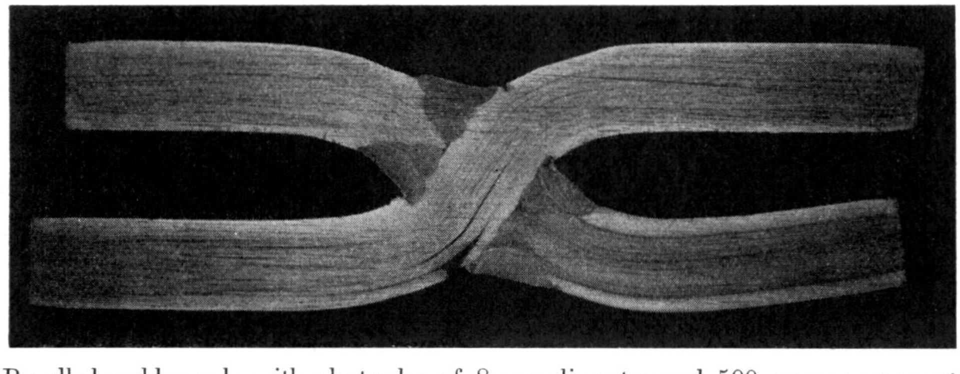
From this point of view specimens taken for the purpose of studying the weldability of a steel offer great advantages because, while approximating to the actual working conditions, they yield accurate results as regards behaviour in tension (including the determination of the elastic limits) and resistance to impact (Mesnager or Charpy resilience specimens).



Welds made with electrodes of 4 mm diameter and 190 amperes current.



Bevelled welds made with electrodes of 6 mm diameter and 250 amperes current.



Bevelled welds made with electrodes of 8 mm diameter and 500 amperes current.

Fig. 1.

Cruciform specimens: the seams must remain intact after crushing.

The next step is to check the strength of the different types of weld beads, adopted by the drawing-office under the conditions of execution which actually obtain, and under the conditions of stress which they will actually receive, and to study the nature of the strains which they will undergo after reaching their elastic

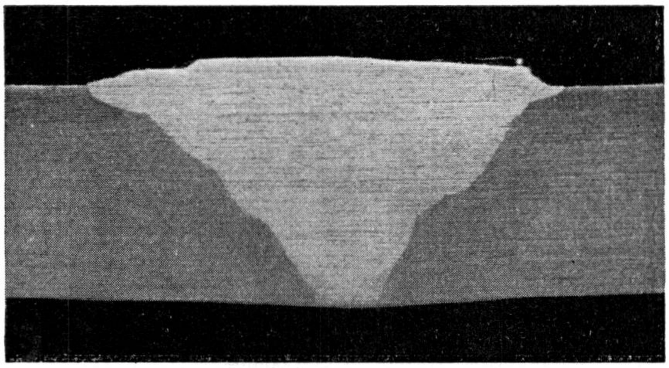


Fig. 2a.

Examination of a welded joint.

Chemical analysis.

Steel of 58—65 kg/mm² ultimate strength.		Metal deposited with „Arcos Stabilend“ electrodes.	
C.	0.310	C.	0.080
Mn.	0.836	Mn.	0.430
P.	0.060	P.	0.014
Si.	0.075	Si.	0.015
S.	0.037	S.	0.032

Mechanical tests.

Breaking stress	58 kg/mm²	50 kg/mm²
Elastic limit	38 kg/mm²	36 kg/mm²
Elongation at fracture	24 %	28 %
Resilience	6 kgm/cm²	10.6 kgm/cm²

Average results of 80 tests.

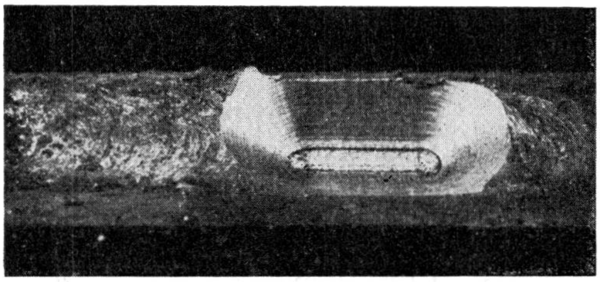


Fig. 2b.

