

The History of Study Group 212

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The start

In 1962, as part of its annual Autumn Meeting, the Institute of Welding organised a Symposium entitled *Physics of the Welding Arc*. This meeting, held at the Institute's headquarters in London, was very successful and attracted a number of delegates from other countries. One of those attending from Russia was Professor N.N. Rykalin of the Baikov Institute in Moscow. Rykalin suggested that it would be profitable for the International Institute of Welding to provide means for continuing the work of this conference, and with commendable speed the secretariat of IIW set up Study Group 212, which had its first meeting in November 1962. The arrangements for this group differed from that of a commission; member societies were only entitled to appoint delegates if their country was actively engaged in the study of arc physics. Also, it reported to the Executive Council rather than to the Governing Council. The curious number 212 derived from the notion that we would provide a service to Commissions II and XII. In practice relations with Commission XII have been very close, but with Commission II almost non-existent. This is not surprising, since apart from some very useful observations by Dr. Becker, the Study Group has not done much work on welding with coated electrodes.

Initially the Group was well-staffed. We had an honorary Chairman, Professor Rykalin, a Chairman, L.F. Defize, Vice Chairman J.F. Lancaster, General Secretary J.C. Needham and Technical Secretary F. Dennery. Time, and the needs of employers, eroded this organisation quite rapidly. Mr. Defize resigned in 1965, the Secretaries found other work and for most of its life the Group has survived with (until his death in 1985) Professor Rykalin as Honorary Chairman and (from 1965 to 1992) the present writer as Chairman. Professor G. den Ouden became Chairman in 1992.

For the first few years of its existence the Group organised an intermediate meeting in the spring and a second meeting during the week preceding the Annual Assembly. We were not permitted to meet during the Assembly lest the work of the Commissions be disrupted. Thus it happened that at the Delft Assembly in 1966 the Chinese delegation attended our pre-assembly meeting. During the following weekend one member of the Chinese group died under curious circumstances, there was a diplomatic incident and

the remainder of the Chinese delegation failed to attend the Assembly. Thus we were the only IIW working group to welcome a Chinese delegation for some years to come. Subsequently we have had good contributions from China and in 1980 a course on physics of welding was organised by Tianjin University.

At a later date the Study Group was permitted to meet during the Assembly itself. No untoward incidents have occurred as a result of this change.

The Lausanne colloquium

The first project undertaken by the Study Group was to prepare for a Colloquium on Physics of the Arc which was held during the 1970 Annual Assembly in Lausanne. To this end we started work on the preparation of a film of metal transfer in arc welding. This was eventually compiled by the Welding Institute at Abington, using high speed sequences contributed by several member societies, including a historic shot of workers at the Institut de Soudure making a film of stick electrode transfer before World War I using a hand-cranked camera.

The IIW film was well-received on its first presentation at Lausanne, and subsequently numbers of copies were sold, particularly in France. Marketing a film was an innovation for IIW, and its production was a considerable success for the Study Group.

The other material presented at Lausanne consisted of four interpretive reports on different aspects of welding physics. These, with the exception of the presentation on the electric arc, were not so successful. The initial intention had been to put these contributions together and to arrange for their publication. Reviewing the material after the Colloquium, it became clear that understanding of some of the basic phenomena was very inadequate. For example, although welding experts talked knowingly about the 'pinch effect' as a cause of metal transfer, a proper analysis of this effect was not available. At the time there appeared to be no advance on the calculations of E.F. Northrup, which were first presented in 1907. The case of plasma flow in the arc column was similar. Maecker had predicted the existence of such flows over twenty years earlier, but the fluid dynamics of the plasma jet had not yet been explored. Not surprisingly, in view of the lack of basic knowledge, the mechanism of metal transfer remained a mystery. So it was felt inadvisable to prepare any of the Lausanne material for publication, and the immediate endeavours were directed towards understanding the basic physics of fluid flow in welding.

