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Why We Need Non-Destructive Testing of Welded Constructions

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Phil. Trans. R. Soc. Lond. A 1979 **292**, 201-206
doi: 10.1098/rsta.1979.0054

Phil. Trans. R. Soc. Lond. A. **292**, 201–206 (1979)
Printed in Great Britain

Why we need non-destructive testing of welded constructions

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[Plates 1 and 2]

Most process plant and a great deal of structural steelwork for the nuclear, petrochemical, power generation and gas industries is fabricated with the use of fusion welding. Imperfections occur in such welds, due to problems with materials, procedures and techniques, and non-destructive testing is employed to detect such imperfections. The two principal reasons for the use of non-destructive testing are (*a*) to monitor and control the quality of weld workmanship and (*b*) to assess fitness for purpose and to ensure that failure will not occur from a weld fault within the design life of the fabrication. In both cases it is necessary to be able to detect, identify and measure weld defects. The results are compared with quality control levels of defect acceptance in the former circumstance and used in fracture mechanics analyses in the latter to ensure that defects present are not critical. A further important application of non-destructive testing is to assess deterioration of plant and structures in service or undergoing maintenance.

Defects in welds

It may be useful to begin by illustrating some of the typical faults which can occur in welds.

Figure 1, plate 1, shows a solidification crack caused by a combination of compositional effects and high thermally induced tensile strain. Such defects are exacerbated by unsuitable welding techniques. Figure 2 is a radiograph of linear slag inclusions associated with slag entrapment in a multirun weld due to poor weld head profile. A single slag line in cross section is illustrated in figure 3. Figure 4 is of hydrogen cracking in the hardened heat affected zone of a ferritic steel weld. Hydrogen diffusion from contaminated weld metal embrittles this zone to such an extent that only a low level of strain results in fracture. Lamellar tearing illustrated in figure 5, plate 2, is a form of cracking in steel associated with the presence of narrow zones of non-metallic inclusions. These have the effect of reducing short transverse ductility to such an extent that thermally induced strain in heavy joints cannot be accommodated and fracture results. Figure 6 illustrates clusters of porosity in some runs of a multirun weld. Such porosity is due to gas, usually associated with contamination of metal surfaces or of welding consumables. Figure 7 shows lack of fusion on the sidewall of a V butt weld due to the use of an unsuitable welding technique. While this particular illustration shows associated slag, such defects frequently occur as true linear flaws with no slag or void in association with them.

The need for non-destructive testing

Why do we need to detect and identify such defects and having found them what else do we need to know about them?

There are two principal reasons why we need to use non-destructive testing for the location of internal flaws. Both are of importance, but because of lack of knowledge of the effects of defects on weld performance in the past, the two reasons have often tended to become confused.

The first reason is that the presence of certain types of defect is indicative of inadequate control of material or welding procedure selection or poor welder workmanship. Defects detected at an early stage in fabrication can lead to immediate corrective action and thus avoid the deterioration of weld quality to such an extent that the welds do not satisfy the requirements of the code of construction specified by the customer.

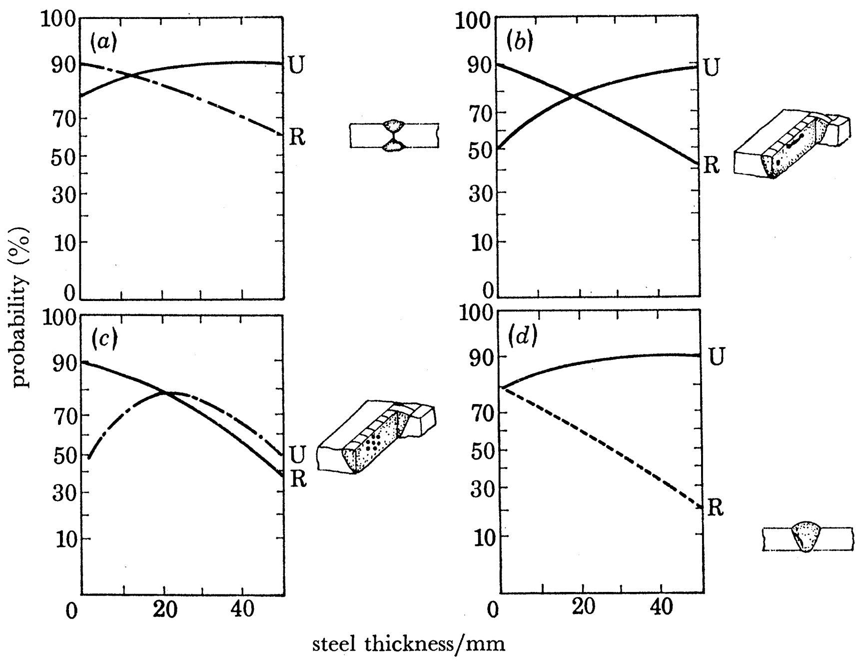

FIGURE 8. Probability of detection of defects by ultrasonic and radiographic methods versus steel plate thickness: (*a*) incomplete penetration; (*b*) linear slag inclusion; (*c*) porosity cluster; (*d*) crack parallel to sidewall.

The second reason is that defects of certain types and sizes will impair the engineering function or fitness for purpose of the structure. A complete analysis of the significance of defects implies knowledge of defect type, position, orientation and size in relation to weld geometry, knowledge of failure modes and the material properties which are relevant to such mechanisms of failure and a knowledge of the stresses and temperatures which may arise in the defective region. We thus need to invoke the science of fracture mechanics.

Research on the significance of weld defects has indicated quite clearly that the important defects to detect, identify and size are planar flaws–cracks, lack of fusion and incomplete penetration and that the three-dimensional defects such as slag inclusions and porosity are of relatively minor significance and can often be ignored. Furthermore, the work has concluded that in most situations the important dimension of a buried defect is its height in the through-thickness direction rather than its length.

These conclusions have an important influence on the selection of non-destructive testing methods for weld examination.

