Testing methods in workshops and ad site

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Testing Methods in Workshop and ad Site.

Prüfungsmethoden im Werk und auf der Baustelle.

Méthodes d'essai à l'atelier et sur le chantier.

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The mechanical testing laboratory attached to the welding shop of the Penhoët Dockyard has not been established for the purpose of carrying out theoretical researches on welding by fusion but to provide for scientific control, as methodical and as uniform as possible, over jobs of all kinds carried out in this workshop.

The great majority of these jobs are done by arc welding, and this report will have reference to that particular kind of fusion welding alone. No mention will be made either of resistance welding or of spot welding — despite the great interest offered by these methods in steel construction — nor of fusion welding with the burner, the application of which is still limited in this shipyard.

The shipyard in question is well enough known from the fact that it has produced the liner "Normandie", and no more need be said than that it is continually turning out hulls for ships, steam engines, internal combustion engines, marine and land boilers: an enumeration which will suffice to indicate the number and variety of the applications that arise there for arc welding, a process which is tending more and more to replace riveting in the assembly of plates and rolled sections, and also castings in the case of certain parts of machines.

This last mentioned application will not be considered here, but only the question of welded joints in steel structures.

The adoption of arc welding in place of riveting has not altered the conditions that require to be fulfilled by a joint in a metallic construction to ensure its stability under load: success remains dependent on combining sound design of the members and of the joints with a suitable choice of materials and with sound execution. Of these factors the design is a purely technical matter, and reference will be made here only to the choice of materials and to the method of execution.

It was for the study of these two questions that the installation of a laboratory for mechanical testing was felt to be justified, and it is proposed here to explain the method of control adopted by us and the results of the experience which we have been able to draw from it.

1) *The parent metal:*

In a welded joint a distinction is drawn between the parent metal and the weld metal. We shall begin by discussing the first of these. Considerations relative to welding do not determine the choice of the mechanical properties which it must posses, but they do determine its chemical composition, for the influence of the latter on the qualities of the weld and even on the possibility of making a weld is indisputable.

There are, in fact, weldable steels and non-weldable steels: nor is it sufficient to leave the matter there, for the significance of this statement has to be defined and some method of testing established which will allow of a given steel being classified under one or other of these two heads. What, then, is a weldable steel? Before attempting to answer this question it should be remembered that in every weld there are three distinct zones: at the centre the weld metal, at the edges the parent metal, and between the two a zone of limited extent which is known as the contact zone.

These three zones differ in origin and as regards thermal treatment. The weld metal is derived from the electrode, and to some extent from the covering of the latter; it is obtained by complete fusion at a more less high temperature and subsequent rapid cooling.

The contact zone is formed by a more or less intimate mixture of the electrode metal with the parent metal, the temperature for the contact zone during the welding operation lying between that of the central zone and that in which fusion of the weld-metal begins.

Finally, in the neighbourhood of the contact zone, the parent metal at the moment of welding has been brought to a high temperature (though lower than the temperature of fusion) and has subsequently been cooled down more or less rapidly to air temperature. The thermal treatment which it has thus undergone has to a certain extent altered its mechanical qualities.

These facts are well known and there is no need here to enter into details regarding them. They have been treated in a very thorough lecture by *M. Portevin* at the University of Lille on 23rd February, 1933, leading up to the proposal that weldability might be defined as "the aptitude of metals, to form, when worked in accordance with the rules established by welding technique, a compact and continuous connection free from physical defects and as homogeneous as possible, thus securing uniformity in those properties which are necessary for the purpose to which the welded member is to be put".

This definition as a whole may be accepted, though subject to some reservations of detail which there is no need to go into here. The question arises as to how it can be applied to the actual study of weldability of a steel. Theoretically each of the three parts of the weld — namely the weld metal, the parent metal in the heated zone and in the contact zone — ought to be isolated, and the physical and mechanical properties of each determined with a view to comparing them with those of the parent metal in its original state. As regards the weld metal this would occasion no difficulty: specimens of normal dimensions may be taken from it, and may be tested by ordinary methods in the usual machines.

The case is different, however, in regard to the heated zone and the contact zone. These two zones, especially the contact zone, occupy a very small width in the direction transverse to the weld, and they do not lend themselves to the extraction of normal types of specimens apart from those used for notching action. Hence the observation of *M. Portevin* in the course of the lecture cited above: "The methods of testing to be adopted ought necessarily to be as localised as possible. They might, with advantage, be carried out on very small specimens using machines specially designed for the purpose."

Machines conforming to this criterion were made the subject of a paper by *M. Pierre Chenevard* before the *Académie des Sciences* on 30th January, 1935. (*Technique Moderne* of 1st May and 1st June, 1935.) But while researches of this kind may be feasible in the laboratory of a metallurgical works where it is a question of perfecting the formula and the method of preparation of some new steel, they will scarcely meet the needs of the industrialist who has neither the time nor the necessary equipment and who only requires to know, without great expenditure or loss of time, whether or not a steel which he proposes to use is in practice weldable: that is to say whether there exist on the market any electrodes wherewith that steel, if adopted as a parent metal, can be made into joints that are practically homogeneous.