Plasma flow

In fact we had already started work on plasma flow before the Lausanne meeting. This was clearly a magnetohydrodynamic phenomenon, so help was sought from

J.A. Shercliffe, who was the author of a textbook on the subject.

Professor Shercliffe attended some of our meetings and discussed the welding problem. As a result he published a paper in which the mechanics of flow due to a point source of current at the surface of a semi-infinite fluid was examined for the case where the viscosity was zero. Although this condition is unrealistic, it was a start, and the problem was then picked up by C. Sozou and his colleagues. As a consequence, during the period 1971 to 1975, the character of electromagnetically-induced flow was determined for a point source of current, for a distributed source, and for the case where the flow occurred inside a hemispheroidal container. These results make it possible to obtain a sound basic understanding of the nature of electromagnetically-induced flows. They also show that where the surface flow is directed inwardly towards the origin (i.e. the axis of the jet) it may become unstable, whereas if it is directed outwards across the surface it is stable for all values of the driving force. This conclusion is important in relation to the problem of variable penetration in stainless steel TIG welds.

The pinch effect

During the same period (the early 1970s) Professor Herlofson of the Technical University, Stockholm joined the group, and introduced us to the work of his colleagues on instabilities in liquid cylinders carrying an electric current. This work had been initiated by H. Alven, an astrophysicist, with the object of modelling certain celestial processes – the condensation of matter to form stars in the spiral arcs of galaxies being a possible example. Experiments were made with falling columns of mercury, whilst at the same time the theory of instabilities in liquid cylinders carrying an electric current was developed by Murty, an Indian physicist who worked for a period in Stockholm. Murty extended Rayleigh's analysis of capillary instabilities to the case where there are electromagnetic forces. For such conditions there is a hierarchy of unstable modes, designated by $m = 0, 1, 2$ etc. The simplest mode ($m = 0$) is the cylindrical pinch, where constrictions form at intervals along the cylinder, which eventually disperses into drops. Higher modes are promoted by a higher current density and by the presence of a longitudinal magnetic field. The theory provides a good qualitative description of the various transfer modes in GMA welding. The pinch instability dominates in the spray arc transfer mode, where drops are detached individually and projected across the arc; also in pulse-arc welding. The kink instability ($m = 1$) in which the cylinder collapses into a rotating spiral, occurs in 'rotating' welding and in the plasma-MIG process. The flute instability ($m = 2$) occurs when a longitudinal magnetic field is applied to high-current MIG; the rotating spiral disappears and instead the liquid drop at the electrode tip splits longitudinally and two drops detach simultaneously. A quantitative result is not to be expected, firstly because the Rayleigh-type analysis is an approximation that only applies to small displace-

ments, and secondly because there are many complicating factors; for example, the arc root tends to spread over the whole surface of the drop in the spray transfer mode. Nevertheless, Murty's work was felt at the time to provide a firm basis for understanding the various metal transfer modes in MIG welding, and subsequent experience has reinforced that view.

Physics of welding

The notion of producing a book on welding physics was a natural result of all this theoretical activity. Work started in 1972, but progressed rather slowly until 1979 when increased confidence in the analytical work together with an accumulation of research data made it practicable to finalise the text. We were fortunate in having A.E. Guile to write the chapter on the Electric Arc. Alan Guile is an electrical engineer who has made important contributions to knowledge about the mechanism of non-thermionic arc cathodes, as well as being a recognised expert on problems associated with switchgear arcs. Another contribution was the compilation of data on physical properties of fluids which was due to Dennery and his colleagues at Air Liquide in Paris. The first edition of the book was published in 1984 and sold well, such that the publisher asked for a second edition, which appeared in 1986. Then the Japanese members of the Study Group undertook the onerous task of translating the text, and eventually produced a Japanese edition. This was particularly appropriate because Japanese workers had made a major contribution to basic knowledge about the electric arc in welding and the behaviour of weld pools.