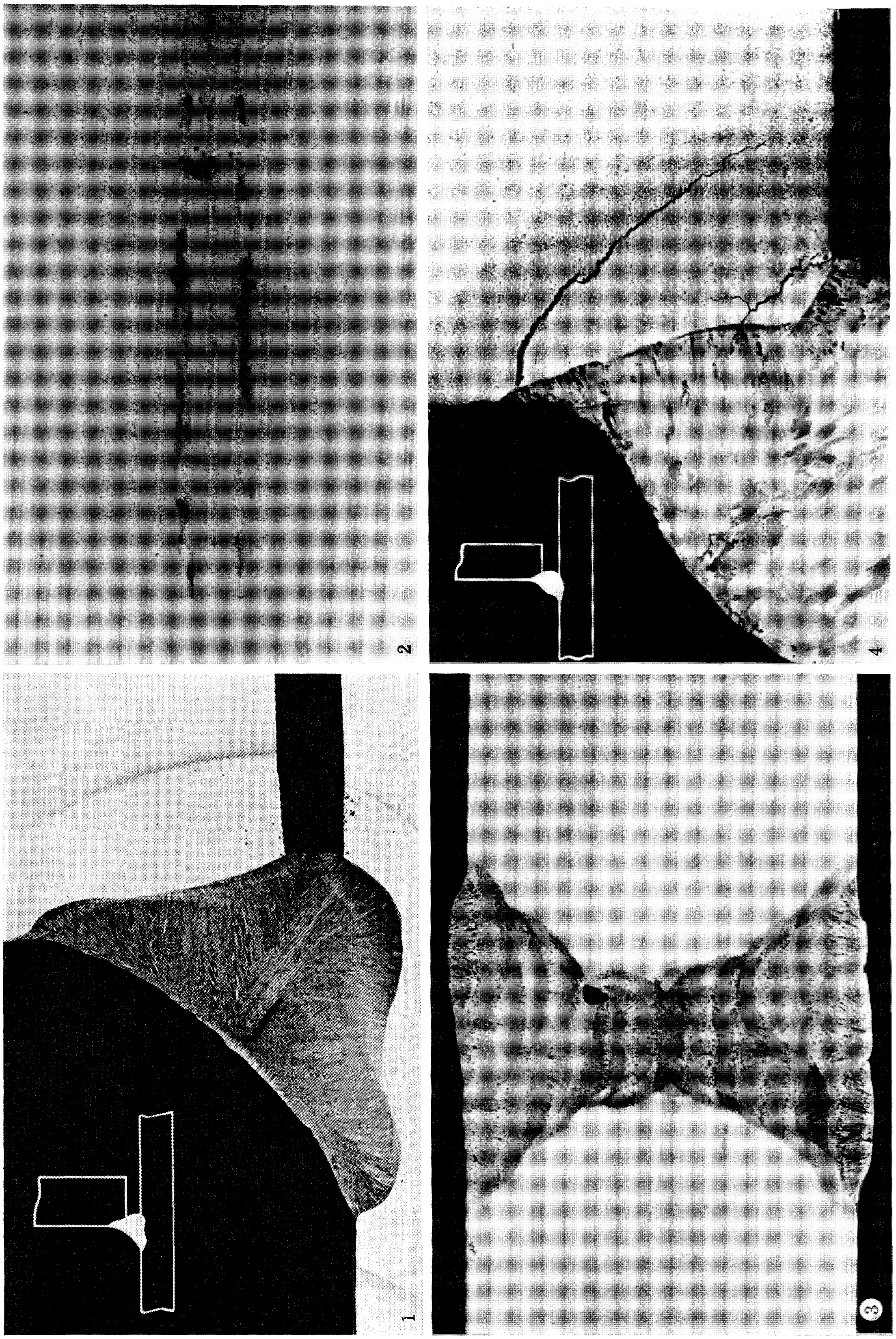

FIGURE 1. Solidification crack (cross section).
FIGURE 2. Linear slag inclusions (radiograph).
FIGURE 3. Slag inclusion (cross section).
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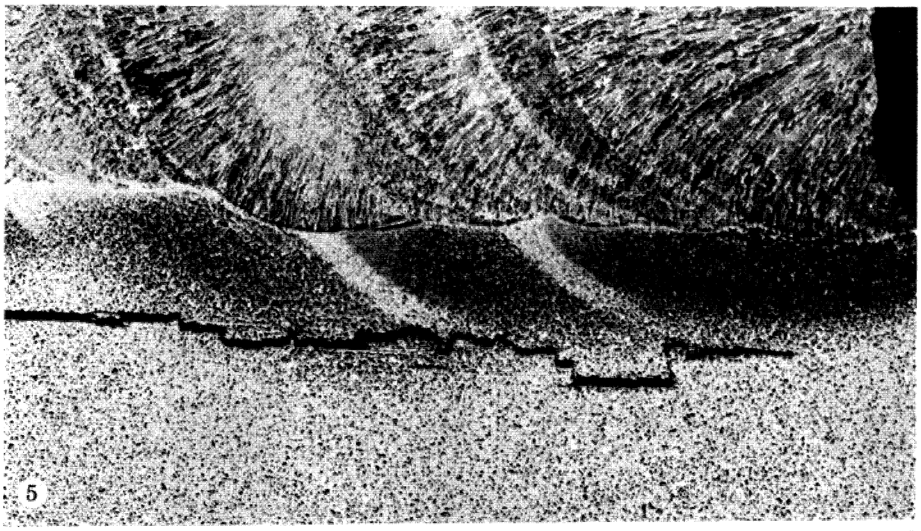