Expressed in this way, the problem would appear to admit of a single solution such as the Author had occasion to apply several years ago in connection with welding work on the steamship "Paris".

The method consists of simultaneously examining the heated zone and the contact zone in a specimen prepared as follows: An ordinary tensile test specimen of rectangular section is cut from the original parent metal (Fig. 1). On this specimen, by means of the electrode which it is proposed to use, a longitudinal weld is deposited symmetrically over the axis of the specimen and entirely covering the latter. The deposited metal is subsequently milled away, leaving a specimen which reproduces the molecular condition of the zones to be studied faithfully enough for all practical purposes. For this condition to be fulfilled the thickness of the specimen must be small, depending on the diameter of the electrodes which it is intended to use in the welding job; for an electrode of 3.8 mm diameter the thickness of the specimen is 10 mm.

The resulting specimen is tested in a machine of the ordinary type (in our own laboratory an Amsler 50-ton machine is used), and its limit of elasticity, breaking stress, elongation, and constriction are recorded.

A similar series of measurements has previously been taken on an identical specimen of the parent metal whereon no weld metal has been deposited, and a comparison between these two series of results makes it possible to form an opinion as to the homogeneity of the joint. The comparison is completed by a further test designed to show the elongation of the metal in the contact zone: for this purpose a folding test specimen is prepared, on one face of which a weld metal strip is deposited and is then removed by milling, whereupon the test is carried out with the face which has received the bead placed on the tension side. A comparison between the angle of folding attained before cracking occurs on this specimen, and in the corresponding specimen of the original metal, can then be taken as a basis for comparing the elongations.

Finally there is a third test, that of notching action. For this purpose we generally make use of a Mesnager specimen, arranging the weld strip (Fig. 3) on one of the longitudinal faces perpendicular to the notch. The strip is removed by milling as in the case of the tests described above, and one specimen is taken from the original metal for reference.

Undoubtedly this procedure yields less information than does the series of tests proposed by *M. Portevin,* and it can be objected that as regards the tensile test no distinction is drawn between the two zones: it does, however, enable a sufficient degree of discrimination to be exercised cheaply and rapidly, between weldable and non-weldable steels, and up to the present no difficulties have been experienced in its use.

Some examples of results attained will now be given.

All the tests about to be mentioned were carried out using the same type of electrode which will be designated by the reference E_1 and had previously yielded satisfactory results. The weld metal from this electrode had the following mechanical properties:

Modulus of elasticity 47.3 kg per sq. mm.
Breaking stress 59 kg per sq. mm.
Elongation 20 %.
ρ (Mesnager) 6.42.
$\alpha = 135^0$.

The specimens numbered 1 are those shown in Figures 1 to 3. The specimens numbered 2 are represented in Figures 4 to 6 and are welded from side to side. The reference marks A, B, C, etc. are applied to distinguish the various grades of steel examined.

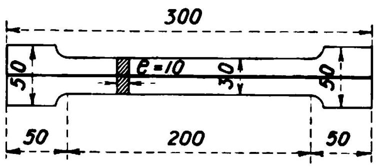

Fig. 1.

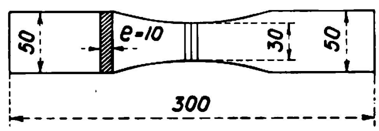

Fig. 4.

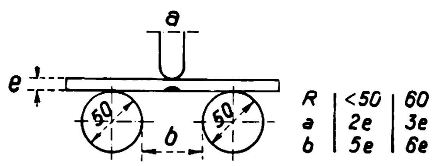

Fig. 2.

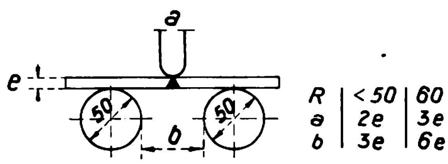

Fig. 5.

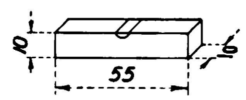

Fig. 3.

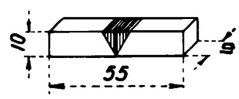

Fig. 6.

The steel mentioned last in the table is the best of the four steels tested, giving as it does a practically homogeneous connection with the deposited metal. The same is not true in reference to steels A and C, and it may be observed that the last is the only one of the steels which gives a value for the breaking stress lower in the heated zone than in the original metal. This is attributable to the fact that the increased strength of the original metal has been obtained by cold-working in the rolling process and the effect of this cold-working has disappeared in consequence of heating so that strength was again lost.

This point need not be further dealt with here. The tests of which some results have just been mentioned enabled us to make a choice between the various compositions of steel offered for use in a very special application, namely, a semi-rustless steel of high strength for the keel of a steamship.