Examinations by boring.

Fig. 2.

Examination of a specimen welded with alternating current using "Arcos Stabilend" electrodes; parent metal is of steel 58—65 kg/mm² ultimate strength.

Acceptance plate for steel of 37—44 kg/mm² (24 tests).

Breaking stress	min.	50 kg/mm²
	max.	56 kg/mm²
	average	54 kg/mm²
Resilience	min.	8.9 kgm/cm²
	max.	12.6 kgm/cm²
	average	11 kgm/cm²

Bending over mandril dia. = 3 · e, good at 180°.

Acceptance plate for steel of 58—65 kg/mm² (24 tests).

Breaking stress	min.	55 kg/mm²
	max.	69 kg/mm²
	average	58.5 kg/mm²
Resilience	min.	5.52 kgm/cm²
	max.	8.27 kgm/cm²
	average	6.7 kgm/cm²

Bending over mandril dia. = 5 · e, good at 180°.

Fig. 3.

Without heat treatment. After normalising treatment.

Weld metal.

Weld joint.

Close to joint.

Raw metal.

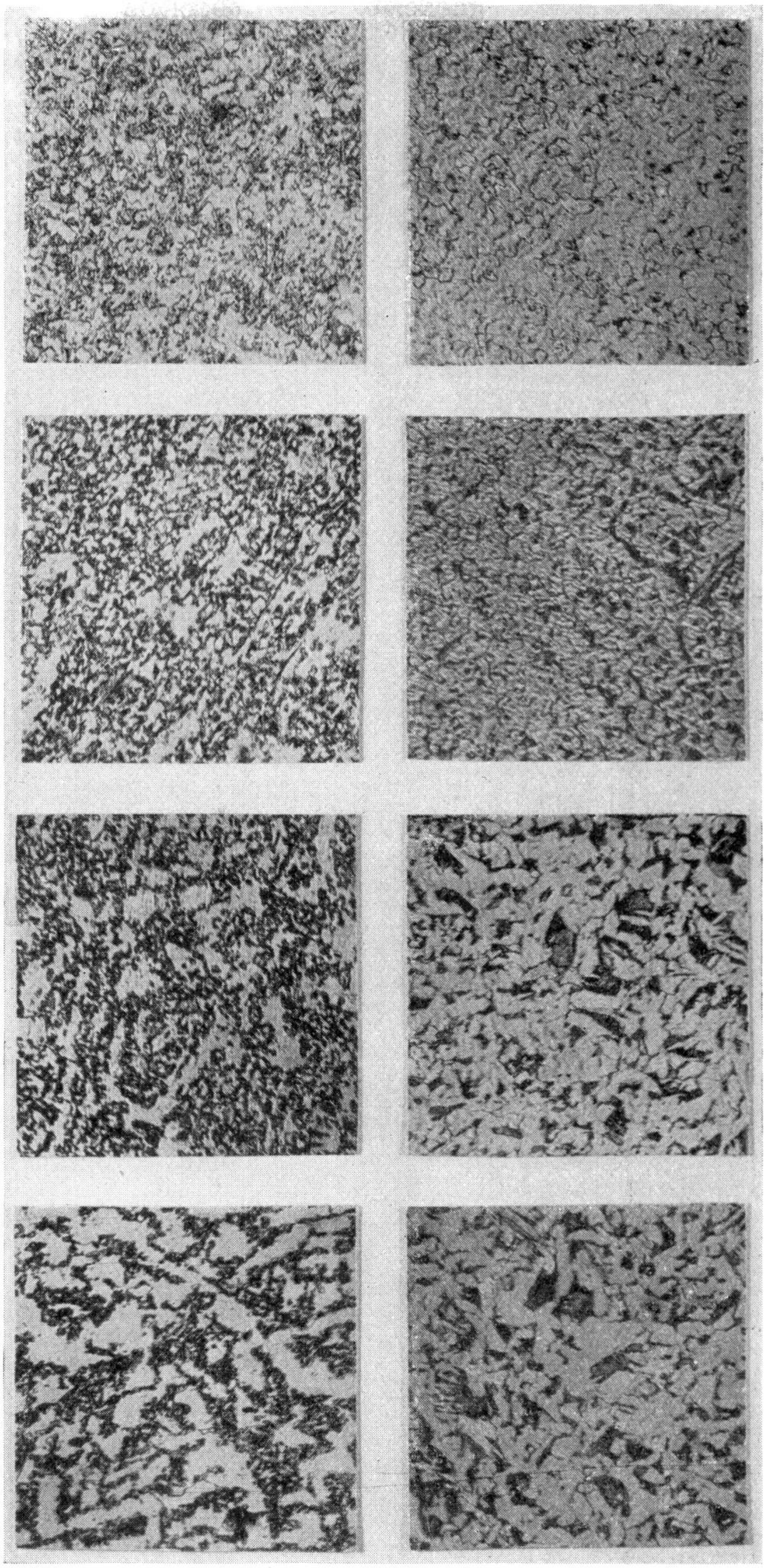


Fig. 4.

Micrographical study of a welded joint.

Carbon steel of 58—65 kg/mm². Electrode: "Arcos Stabilend".

limit. The distribution of the stresses may be studied by the tensometric method, either on a small scale model or on a model of the size adopted by Professor *Campus* for investigating the welded intersections of the frameworks for the Institut de Chimie et de Génie Civil at the University of Liége.

The first check is afforded by visual inspection of the weld beads on the part of a specialised supervisor. The welds are stamped by the welder with an identi-

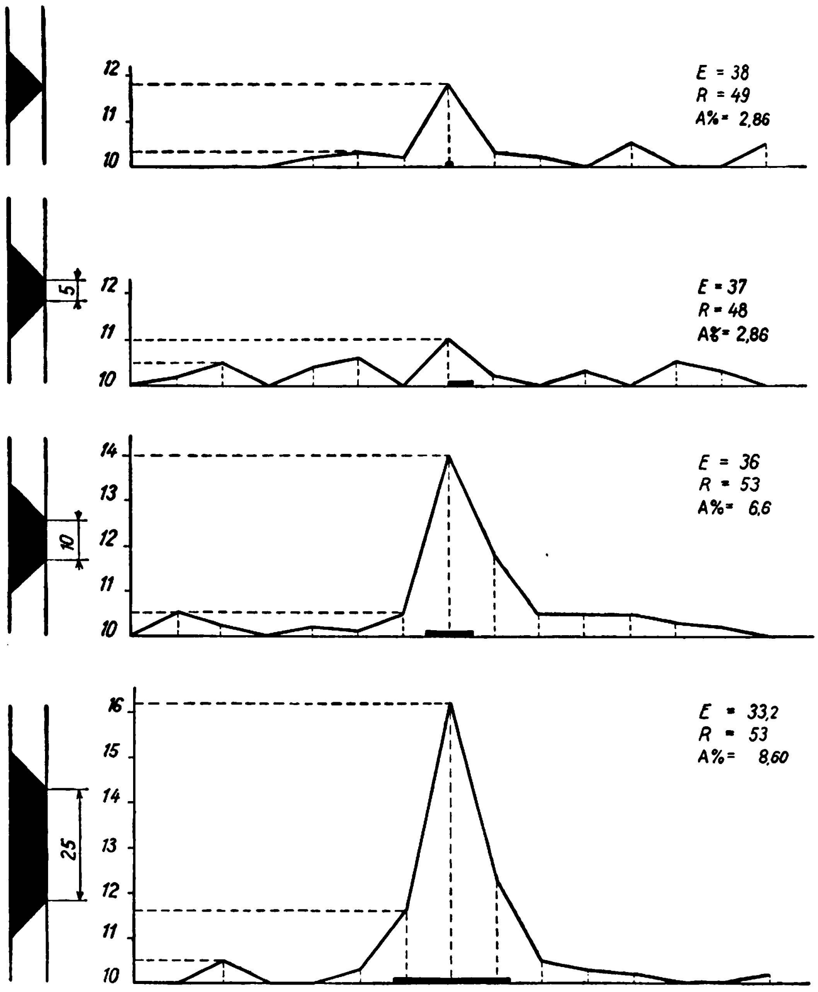


Fig. 5.