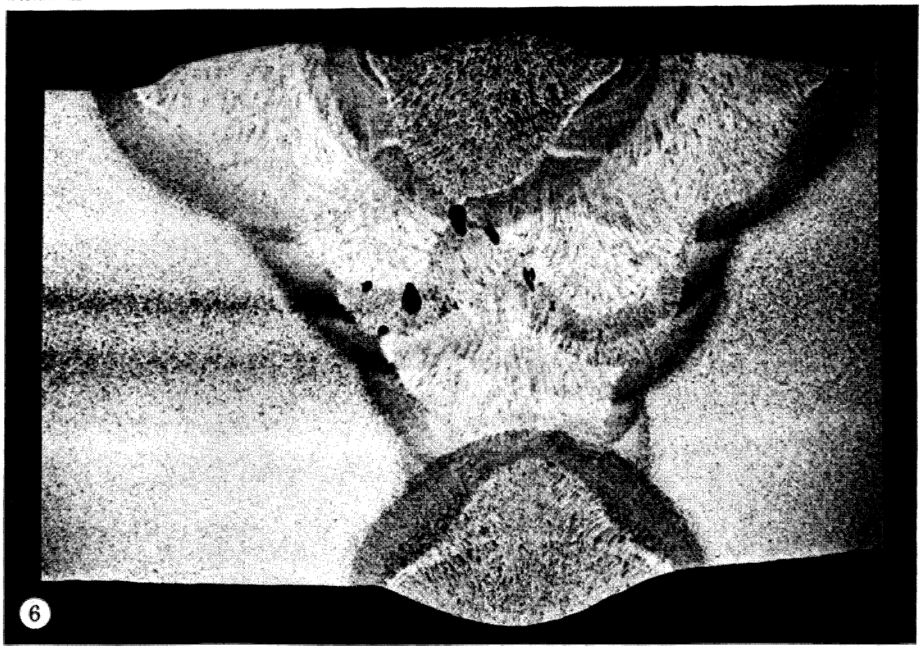

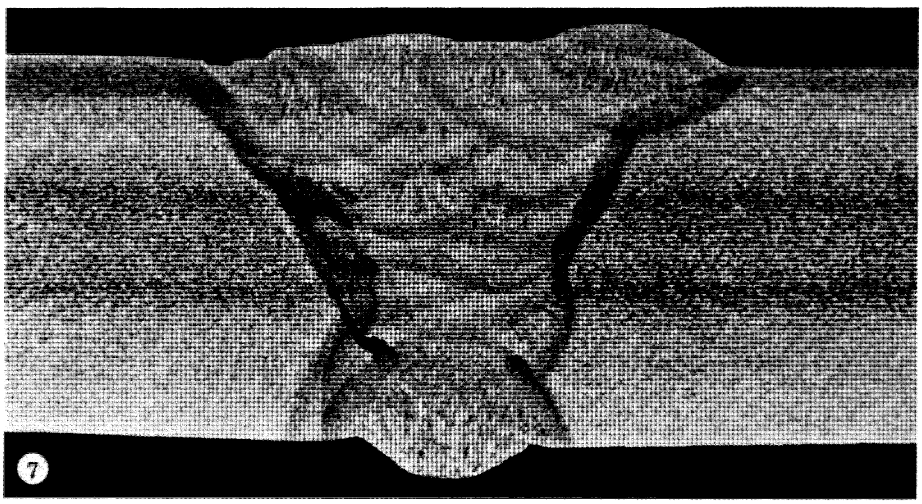

FIGURE 5. Lamellar tearing (cross section).

FIGURE 6 Porosity (cross section).

FIGURE 7. Lack of sidewall (cross section).

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The capabilities of ultrasonic and radiographic methods

Let us consider in general terms the capabilities of the two methods under discussion. The curves in figure 8 reported by Meyer (1975) are probability plots of detectability of defects against thickness in steel butt welds in plate up to 50 mm thick. They should only be considered as a general guide.

The principal conclusions of this work are as follows (and we are concerned with detectability, not estimation of size):

(1) Radiography becomes progressively less effective as thickness increases. If we extrapolate to greater thicknesses than those reported, it completely fails to detect typical volumetric defects.

(2) Ultrasonics becomes progressively more effective with increasing thickness with the exception of clusters of porosity.

When we consider the comparative ability of the two methods for measuring size we must conclude that radiography can reasonably determine the extent of porosity and the length of slag and that it has some prospect of determining the length of favourably orientated planar flaws, always provided that thicknesses are not so great as to preclude the achievement of sufficient test sensitivity. Radiography as conventionally practised offers no hope of measuring planar flaws in the direction which fracture mechanics tell us is important: the through-thickness dimension.

Ultrasound, on the other hand, not only offers the prospect of detection of the more important planar defects, it can also measure them in this important direction under favourable conditions.

We can conclude that if we are concerned with fitness for purpose, we must move away from radiography to ultrasonics and this trend has been proceeding for some years. However, the trend has not been without its problems since ultrasonics is capable of detecting insignificant flaws which would in the past have escaped detection by radiography. This has led to the unnecessary rejection and repair of work which would have been fit for service.

Before pursuing the problems in ultrasonics and the need for further developments in weld testing, it will be useful to make reference to the historical development of acceptance levels required by codes and standards.

Acceptance levels

When industrial radiography was first applied to welds, a fairly strict approach to defects which could be readily detected by this method was adopted. The expression 'radiographically sound' was used and some authorities insisted that for their purposes welds should be repaired if *any* indication appeared on radiographs. This resulted in the unnecessary removal of many harmless defects. Rewelding often introduced defects of a planar nature which subsequent radiography was unable to detect. The inevitable result was that many structures went into service with undetected planar defects. In most cases the material in which the defects lay had sufficient notch toughness to sustain such flaws without service failure, or designs were so inherently conservative that defects did not matter. The instances of disaster are thus fortunately few.

With the widespread use of radiography, it was eventually realized that it would be sensible to set acceptance criteria for some of the more common indications since otherwise a high proportion of all welds would require expensive repairs. This led to the adoption of codes and standards which described or illustrated acceptable defects such as the porosity chart taken from a draft Standard and shown in figure 9. This is an example of the arbitrary approach to weld defect acceptance which has been employed for many years and which, while it has its critics, also has had beneficial effects. Thus if fabricator and inspector have to agree on the standard required and this standard, although arbitrary, is realistic in relation to achievable quality, frequent rejection and repair is avoided. Such standards are thus valuable for monitoring the quality of workmanship in welding.

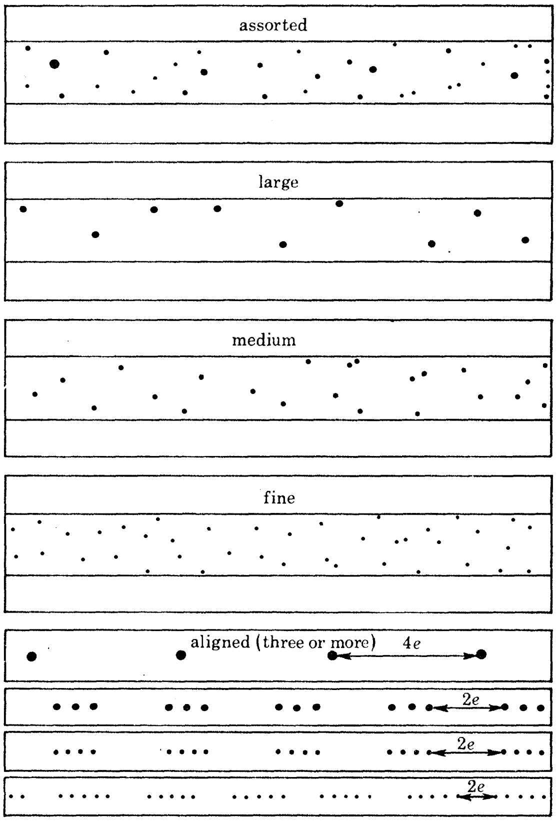

FIGURE 9. Typical porosity chart for welds in plate over 6.4 mm up to 12.7 mm thick.