Characteristics (1)		Parent metal (2)	Specimens No. 1 (3)	Ratio (3)/(2) (4)	Specimens No. 2 (5)
Steel A					
Tension	E = modulus of elasticity	35.9	46.2	1.29	
	R = breaking stress	62.4	64.6	1.04	55.3
	A = elongation	24 %	7 %	0.29	
	R+2A	110	79	0.72	
	Reduction of section	64 %	32 %	0.50	
Folding	First crack	180°	62°	0.35	
	Breakage	—	69°	—	
Resilience:	Mesnager	7,4	3.1	0.42	6.6
Steel B					
Tension	E = modulus of elasticity	36.9	—	—	
	R = breaking stress	54.7	57	1.04	52.7
	A = elongation	25 %	16.4	0.64	
	R+2A	105	90	0.86	
	Reduction of section	56 %	31 %	0.55	
Folding	First crack	—	—	—	
	Breakage	180°	147°	0.82	
Resilience	Mesnager	21.6	9.1	0.42	
	U. F.	10.9	7.9		5.5
Steel C					
Tension	E = modulus of elasticity	42.1	48.6	1.16	37.9
	R = breaking stress	68.2	56.8	0.83	50.7
	A = elongation	25 %	3 %	0.12	
	R+2A	118	63	0.53	
	Reduction of section	54	8 %	0.15	
Folding		180°	39°	0.22	
Resilience		6.8	0.9	0.13	6.9
Steel D					
Tension	E = modulus of elasticity	34.6	33	0.96	No results
	R = breaking stress	54.5	59.5	1.09	
	A = elongation	23 %	17 %	0.74	
	R+2A	100	94	0.94	
	Reduction of section	52	33	0.64	
Folding		180°	107°	0.60	
Resilience:		7.8	7.5	0.97	

Marks and indications	Electrodes			Current		Loss of weight in g per kg of metal deposited		Time per kg of metal deposited		Elastic limit kg per sq. mm	Breaking stress kg per sq. mm	Elongation °/o on 50 mm	Angle at first crack	Angle folded without cracking	Resilience		Brinell number	Breaking stress of parent metal = kg per sq. mm
	Diameter mm	Weight g	Length cm	Amperes	Volts	Volatilisation	Total	Fusion	Total						Mesnager	U. F.		
E_1 deposited metal	4	44	45	160	22	137	261			44.2	55.2	16.5	125°			7.2	142	
E_1 edge to edge P	4	44	45	155	22	180	270	46m. 30s.	1h. 1m.		55·9		146°			6.6	142	55
E_2 deposited metal	4	44	45	160	26	59	179			47.3	59.0	20.0				8.2	155	
E_2 edge to edge P	4	44	45	150	26	109	227	44m. 6s.	1h. 37m.		59.7		120°			7.03		60
E_5 deposited metal	4	39	40	147	19	185	330	1h. 17m.	2h. 30m.	32.0	40.0	15.6	16°		4		113	
E_5 edge to edge P	4	39	40	130	22	93	222	1h. 8m.	2h 46m.		42.0		88°					
E_5 edge to edge V	4	39	40	145	21	103	233	1h. 8m.	2h. 17m.		40.0							40
E_5 edge to edge T	4	39	40	150	20	157	310	1h. 17m.	2h. 42m.		44.0							
E_9 deposited metal	4	44	45	170	22	75	222			48.7	57.8	27.0			21.6	13.7	155	
E_9 edge to edge P	4	44	45	170	22			48m. 30s.	1h. 27m.		61.6			180				
E_9 edge to edge V	4	44	45	170	22						62.6							60
E_9 edge to edge T	4	44	45	170	22						64.6							

2) *The weld metal.*

The study of the weld metal is nothing more nor less than that of the various qualities of electrodes. The number of these on the market is constantly increasing. Their makers, in offering them to the industry, emphasize the qualities they claim for their products, and it is well to verify these claims by means of personally conducted tests. We ourselves do so continually.

The tests which we apply cover not only the investigation of mechanical properties but also other data which may be less scientific, but are of interest from the economic standpoint. The tests in general include the following:

1) In regard to the deposited metal: —
   a) A tensile test on a cylindrical specimen.
   b) A notching-action test on a U. F. or Mesnager specimen according to the requirement of the customer for whom the welded work is intended. The testing machine used is a Charpy pendulum.
   c) A folding test.
   d) A measurement of the apparent density.
2) In regard to a butt welded joint: —
   a) A tensile test on a rectangular specimen (the elongation is not measured).
   b) A folding test.
3) In either case a note is made from actual practice of the speed of welding, and of the weight of electrode lost through volatilisation or in projection.

To serve as an example, a table is reproduced below giving a complete statement of the information obtained in regard to an electrode marked E_2.

As a general rule the results thus obtained are made known to the suppliers of the electrode so as to allow them to take note of the observations.

Thus in the case of electrode E_3 the general results obtained were the following.

Deposited metal:
Breaking stress 43 kg per sq. mm.
Modulus of elasticity 38 kg per sq. mm.
Elongation 48 %.
$\alpha = 18^0$, ρ (Mesnager) 11.1.
Test on the joint from side to side:
Breaking stress 47 kg per sq. mm.

