HOW DOES A WELDING ELECTRODE FUSE?

By J. Sack.

If an arc-welder is asked what he thinks of two particular welding electrodes, he will usually answer that one welds better than the other. The ease or difficulty of welding is closely associated with the conditions of fusion at the end of the electrode. In this article it is not intended to give a complete explanation of the conditions of fusion of an electrode, since many aspects of the problem are still obscure and form the subject of current research. Reference here will be limited to a few of the more common methods of investigation now being employed for studying this problem.

The fusion of a welding electrode cannot be followed in detail with unprotected eyes merely screened against glare by coloured glasses; in fact the formation of drops of metal is only just distinguishable with electrodes which melt slowly and form large drops. The drops are seen to grow, and at the moment of coming into contact with the molten metal in the pool, they become detached from the electrode and merge into the pool. The currents of gas and vapour at the arc and their dazzling light are very troublesome when observations are made with the naked eye. Observation is facilitated by projecting an enlarged image of the arc on to a projection screen, a method used by Creedy 1) in his investigations on the influence of the electromagnetic forces on drop formation. It has been found that by a considerable reduction in the welding current, the rate of drop-formation can be decreased so much that the process can be followed on the screen. On the other hand, the fusion process at these low current intensities of, say, 5 amps, differs fundamentally from that obtained at normal currents, e.g. 150 amps. In the former case the drops detach themselves from the electrode in the same way as water drips from a tap, while in the latter case the drops disappear very suddenly with a more or less loud click. This observation was made in investigations with bare electrodes.

The registration of welding conditions on a photographic film, and in particular by means of a slow-motion cine-camera, has constituted a marked advance in these investigations. If an ordinary type of film is used, the interesting part of the process, i.e. the formation and separation of the metal drops is completely masked by the arc. The Chicago Steel and Wire Co 2) has therefore made use of a special infrared sensitive film and a filter only permitting the passage of infrared (thermal) radiation. These rays are mainly emanating from the glowing metal and the incandescent gases and are able to penetrate through the cloud of vapour surrounding the arc. Pictures were taken at the rate of 60 exposures per second, which on projecting at the rate of 20 pictures per second gave a threefold slowing-down of the actual process. This method for the first time revealed photographically the transfer of material during welding and was applied to all types of bare and coated electrodes. In particular the influence of the chemical composition and the physical properties of the core and coating was studied.

A short time later Hilpert 3) in Germany also made film records of the welding arc. His apparatus constructed by Thun took 800 pictures per second and thus gave a 40-fold expansion of the actual time of welding. Precautions to cut out the intense glare were, however, omitted, with the result that the light rays from the arc strongly predominated and the drop-transfer could hardly be followed. Nevertheless these records have been useful. They showed that even with a 40-fold retardation, the arc still moved to and fro very quickly. The number of pictures per second was therefore further increased to a maximum of 4000, and the arc and the ambient region no longer registered by means of the intrinsic light but as a silhouette obtained with a more powerful source of light. With these modifications the transfer of material with bare electrodes was studied. In addition to photographic registration, the welding current, the welding voltage and as a time standard an A.C. voltage of 50 cycles were also recorded by an apparatus constructed by Thun took 800 pictures per second and thus gave a threefold slowing-down of the actual process. This method for the first time revealed photographically the transfer of material during welding and was applied to all types of bare and coated electrodes. In particular the influence of the chemical composition and the physical properties of the core and coating was studied.


1. a thread-shaped transfer, which may be com-
pared to a narrow stream of metal being poured
from the molten end of the electrode on to the
piece of work, and
2. a mushroom-shaped transfer where a very
thick drop of irregular shape moves to and fro
and seems to be reluctant to combine with the
piece of work.

The French investigator L. Bull, also took
4) cinematograph pictures of silhouettes of the
welding are. Using heavily-coated electrodes and
taking 60 to 80 pictures per second, he observed
the rapid transfer of spherical drops without any
short-circuit occurring, such as was usually
observed with bare and thinly-coated electrodes.
These pictures were taken with solar rays, a
heliostat being employed to direct a powerful ray
of sunlight on to the object being photographed.

From these methods of direct observation of
the welding process, we shall turn to the in d i r e c t
methods which have been devised for the same
purpose. First of all the method mentioned above
of registrating the welding current and voltage as
a function of the time by means of the oscillograph
should be considered. A short-circuit on drop-
transfer is indicated in the oscillogram as a voltage
drop to nearly zero and an increase of the current
to the short-circuit value. We are primarily in-
terested in the instant the short-circuit occurs and
how long this condition lasts. This information
is not only of value as regards the behaviour of the
electrodes, but principally as an indication of the
efficiency of the welding aggregate as a whole. To
this end oscillograms have been employed to
determine the intensity of the current-impulses
and the speed of adaptation of the welding set
to variations of arc length.