The inherent conservatism of the arbitrary approach leads to the requirement in most engineering application standards that no cracks or planar defects are acceptable. Because radiography could determine the length of slag inclusions, these arbitrary standards also set limits on acceptable defect lengths, usually related to material thicknesses. This emphasis on the importance of length of slag and the unacceptability of cracks unfortunately carried on when ultrasonics began to take over from radiography and the acceptance codes were slow to take this into account.

ULTRASONICS FOR WELD TESTING

British experimentation with ultrasonics for weld testing began in the late 1940s but the first definitive paper on the subject was that produced by Sproule (1959). This was followed by a select conference in which Abrahams (1963) presented the concept of defect measurement by careful calibration of shear wave beam profile and probe movement with the use of manual pulse–echo techniques and which was formalized in a handbook by the Institute of Welding (1965). This, of course, is now widely practised in Britain as the 20 dB drop method, and is largely the reason why British trained manual ultrasonic weld testers are the envy of the non-destructive testing world and why British manual practices are so far ahead of practices described, for example, in the widely used American Codes.

The probe movement technique with the use of manual scanning is not the only technique for defect measurement and many methods rely on reflected signal amplitude compared with the amplitude of a signal from a known calibrated reflector. These techniques are normally the most suitable for mechanized systems where, with suitable sensitivity settings and signal gating systems, only signals above a certain amplitude are recorded as weld defects. The problem with this approach is that small but favourably orientated defects can give stronger signals than larger but unfavourably orientated defects.

Problems in manual testing

The deficiencies of manual scanning are often emphasized and there is no doubt that there is a tendency for some operators to exaggerate the importance of defects of minor cross section, causing unnecessary repairs and delays to production. They may also fail to record defects that exceed allowable sizes, although the evidence for this is meagre. Both types of error are costly.

Despite these deficiencies, I am convinced that mechanized methods will only supersede manual techniques for limited applications. This does not mean that we should be satisfied with present practices. It is one thing to be able to carry out proficient testing under favourable workshop conditions and quite another to achieve a good and consistent performance under poor environmental conditions. Much attention has been paid to operator training, and the assessment of his competence and work is under way with a view to a more precise definition of the technical problems which influence accuracy, but the proper scientific analysis of the effect of external factors on an operators accuracy has been largely ignored. We are well aware that such studies have been conducted for other types of worker. It is time we started work on the influence of boredom, lack of personal comfort, the presence of danger, personal problems and other stress conditions on the performance of the skilled ultrasonic operator.

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Discussion

J. M. Coffey (*N.D.T. Applications Centre, C.E.G.B., Manchester M23 9LL, U.K.*). I was intrigued when Mr Young showed simple graphs showing the probabilities of detecting cracks, porosity and other weld defects by ultrasonics. Two points need making. First, Mr Young did not

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explain what he meant by 'detected'. By turning up the amplification of an ultrasonic detector, it is usually possible to see at least some signs of even a poorly reflecting defect, but how large does the echo have to be before we consider it 'detected'? Secondly, the echo strength from a defect is sensitive to defect shape, size, angle of incidence and other variables. Mr Young's graphs, by contrast, imply that the probability of detecting a defect is a function mainly of the *thickness* of the component. In view of the complicated dependence I have just mentioned, I personally think these graphs are misleading and naïve. Nevertheless, I do agree with Mr Young about the superiority of ultrasonics for detecting planar defects.

R. F. Lumb (*British Gas Corporation, Newcastle on Tyne, NE*99 1*LH, U.K.*). Mr Young quite rightly emphasized the problems of manual ultrasonic testing, i.e. the skilled nature of the work which has often been done in hostile environments and unsociable hours. I remember reading of some work done at Glasgow University, some 5 or 6 years ago now which measured the performance of people undertaking work requiring some skill and manual dexterity when done under adverse conditions. It appeared that there was a measurable reduction in competence when the ambient temperature fell below 12 °C.

In view of the large representation from the medical fraternity at this meeting, could I ask whether there is any more recent work available dealing with the effect of the environment?