Following upon a visit to our laboratory by the Director of the firm concerned, we were offered, a few months later, a new type of electrode E_4 which showed the following characteristics:

Deposited metal:
Breaking stress 48.7 kg per sq. mm.
Modulus of elasticity 40.1 kg per sq. mm.
Elongation 27.9 %.
ρ (Mesnager) 13.
Test on joint from side to side:
Breaking stress 52.5 kg per sq. mm.
$\alpha = 132^0$.

It will be seen that, concurrently with an increase in the breaking stress, the other qualities of the joint and especially its ductility have been appreciably increased. The joint made with free edges was formed on plates of 50 kg per sq. mm breaking stress, but this electrode is very suitable for use on steels of the present Veritas type having a maximum breaking stress of 48 kg per sq. mm, and it produces homogeneous joints in these steels.

Finally, it seems to us important to outline the progress attained in the course of a few years in the development of electrodes for arc welding, and for this purpose we give on page the results of the test carried out at different times on the supplies obtained from the same French manufacturer.

The electrodes E_6 are intended for the welding of a metal which has the following mechanical characteristics, and which has been accepted as weldable by means of these electrodes in the sense here attributed to that expression:

Breaking stress 60 kg per sq. mm.
Elongation 30 %.
ρ (U. F.) = 6.

The homogeneity of the joint, as measured by the agreement between the deposited metal and the parent metal, is as high as possible, and the weldability test has shown that this homogeneity is sufficient in the transition zones also. It may be accepted, therefore, that provided the execution is sound, welded joints carried out in this steel will give a full degree of security. From this rapid survey we may draw the conclusion that there now exists a range of types of electrodes with which it is possible to form homogeneous joints having a tensile strength of between 40 and 60 kg per sq. mm with elongations and coefficients of resilience comparable to those of the parent metal.

3) *Execution.*

a) *Personnel.* It remains to be explained how the supervision over the execution of the work may be organised in such a way that the security attained in the choice of materials is preserved throughout the completion of the job.

The main objection which has been raised to the generalised use of fusion welding is the contention that the quality of the weld depends essentially on the skill and conscientiousness of the welder: however great the care with which the engineer may have studied the design of the joints, whatever the researches that may have been carried out to ensure a suitable choice of materials and a homogeneous joint, all these precautions will be useless if the weld is badly made; hence in the absence of any practical means of distinguishing afterwards between good and bad execution, the supposed security must be illusory.

It may be remarked, first of all, that this alleged impossibility of checking the quality of workmanship in the finished job is not peculiar to arc welding. It also applies to reinforced concrete, and when accidents occur in structures so made they are not infrequently attributed to faulty workmanship.

Some years ago, it is true, doubts of the most serious kind might justifiably have been entertained regarding the skill in their trade of the workmen who described themselves as arc welders. But to-day this is no longer the case. In every country there are now many welding schools, most of which are the result of private initiative — which in our opinion is an excellent thing, for the art of arc welding is far from having reached the end of its evolution. It is being transformed and perfected from year to year, and nothing could be more injurious from this point of view than that it should be placed under administrative tutelage. So far as welding is concerned we advocate liberty of instruction, and we are opposed to the idea of instituting diplomas of more or less official character which would be granted to workmen as an attestation of the fact that they have passed through a school.

Skill in any trade, and perhaps especially so in welding, diminishes and finally disappears if not maintained by practice. Diplomas, therefore, can only be of value for a limited period of time, and their introduction would be useless, since it would not eliminate the need for periodical tests which we regard as indispensable in any case.

Our own welding school was established in 1930. The workmen who pass through it have to carry out butt welded and cruciform joints in the three principal positions, namely horizontal, vertical and overhead. Tensile test specimens are taken from the welded pieces, and the results obtained from these serve as a means of classifying the workmen. Those who have not achieved a certain minimum of proficiency on work in any given position are not permitted to weld in that position. This provision applies particularly to overhead welding, — in respect of which it may be remarked, by the way, that certain regulations show an exaggerated distrust, for it is a fact that two-thirds of our own welders are capable of making overhead joints which give results equivalent to those obtained in horizontal welds, and that such joints are constantly being made without any difficulty in ships under construction. The reduction in permissible stress imposed in the case of overhead welds is unjustified, and it would be enough simply to enforce a rule that this type of weld should be carried out only by those welding workmen who have been proved by qualification tests to be able to execute it correctly.

The minimum value of breaking stress accepted for classification was originally 35 kg per sq. mm in the butt test, and 28 kg per sq. mm in the cruciform test. Following upon improvements in the quality of the electrodes the minimum has been increased, and with the electrode E_6 and steel plates of 50 kg per sq. mm breaking stress it is now 46 kg per sq. mm in the butt test, and 33 kg per sq. mm for the cruciform test.

The period spent in the welding school varies between six weeks and two months. It would of course be absurd to pretend that this relatively short period of time is sufficient for the complete training of a welder: he must continue to improve his skill during the first few months of practice in his new trade. It might be said that from being an apprentice he has now become a journeyman, but is not yet a master.