Tensile tests on flat specimens of 100 mm² cross section, 140 mm long, with varying amounts of weld, measurements of elongation being made at every 10 mm. Carbon steel 58—65 kg/mm². Arcos-Stabilend electrodes. The distribution of the elongation, and the smallness of its total amount, should be noticed. A control specimen cut from plate gave 20%.

fying number, which makes him responsible for his work and enables defects to be traced to him, even if they do not appear until a long time afterwards. A record of these marks is kept in a special register with all relevant information.

Borings made into the weld seams with a drill may be made to yield useful information at the beginning of a job for the purpose of checking penetration, etc., but at later stages this destructive method possesses no more than a secondary interest due to its moral effect on the workman who knows that his work is being checked in this way.

The use of the stethoscope is not effective in the applications here considered.

Control by means of the magnetograph can be made to yield very valuable information in special cases, particularly in the advance examination of butt welded specimens. The method consists in using a magnet to produce a magnetic field and in studying the deviations imposed on the lines of force by the presence of the weld or in measuring the variations of this field. Any increase in the magnetic resistance of the weld due to faulty zones (cracks, air bubbles, coagulations), is made apparent in the lines of force of the spectrum.

In examining pieces of small dimensions remarkable results may be obtained with the Giraudi patent "metalloscope". Here the intensity of the field has to be made so great as to bring it to saturation, and a liquid which carries magnetic metallic oxides in suspension is poured over the pieces, becoming attracted to those points where the flux is dispersed in the surrounding air. In this way a pattern is projected on the surface which corresponds to any defects existing below.

The radio-metallographic method of control, which is the only effective one to be made practicable up to the present time, consists of photographing the weld lines with the aid of X-rays. The intensity of the rays must be regulated as a function of the thickness of the pieces and of the dimensions of the defects to be detected. The Phillips "Metallix" macroradiographic apparatus, either fixed or mounted on a motor trailer, gives a penetration of the X-rays amounting to 80 mm through steel. The electronic intensity is regulated by a rheostat, and complete protection is afforded to the operator (Figs. 9, 10, 11 and 12).

II. Spot welding.

Principles of use.

Electric resistance welding by the spot system is at present scarcely applied to bridges and building frames, except in the construction of beams, grillages and secondary members, but its use is continually extending.

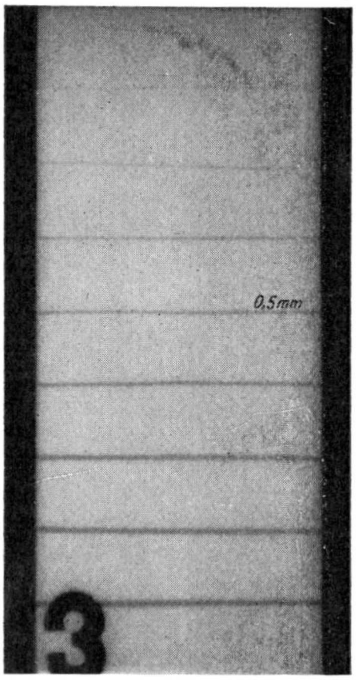
The proper execution of a spot weld depends on three conditions: the temperature of the welded zone, the time taken and the pressure exerted on the pieces to be joined during and after the operation.