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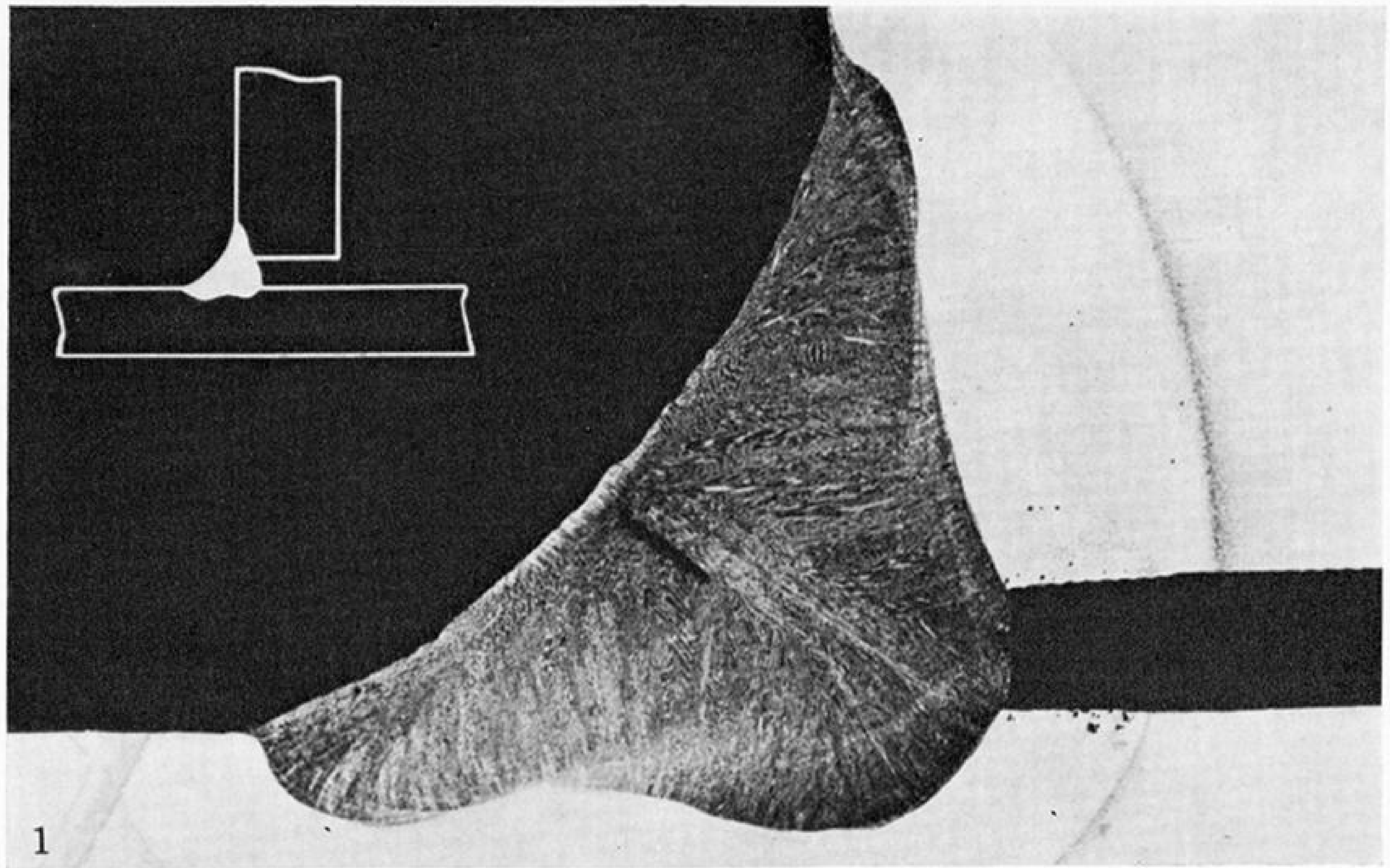