It would, therefore, appear to be a matter of elementary prudence not to entrust him at the beginning of his career with any such jobs as might affect the safety of the finished work, and on the other hand to follow his progress — which may possibly be negative — by means of supervision tests carried out at fairly frequent intervals. The principle which we adopted at first was to repeat the classification tests at intervals of three months during the first year, but experience has shown the propriety of adopting a slightly longer interval, and now these tests take place every four months.

At the end of a year the workman who has maintained his skill in the trade without any lapse is capable of inspiring confidence, and he is entrusted with jobs of an importance corresponding to his classification. We continue, however, to repeat the efficiency tests, but the period between them simply being increased to six months.

In this way the men are kept keyed up to their job and a useful spirit of emulation is encouraged both among the workmen and among their employers. The following table is given for information regarding the successive tests of workmen trained in our school.

Breaking stress in butt-welded joints.

Classifikation N°:		38.022	38.027	38.049	38.050	38.098
Passing-out tests . .	H	39.4	41.1	49.9	48.9	38.0
	V	34.8	35.7	45.8	45.5	31.4
	O	36.4	35.7	43.0	45.8	20.5
1st 3-monthly test . .	H	47.9	42.0	49.9	44.5	39.4
	V	39.1	38.1	45.3	45.3	41.9
	O	40.6	30.9	39.5	40.9	39.0
2nd 6-monthly test . .	H	44.1	37.2	46.5	44.6	41.1
	V	38.6	40.8	40.8	42.2	45.9
	O	34.7	35.2	31.1	45.6	44.2
3rd 3-monthly test . .	H	44.4	43.5	47.6	45.7	45.4
	V	43.5	42.3	42.6	41.2	42.3
	O	43.8	36.1	47.2	42.0	47.6
1st 6-monthly test . .	H	45.6	40.7	48.7	46.9	46.6
	V	41.6	43.3	44.8	44.1	43.5
	O	45.6	42.4	44.2	44.0	41.2
2nd 6-monthly test . .	H	47.1	41.8	45.6	49.1	41.8
	V	40.2	42.8	44.8	44.6	42.1
	O	45.3	38.0	46.0	44.4	41.8

All these tests are carried out with the same electrodes, which give a weld metal having a minimum breaking stress of 40 kg per sq. mm, and the plates used are of the ordinary quality. Since about a year ago electrodes which give a weld metal of greater breaking stress than this value and plates guaranteed to be of corresponding quality, have been introduced.

The latest of the tests under these conditions made by the welders referred to above give the following results.

H	55.3	64.9	58.4	62.9	54.3	
V	55.8	73.0	57.0	57.3	46.5	
O	59.8	70.0	57.9	63.2	59.1	
Parent metal	50	60	50	60	50	kg per sq. mm.

It will be seen on examining the figures in this table that after a welder in the school can carry out horizontal joints properly it takes him as a rule a year's practice, before he can bê counted on to make satisfactory vertical and overhead joints.

Periodical tests such as we have insisted upon since the beginning of our school are likewise shown to be of capital importance from the point of view of safety. There can be no doubt that these entail an increase in the general charges of the workshop, but they are looked upon as an insurance against accidents of the kind that might result from defective welds, and it is our opinion that no employer ought to be permitted to undertake welding work of nature involving public safety unless he can show that a similar organisation to this has been in existence for at least a year. Spicifications which require only individual tests at the beginning of the work do not afford a sufficient guarantee.

b) *Material.*

We have just discussed how a welding personnel with aptitude for very varied jobs may be formed and maintained. In order that such a personnel may be able to apply to the fullest advantage its skill in its trade, it must have at its disposal a suitable equipment, and the fundamental part of that equipment is an assured supply of current for welding. It would be beyond the scope of the present study to discuss here the various methods whereby the distribution of this may be arranged and the conditions which ought to be complied with to ensure correct welding; it is proposed merely to recall that one of the most important of these conditions is good regulation of the amperage of the current. In the author's opinion it is essential that each welder should have for his use an ammeter in series with the electrode. The indication given by this ammeter will serve not only to enable the workman to select an amperage conforming to his instructions, but will also make it possible for the foreman to check easily and quickly whether each of the welders is operating in conformity with those instructions. It will so provide direct and permanent supervision over the proper execution of the work, and will supply the second of the rejoinders that can be put forward in answer to the objection raised against the generalisation of arc welding in metallic construction: not only are welding workmen selected by a system without parallel in any other trade, but one of the most important elements in its success — the manner of performance — is supervised throughout.

We make use of two methods of current distribution. In one of these each welder has at his disposal a transformer set which is supplied with energy from a 440 volt circuit carrying low-tension current suitable for welding. We have made it a point that each of these transformers should be equipped not only with the ammeter mentioned above, but also with a voltmeter. The latter cannot, of course, be consulted by the welder, but it furnishes the foreman with a very useful indication on the conduct of the work.