Change of name

As noted earlier, the Group was originally given the name 'Physics of the welding arc'. However, we very soon extended our field of study to other aspects of welding; metal transfer and weld pool behaviour for example. In 1978 therefore it was decided that the name should be changed to 'Physics of Welding' and the terms of reference were modified accordingly. There was some concern at first that the work of the Group might overlap that of some Commissions but this did not prove to be a problem. For example, the subject of variable penetration in GTA welds was of interest to Study Group 212 and also Commissions IX and XII. These Commissions were kept fully informed of the progress of our work and accepted the final report without comment.

Variable penetration in GTA welds

This project was undertaken with the object of producing recommendations for the avoidance of variable penetration. It was carried out in co-operation with VAMAS and with the National Physical Laboratory (UK). The final report was approved by the Group and recommended for publication, and this is now scheduled for late 1993.

It is interesting to recall that Professor Ishizaki predicted that surface tension gradients would cause circulation in the weld pool, and demonstrated this effect by melting a pool of paraffin wax with a soldering iron. The circulation was made visible by particles of aluminium. A film of this experiment was shown at the 1966 meeting in Delft, and caused a great deal of interest at the time. However, later work by Andersson appeared to show that in the case of hot liquid mercury such flow would only occur in vacuum and was inhibited by the presence of an oxide layer on the metal surface. Therefore we failed to pursue the subject until Heiple and Roper raised the possibility of surface-active agents reversing the direction of flow. In more recent years the tide has turned again, and it is generally thought that the effect of surface-active agents is to nullify surface tension induced flow and produce a weld pool in which any flow is irregular and confused. Thus, the shape of the weld pool is little affected by flow and is more or less semi-circular in section.

Other recent work

Three other subjects have been of interest in recent years: spatter, undercut and precipitation in the weld pool. The spatter problem exists because calculations predict that the interface temperature when a drop strikes the metal surface should be below the melting point, therefore it should not stick. A proportion of spatter does stick, however, and Professor Rehfeldt has shown that such spatter is indeed fused to the metal surface. This condition can only be accounted for if there is flow in the spatter drop, such that its effective conductivity is high. It is possible that such flow could be induced by surface tension gradients associated with temperature gradients in the drop.

Interest in undercut arose because tests on the surface melting of cast iron disclosed that the effect of surface active elements in reducing surface energy was much greater in solid iron than in liquid iron; thus the liquid weld pool might under some circumstances tend to draw away from the solid. No progress has been made here.

It was suggested some time ago that the micron-sized oxide precipitates seen in steel weld metal may form in the weld pool and that they could be removed by increased circulation. However, the size of the oxide particles is such that they are more likely to be precipitated either in the more stagnant part of the boundary layer of the pool, or in the solidified metal.

Documents and discussions

It is inevitable that most of the time at meetings of the Group is spent in the presentation and discussion of research papers. The average number of documents per year (obtained for example by dividing the current document number, 830, by 31) is about 27, and allowing 7 for minutes and the like leaves a mean figure of 20. This

number has not changed very much over the years, which is rather surprising in view of the general increase in research activity. It has varied greatly from year to year as has the attendance at Annual Assembly meetings: for example at the Kyoto Assembly we had over fifty participants (admittedly students for the most part), whereas in Tel Aviv there were just three, including the chairman. The average number of attendances has been half-way between these two extremes, about twenty-five. Again there has not been much change but my general impression is that there has been a slight increase in recent years. Intermediate meetings, on the other hand, which were well supported at one time, have in the last few years either been poorly attended or have not been held.

Conclusions

There is no doubt that it was correct to widen the terms of reference of the Study Group and it may well be possible to continue this trend in the future. The Group has always benefited from the interest that senior figures in IIW have shown in its work, and from support of the Secretariat in publishing ventures such as *Physics of Welding*. On the negative side the current lack of interest in the intermediate meeting poses a problem. Lack of funds is an obvious cause and this situation is likely to continue at least in the immediate future. However, the main activity of the Group has always centred around the Annual Assembly meeting, and provided that there is no undue competition (such as that provided by all-day meetings of Commission XII) there is good reason to expect continued and possibly increased support.