It is difficult to measure the temperature of the metal in the neighbourhood of the weld directly. The time of welding has to be extremely small ($^1/_{50}$ of a second for rustless steels "18/8", with a view to the avoidance of certain chemical transformations in the metal) and it has to be varied according to the condition of the pieces. The pressure is kept constant for a given case and is regulated by mechanical, pneumatic, hydraulic or electrical means.

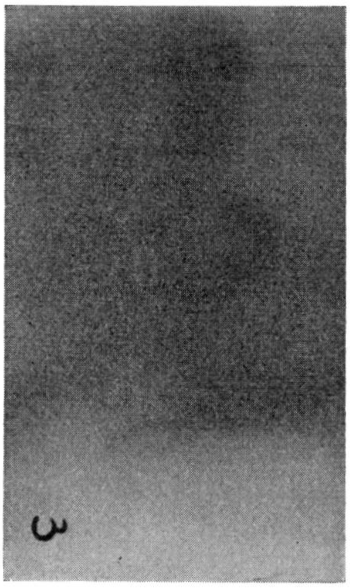
The best results are obtained by using very heavy pressures during the short time that the circuit is closed, and automatically releasing them as soon as the current is interrupted.

Control.

Excellent results are obtained through control of the weld by suitable switches designed to break the current at the proper time. Constant time switches will not always compensate for irregularities when the resistance varies in accordance with the state of oxidation of the pieces and with variations in starting, for their

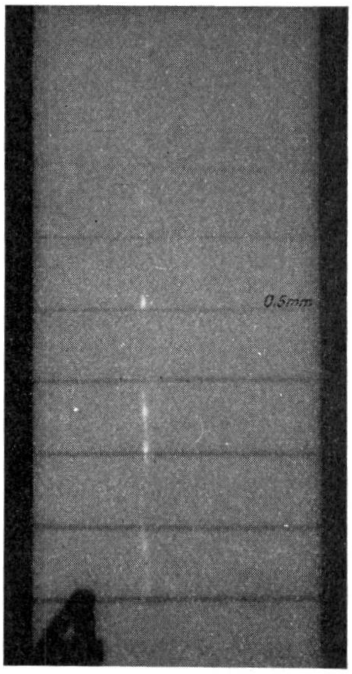


X-ray photograph.
(Exposure: 10 minutes. 70 KV. 4 m A.
Detection of faults down to 0.1 mm).

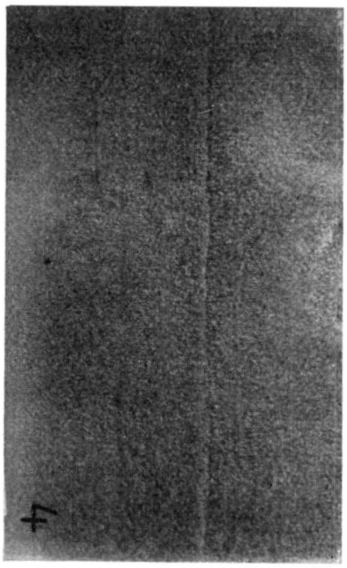


Magnetic spectrum.

Fig. 6.
Welded V-joint. Thickness 10 mm. Electrodes Esab. O.K. 47. Mild steel.
Sound weld.