In the second method of distribution there is provided, in respect of a zone which covers three construction bays and two floating welding sets, a low-tension network which is fed from a central station transforming the current of the sector from alternating at 5000 volts to continuous current at 45 volts. The sections of this network have been calculated to ensure a minimum tension of

35 volts. Each workman can insert a special current-taking device, known as a regulator, at any point in the network; this regulator contains resistances which can be used not only to regulate the amperage and source of the current but also to furnish an extra tension of 20 to 25 volts at the moment of striking the arc or of the almost instantaneous short circuits which arise in welding and are revealed by oscillograms of the welding current. Stability of the arc is thus perfectly ensured. An ammeter is placed on each regulator, but there is no voltmeter because the regulator is connected to only one pole and the return circuit runs direct from the welding work to the fixed main.

The results obtained with this method of distribution (which was described in an article published in the journal *"La Technique Moderne"* of 1st June 1932) proved so satisfactory that a new central station has been set up to serve another part of our shipyard and was brought into operation in 1935.

4) *Tests on Welded Joints:*

It would have been of interest to show, by giving numerical results of the tests carried out on welded constructions, that the methods described in these pages do in fact afford the security which is their object, but hitherto the application of these methods has been confined almost entirely to the hulls of ships, a form of work not susceptible to positive performance tests, since, in the absence of deformation or local breakages, it is only after some period of service under more or less unfavourable conditions of navigation that the value of the work can be judged.

We must, therefore, confine ourselves to recalling the fact that about a year ago the trials carried out on the cruiser *"Emile Bertin"* were reported in the press. This ship was delivered to the French Navy from our yard, and in her construction a great deal of welding work had been done. Some of these trials were made in very heavy seas, but none of the welded joints showed any signs of fatigue or of leakage. An examination of the hull of the *"Emile Bertin"* at the end of six months' winter navigation in the Atlantic yielded the same favourable record.

On the "Normandie" a large number of welded joints were made and at one time the number of welders at work on board this ship totalled 140. Their work, however, was not concerned with the vital parts of the ship, and moreover the "Normandie" has been placed in service too recently to allow of any conclusions being drawn.

In these circumstances the author may be allowed to make some observations on his experience regarding the arc welding of mechanical parts, even though this is a class of work outside the direct scope of the Congress. It was concerned with the butt welding of thick plates: a type of work which may occur in framed steel structures, as for instance in the bearing plates of bridges.

The first case which will be mentioned is that of an engine base formed of two plates 20 mm thick, having a breaking stress of 60 kg per sq. mm. The plate was in a horizontal position and could not be turned over during the course of the work. Its thickness was such as to make an "X" joint suitable. The necessity arose of forming half the seam horizontally from above the plate, and half of it from underneath by overhead welding.

This was done in the following way: the two plates to be joined together were bevelled on both faces at an angle of 60°, and were then arranged parallel to one another with a gap of 5 mm between the bottom of the bevelling. A copper rod of 10 mm diameter was placed in the lower bevel and a first weld was made horizontally. The electrode used for this purpose was one with a diameter of 6.4 mm, and was of the type designated above as E_6, with heavy covering. In view of these circumstances the positive pole was connected to the electrode, and the negative pole to the work, reversing the usual practice. When weld N° 1 had been made the weld-metal was hammered from underneath to eliminate any irregularities and surface defects due to contact with air during the deposition (in spite of the presence of the copper wire), and a symmetrical weld N° 2 was then made by overhead welding from underneath along the whole of the joint.

The remaining welds were then carried out both above and below the plate by two welders working simultaneously, their progress bein so regulated that they always kept in practically the same vertical plane. The metal was deposited by waving the electrode from right to left and from left to right so as to obtain a stratification perpendicular to the axis of the joint instead of parallel to the joint, and in this way the effect of contraction was considerably reduced.

The weld was tested after completion by two methods. In the first place the wastage left on each side of the joint was welded in the same way and at the same time as the joint itself, and specimens for the ordinary tests were taken therefrom. The mechanical tests carried out on these specimens gave the following results:

Breaking stress 61.5 kg per sq. mm.
Angle of folding without cracking 118°.[1]
ρ (U. F.) = 7.6.

Secondly, an examination of the weld itself by X-rays was made along its whole length with the object of detecting, and if necessary of eliminating, any local defects. The apparatus which we possess for radiographical tests is that made by Phyllips. It enables a tension of 180 KV to be obtained between anode and cathode, and gives satisfactory radiographs through a thickness of up to 90 mm of steel. One of the positives obtained in the study of the plate in question is reproduced here. The white circles which may be seen in this reproduction serve as reference marks for re-applying the radiograph onto the plate and identifying the position of any defect. It will be noticed that in order to fix this position in space it is necessary to have two radiographs obtained by pencils of rays along different axes.

The second example which will be given is that of a weld made from side to side on plates appreciably thicker than those referred to above, with the following mechanical characteristics.

Breaking stress 27.8 kg per sq. mm.
Elongation 49.6 %.
ρ (Mesnager) = 14.

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[1] The test was discontinued when the elongation on the tension fibre had reached the minimum fixed by the specification.

The thickness was up to 55 mm. Plates of this thickness would probably not be used in a framed structure, but the observations which follow may also be of interest in reference to thinner plates, such, for instance, of from 25 to 30 mm.

Before the execution of the welds was actually undertaken, experimental studies were carried out on pieces cut from the plates. These measured 600×300 mm and were welded from side to side.