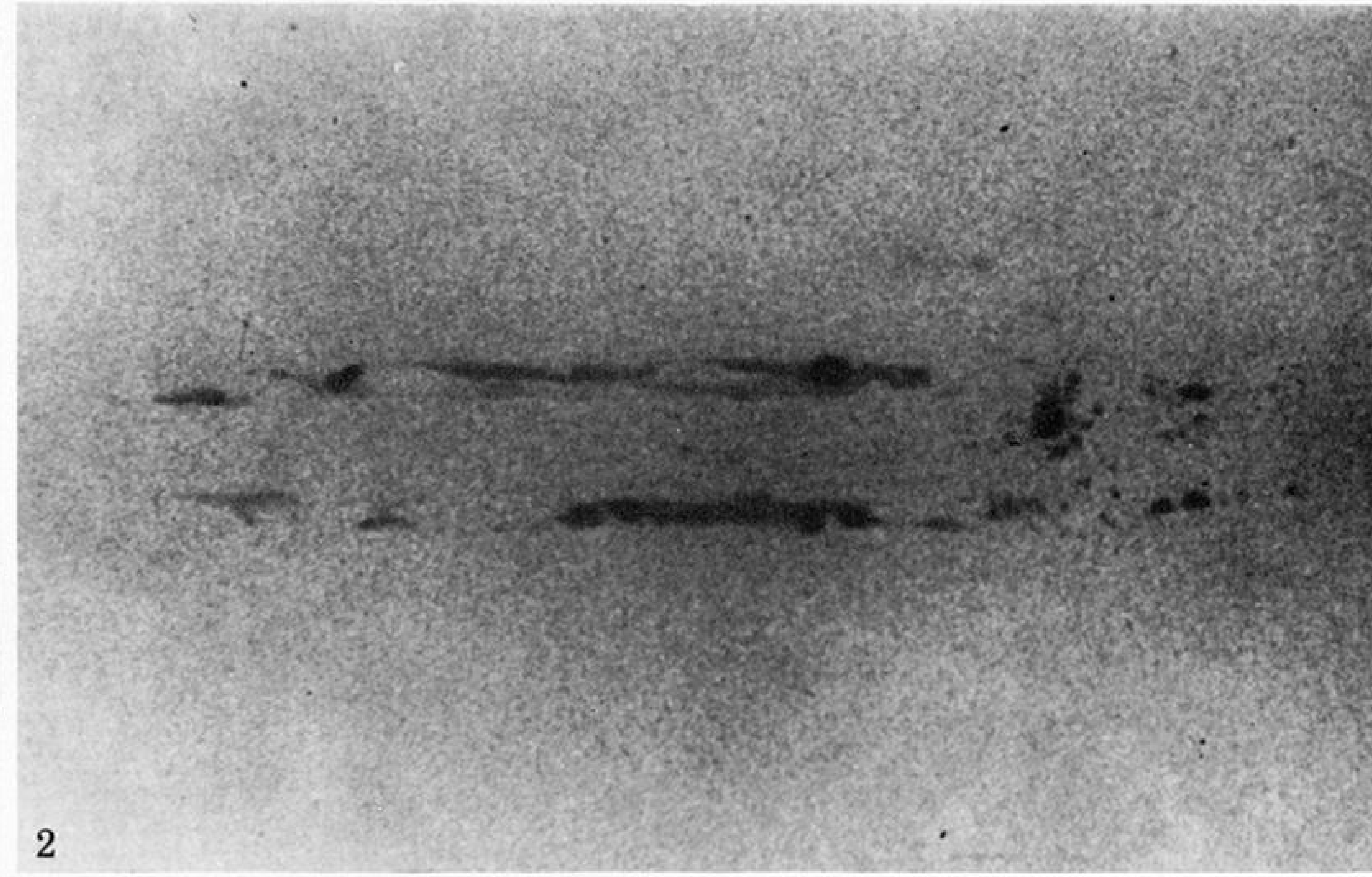

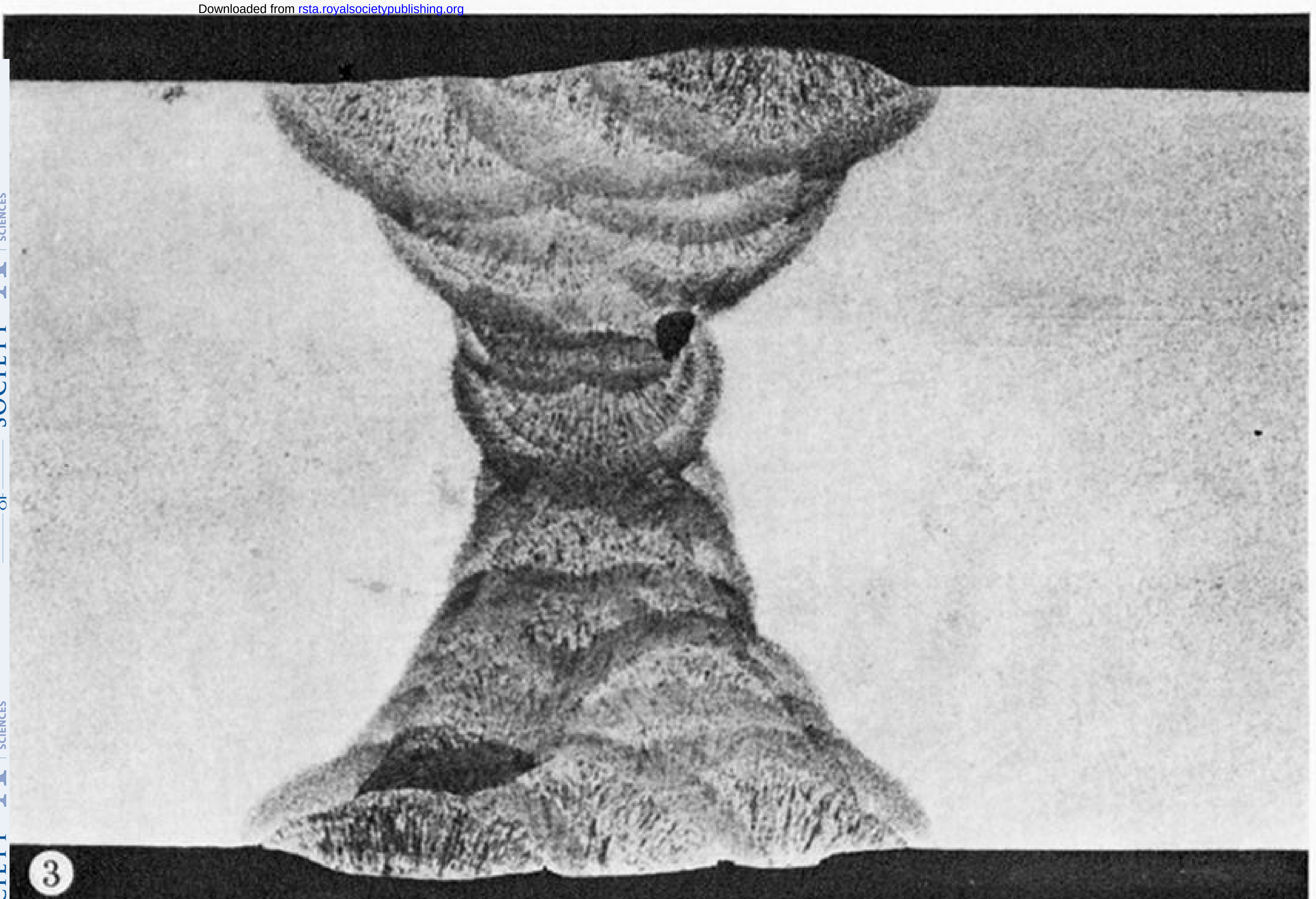

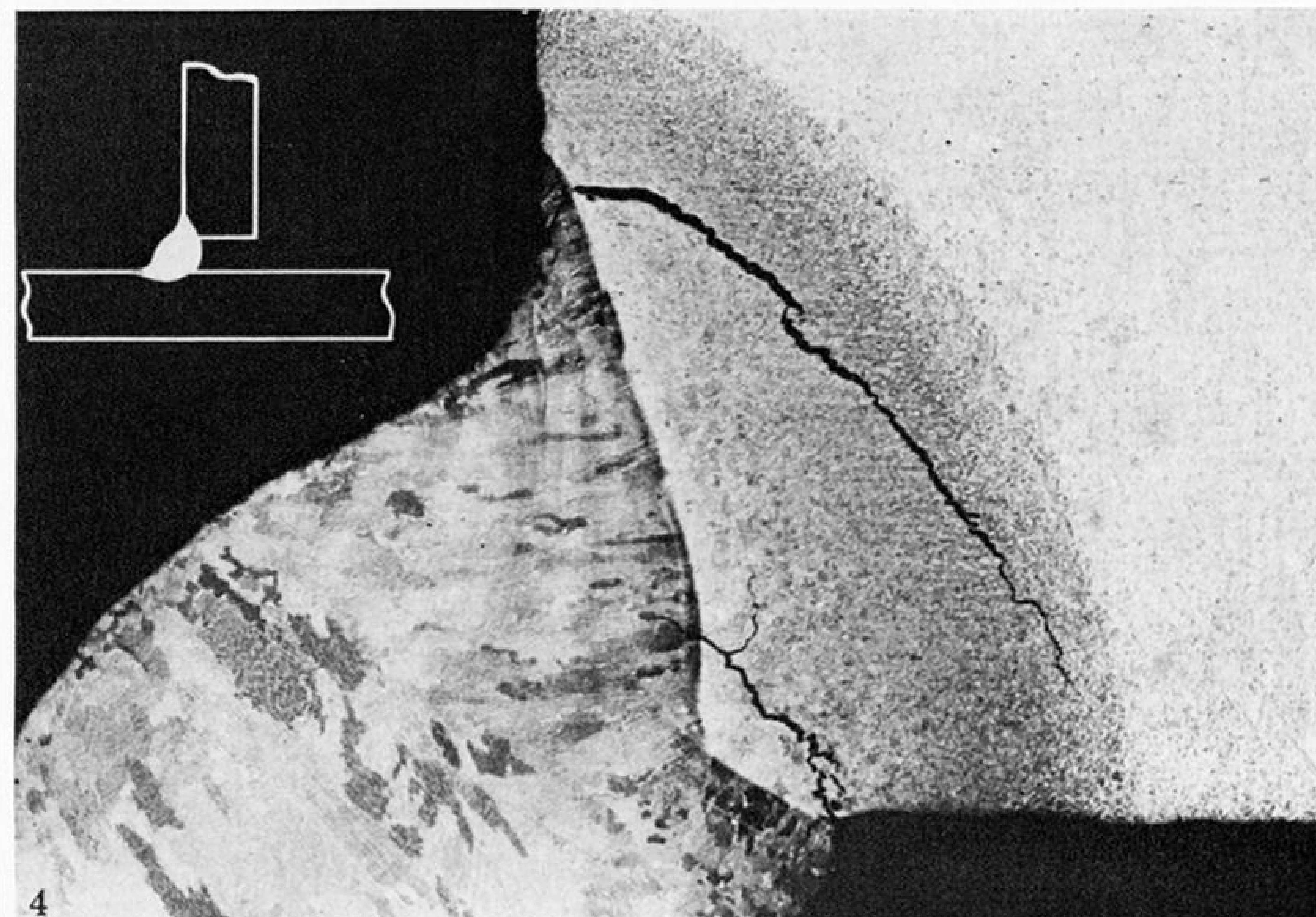