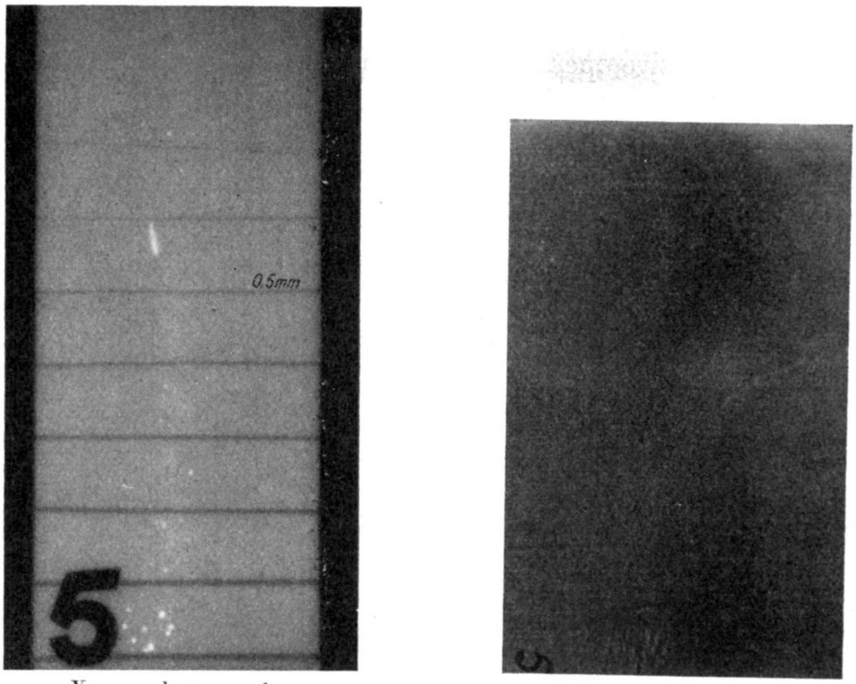


X-ray photograph.
(Exposure: 15 minutes. 70 KV. 4 m A.)



Magnetic spectrum.

Fig. 7.
Welded V-joint. Thickness 10 mm. Electrodes: Esab. O.K. 47.
Carbon steel of 58—65 kg/mm² ultimate strength. A longitudinal shrinkage crack will be noticed.
Externally the weld appeared perfect.

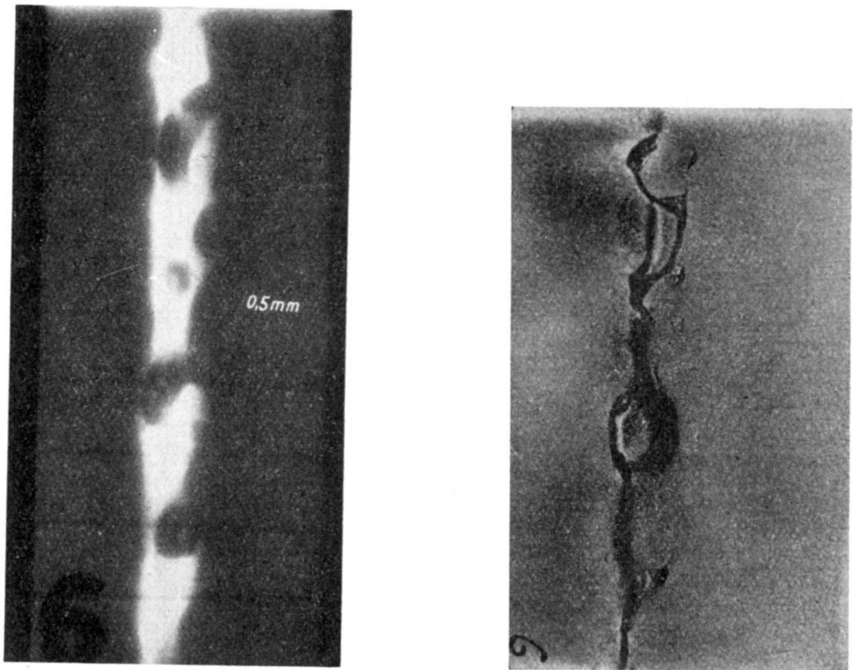


X-ray photograph.
(Exposure: 15 minutes. 70 KV. 4 m A.)

Magnetic spectrum.

Fig. 8.

Welded V-joint. Thickness 10 mm. Electrodes: Arcos-Veloxend.
Pores of the order of 0.1 to 0.2 mm due to excessive strength of current.



X-ray photograph.
(Detection of faults down to > 0.3 mm.
Exposure: 4 seconds. 90 KV. 4 m A.)

Magnetic spectrum.

Fig. 9.