In view of the thickness, the section of bevelling adopted was that of two U's connected at the base (Fig. 7). The electrode used was the same as in the preceding case. The succession of runs and the amperage and tension of the current were regulated at the beginning according to the following table.

Diameter of electrodes	Sequence of runs	Amperes	Volts
3.25	1	80	24—26
4	2, 3, 4, 5	180	24—26
5	6 to 17	230—240	20—24
6.4	18 to 29	320—350	20—24

Before starting the first run a band of copper was placed in the lower half of the joint. All the runs were made horizontally, the piece being turned over each time as required. Between weld N° 3 and weld N° 4 chiselling was performed on N° 1 so to clean the surface of the latter, which, notwithstanding the presence of the copper, had been executed in contact with the air. In this way weld N° 4 was begun only on a perfectly clean surface.

In spite of this precaution, a comparison of the mechanical tests carried out on specimens taken from the surface of the joint with those on specimens taken from the middle portion (and, therefore, containing run N° 1) showed appre-

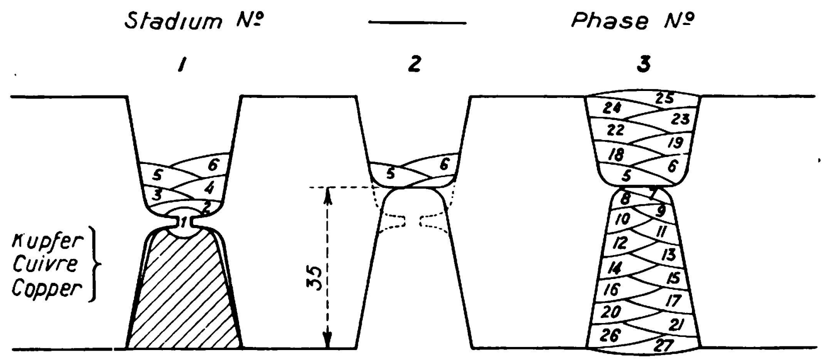

Fig. 7.

ciable differences in ductility as between the surface and the middle of the weld. A slightly different procedure was therefore adopted:

Runs N^os 1 to 6 (inclusive) were carried out without previous chiselling; and all the metal belonging to runs 1 and 4 was then removed, including the parent metal in the neighbourhood of the constricted portion as shown in the sketch. (Fig. 7.) The deposition of the runs from N° 7 onwards followed, and the work then underwent an annealing operation at 640° C for two hours and fifteen minutes (being one hour for each 25 mm of thickness).

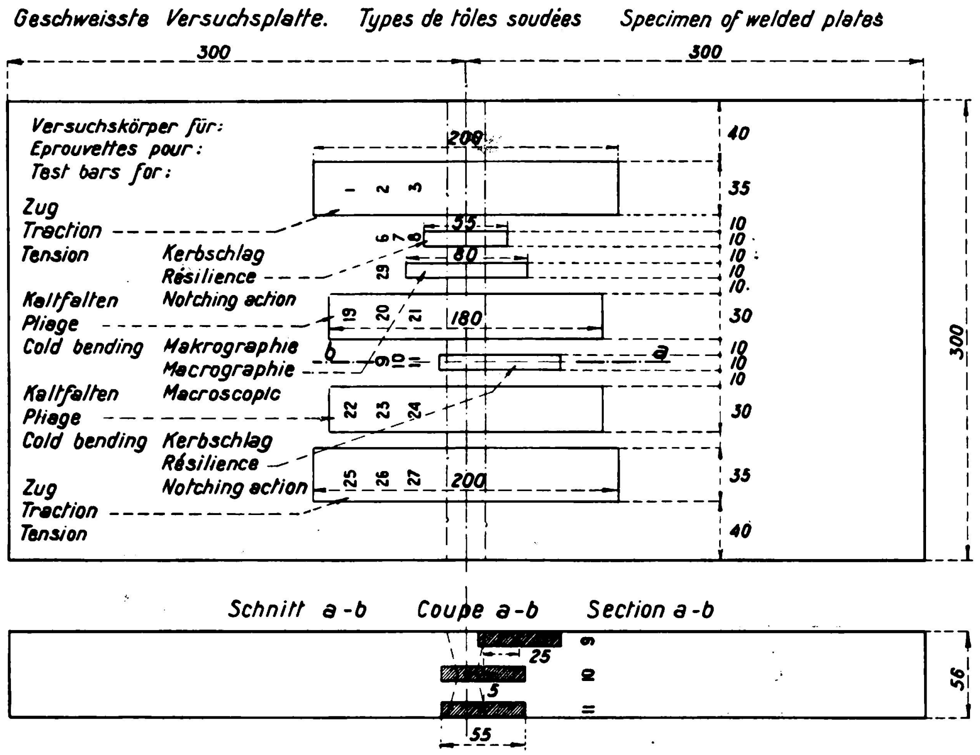

Fig. 8.

Subsequently tensile and resilience specimens were cut out, some from the surface of the piece, others from the middle of its thickness. Fig. 8 shows the distribution of these various specimens. The method gave completely satisfying results as shown in the following table.