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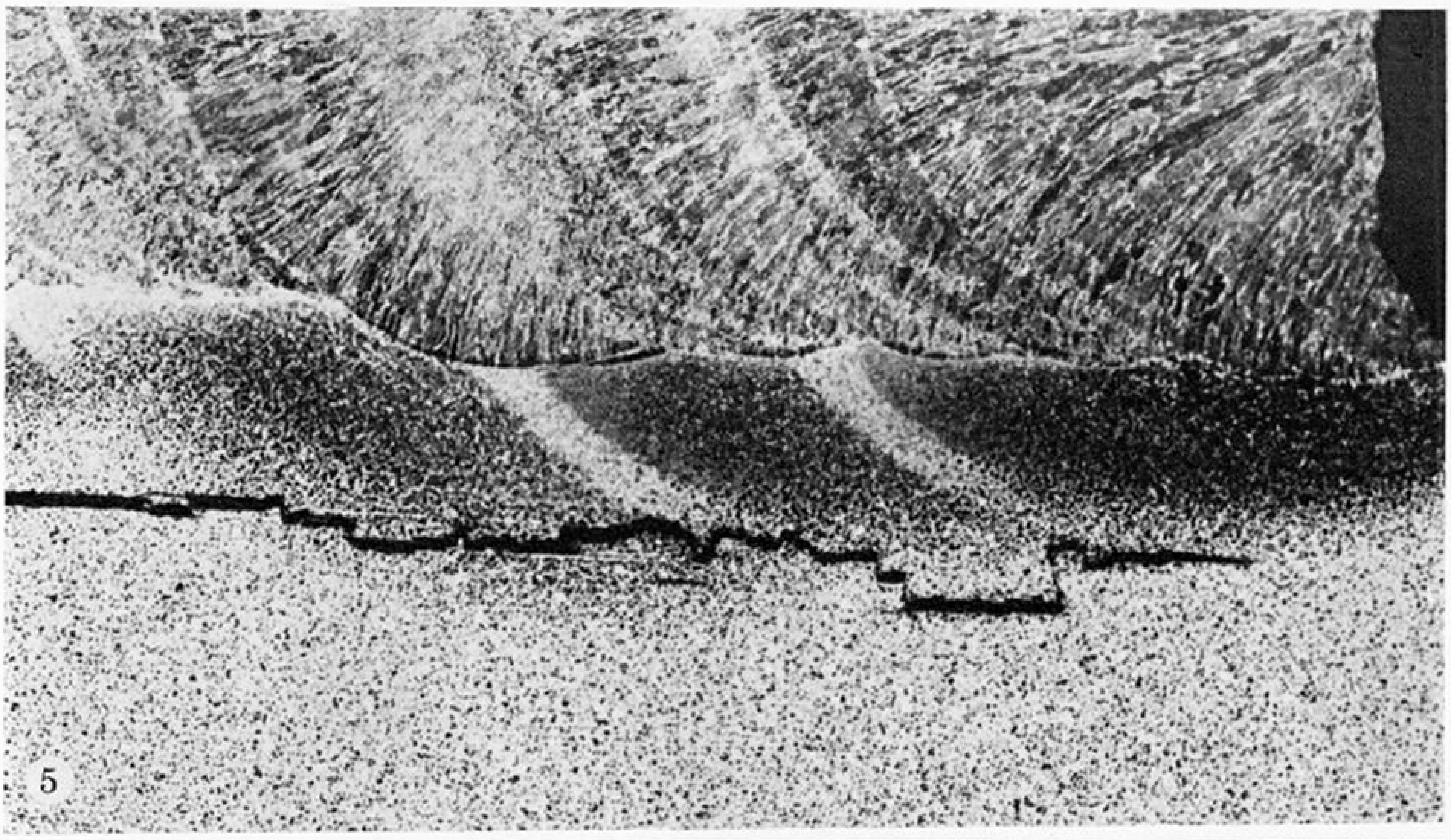