Welded V-joint. Thickness 10 mm. Electrodes: Arcos-Veloxend.
A void will be noticed running the whole length of the seam, with drops of metal enclosed in slag.

efficiency depends on the assumption that the welding temperature will remain constant over two successive operations, and this is not the case unless the induced electromotive force in the secondary remains constant, and unless the sum of the contact resistances between the work and the electrodes is the same at every instant. The latter condition does not hold good unless the plates are absolutely clean, so as to offer both a constant striking resistance and a constant voltage drop.

Constant-minimum-current switches operate by cutting of the current as soon as its intensity passing through the weld reaches a pre-determined value. Their adjustment is delicate and they are at the mercy of the supply voltage.

Ampere-second integrating switches work by cutting of the supply current as soon as a pre-determined total of ampere-second has passed through the machine. It has been found that the ratio between the current passing through the transformer and the energy put into the weld varies constantly, and depends essentially on the surface condition of the pieces, on the pressure, and on the variation of the latter during the welding operation.

Watt-meter switches serve to measure the correct amount of power supplied to the machine, or some function of this power. They are preferably included in the secondary circuit at the electrodes, since in that way they give more precise indications, but they necessitate a current transformer and a complicated form of connection.

A recording alarm controller is available which makes an arc on a ribbon of paper to represent a function of the power supplied in welding each spot, which serves as a criterion of quality. In case of any accident, bad contact, badly connected conductors, faulty regulations, drop in voltage, etc. an alarm bell rings which attracts the attention of the operator, and the welding machine automatically stops until the conditions are put right.

Only clean pieces of work, as far as possible milled or sanded, should be used for welding.

The welded spots.

The welded spots should be examined in the laboratory by micrographical analysis, especially where steels containing copper, nickel or chromium are being

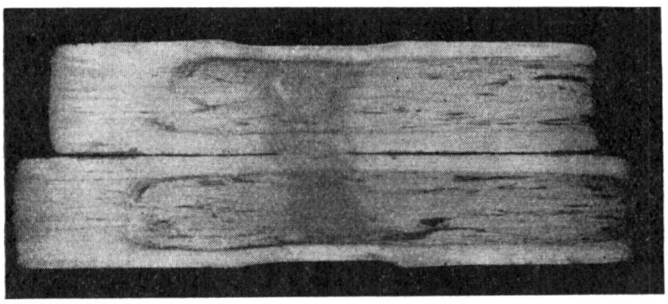
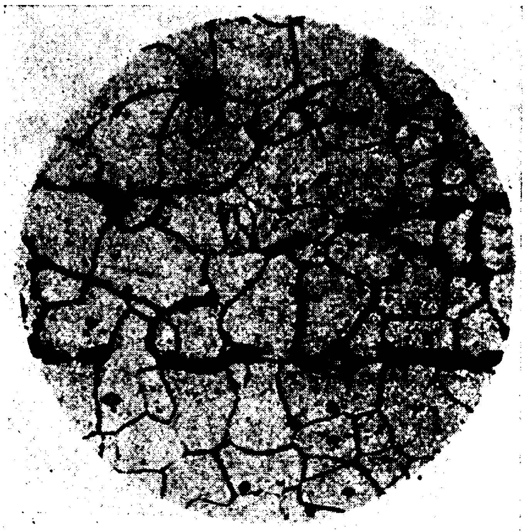


Fig. 10a.

Macro-photograph of a spot weld. Steel 42—50 kg/mm².

used. Any impurities which may be present in the contact zone remain embedded in the molten metal and become concentrated (Fig. 10).

Preliminary punching tests are necessary, and uniformity of results may be assured by using the modern forms of apparatus provided with watt-metric switches.



Raw metal.

Metal in welded zone.

Fig. 10 b.

Micro-photographic study of a spot weld. Steel 42—50 kg/mm^2.

As the time of welding is always relatively short and consequently the cost per spot is small, a large number of spots are used ,so as to be able to work with a low working stress. The indication drawn from practice is that for thicknesses of up to about twice 10 mm the reliability of welding is of the same order as that of the corresponding rivetted work.