Tension						Folding			Resilience		
Mark	Dimensions of specimens in mm	Section sq. mm	Breaking stress total	Breaking stress per sq. mm	Breaking stress average	Mark	Angle of folding	% elongation on extreme fibre in 20 mm length	Mark	ρ Mesnager	Average
1	19.8 × 13.6	270	12800	47.4					$7 F_1$	15.4	
									$7 F_2$	12.4	14.4
3	18.6 × 13.6	254	12100	47.6		20	130°	38	$7 F_3$	15.4	
					47.9						
25	19.5 × 13.6	266	12800	48.1		23	107°	36	$7 F_4$	14	
									$7 F_5$	14	14
27	19.8 × 13.7	272	13300	48.8					$7 F_6$	14	

Examination with X-rays did not reveal any appreciable defect. A reproduction is given of one of the radiographs taken in the course of these tests.

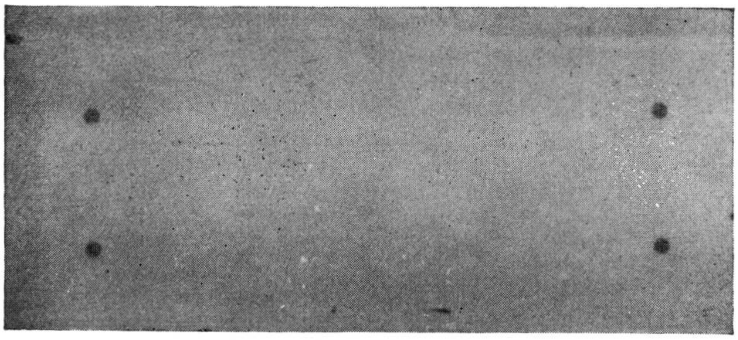

Fig. 9.

X-ray photograph of a butt weld joining two 20 mm plates (pp. 25—27).

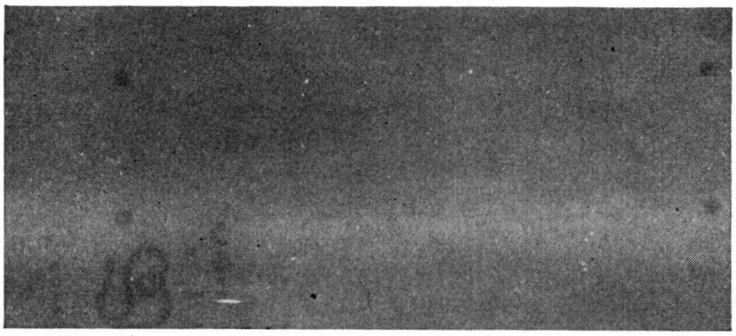

Fig. 10.

X-ray photograph of a butt weld joining two 55 mm plates (pp. 27—31). In every case the weld lies between the longer sides of the rectangle outlined by the four black dots.

The verification stamp of the Veritas Bureau is shown in the lefthand bottom corner of the second X-ray plate.

The different shading of the two X-ray plates is due to the various thicknesses.

5) *Conclusions.*

Experience obtained in the application of arc welding to a great variety of jobs is held to justify the assertion that, given a good system of supervising the materials and the methods of execution, this method of jointing affords a degree of security equal to that obtained by other methods of construction such as riveting or reinforced concrete. One reservation must, however, be made: the tests hitherto carried out are confined to statical tests or impact tests, and they ought to be complemented by fatigue tests under variable loading. We have now added to our laboratory an Amsler pulsator which allows tests of this kind to be made, but so far have carried out only a limited number of them.

Radiographical examination can be used to some extent to supplement the fatigue test as it serves to reveal local defects such as air bubbles or enclosed impurities, which, while having only a small influence on the resistance to static loading, might be the cause of premature breakage under alternating loads. Its use is, therefore advisable whenever possible, but — especially in the case of structural steel work — is difficult to generalise. The apparatus required is relatively heavy and bulky, and elaborate precautions have to be taken to protect the operators from the effects of the secondary rays. Moreover, as a further consequence of these, there is apt to be a lack of definition in radiographs of pieces made up of different thicknesses of plate, and with these rays it is almost impossible to radiograph a connection of crossed pieces. This can be done by the use of γ rays, but the cost of installation and the dangers of these rays to the personnel render it at present impossible to apply them in industry.

It has not been deemed appropriate to refer here to the researches (not numerous) which we have made on the subject of contraction. The object of these was not to determine the residual stresses caused by contraction, but merely to record the changes in dimensions and shapes which contraction might cause in the members of the framework of a ship and to determine how such effects might be eliminated in advance. With this object in view, we have confined ourselves to recording the total deformations after complete cooling, and it is not possible, therefore, to evaluate the residual stresses with any certainty.

Summary.

It is easily possible to have a controlling station in every welding workshop in such a way as to establish a priori the necessary safety and guarantee. For certain cases the supervision can be complemented by X-ray investigations, although it seems that the X-ray method cannot be applied throughout.

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