As already mentioned the oscillograms show
that in general two periods have to be distinguished
viz.,
1. the arc-period B, during which the arc burns, and
2. the short-circuit-period K.

If the total time of the drop-period is T, (i.e. T =
B + K), it will be interesting to know the ratio
B:T or K:T, either as a function of the time or as
an average over a certain lapse of time. A circuit
where a meter indicates and registers the ratio

Film exposures recorded by the X-ray cine-camera (cf. p. 29)
The pictures must always be read from bottom to top.
B:T was used by Flamm\(^5\), and afterwards by Bela Ronay\(^6\), who called his apparatus an “arcronograph”. It was found that with heavily-coated electrodes the ratio B:T was nearly equal to unity, in other words that the drops during transfer produce no short-circuit (K:T = 0). This result confirms the film records obtained by Bull.

Finally, reference must also be made to those methods of investigation which cannot be called either direct or indirect methods. We shall group these under the general head of model experiments, as a model is made of that part of the welding process which it is desired to study in greater detail.

A typical example of this class is given by the experiments of Flamm\(^7\), who studied the formation and transfer of drops and the capillary forces accompanying these processes by using oil as a medium. From his observations he drew various conclusions regarding the transfer of material during welding.

The investigations of Doan and his collaborators\(^8\) also come under this head: they consisted in welding on a continuously-moving band so that successive drops were collected separately. The same applies to the experiments already described at the beginning of this article\(^1\), where the period

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\(^7\) P. Flamm: Die elektrische Lichtbogenschweissung als Kapillarvorgang. Die Schmelzschweissung 9, 105 and 162, 1930.

\(^8\) Gilbert E. Doan and J. Murray Weed: Metal disposition in electric arc welding. Electrical Engineering 51, 852, 1932.
of drop-formation was extended by employing very small currents, and the experiments of Ronay. A method has recently been developed at the Philips Laboratory to make radiographic film pictures of the transfer of material. The welding process is recorded with X-rays on a special X-ray-sensitive film; if the X-ray tube is run on a suitable voltage it is found that the core and coating of the electrode can be readily distinguished on the radiograph, the method thus being of special value with coated electrodes. But also for bare electrodes the method presents advantages, as the gas and vapour clouds surrounding the arc can be completely penetrated by the X-rays and are hence not reproduced on the film. This enhances the clearness of reproduction.

The first pictures were made with an ordinary amateur cine-camera which was reconstructed for X-ray exposures. With this unit 12½ pictures per second could be taken on an X-ray-sensitive film. Subsequent pictures were made with an X-ray cine-camera specially designed for this purpose and with which 50 pictures per second (slow-motion film) could be obtained. Fig. 10 gives a schematic representation of the drop-transfer; the reproductions shown above are parts of the film and show various stages during the drop-transfer.

PRACTICAL APPLICATIONS OF X-RAYS FOR THE EXAMINATION OF MATERIALS 1)

I.

By W. G. BURGERS.

Introduction

The successful application of X-rays to the technical examination of materials does not by any means require a fundamental theoretical knowledge of the laws of crystallography and physics, such as is essential for an exhaustive scientific investigation. X-ray methods have therefore become very useful aids for testing materials and enable valuable results to be obtained also in cases where other means of examination do not succeed. In the modern laboratory, in researches concerned with the structure of matter, an apparatus for taking X-ray diffraction patterns is nowadays as indispensable as the microscope.

It is obvious that satisfactory results cannot be expected without suitable apparatus, which comprise a high-tension generator, an X-ray tube and an X-ray camera. During recent years, X-ray diffraction apparatus have been evolved which are no more difficult to manipulate than the ordinary microscope. The adjoining picture (fig. 1) shows the apparatus employed in the Philips laboratory for registering diffraction patterns. The base of this apparatus has a diameter of 10 in., the overall height being 2.5 ft. It is run directly off the alternating-current mains.

\[\text{fig. 10. Diagrammatic sketch of drop transfer from the welding electrode to the workpiece (cross-sectional view): 1 core, 2 coating of the welding electrode, 3 sleeve, 4 drop enclosed by coating material, 5 piece of work, 6 head, 7 pool.}\]

\[\text{1) In this section we propose to discuss applications of the so-called interference method only, in which diffraction of the X-rays takes place at the atoms of the radiographed material. No consideration will be given to the absorption method by which structural flaws and other internal abnormalities of a material can be deduced from differences in the absorption of the rays.}\]