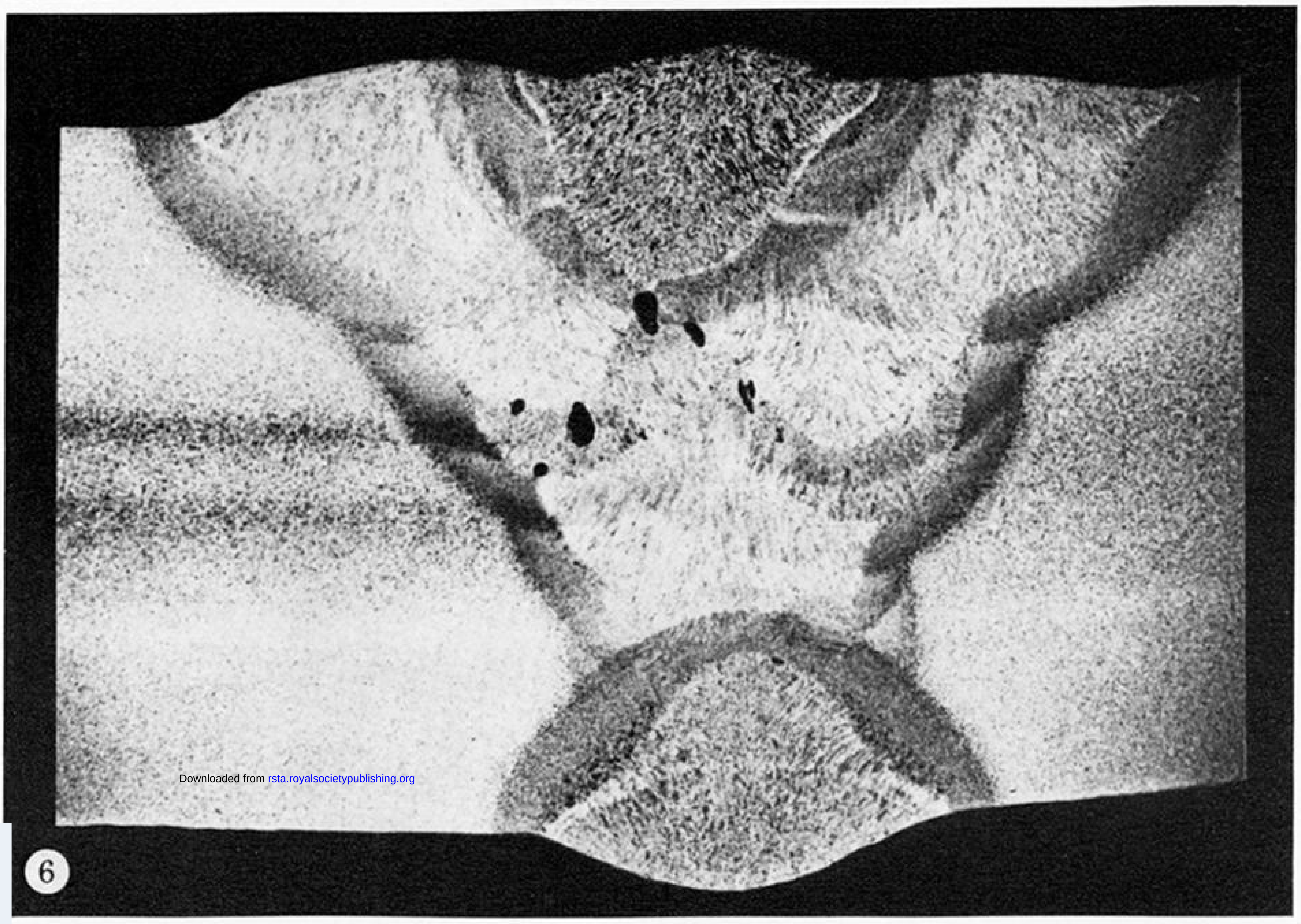

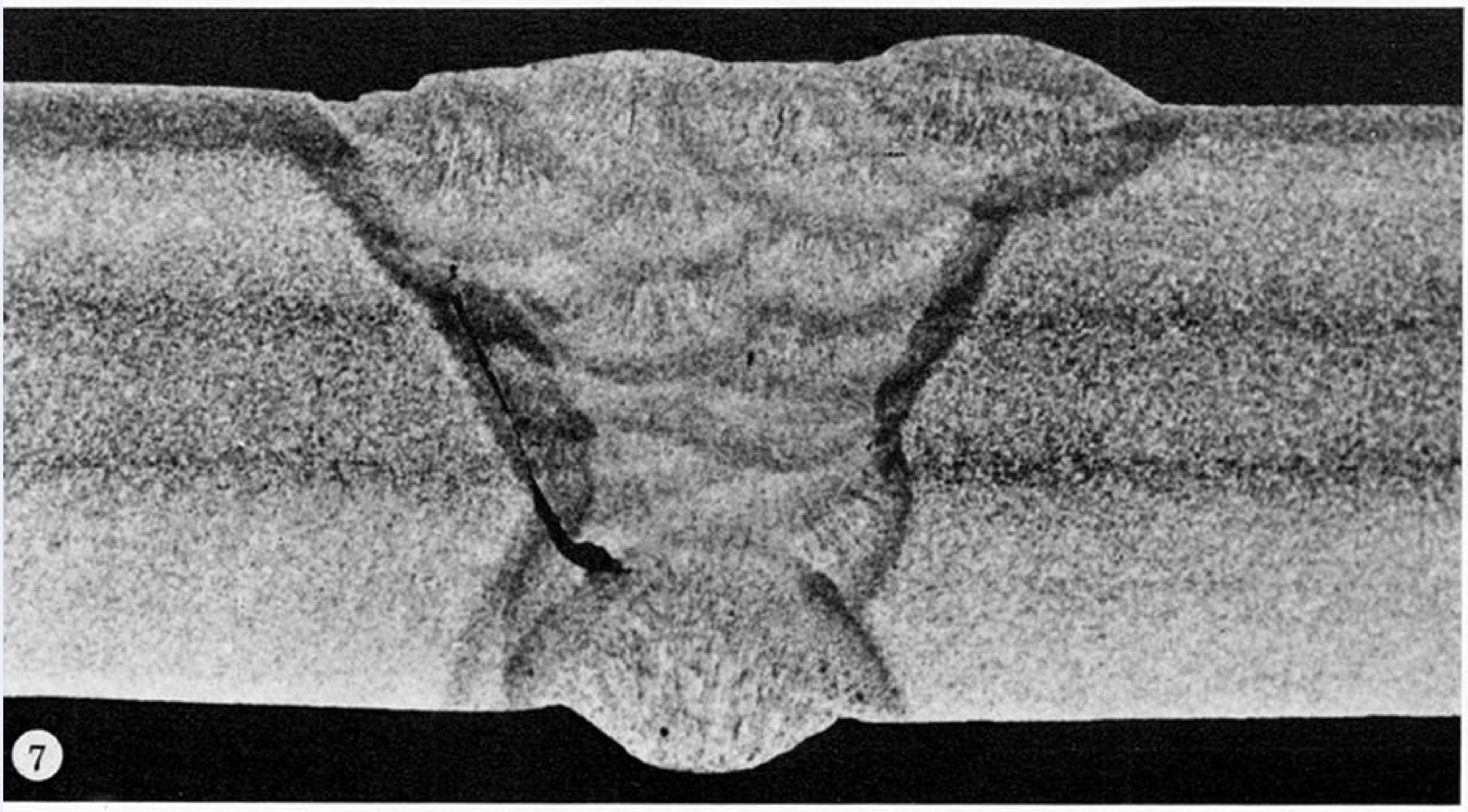

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