LACK OF FUSION CHARACTERISATION OF INDICATIONS

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ABSTRACT

For efficient testing of welded joints, it is indispensable to be acquainted with non-destructive testing methods, as well as to know as much as possible about the defects to be detected. In the welding literature there are comparatively few reports on lack of fusion defects, although the latter is of the most risky weld defects. For their detection, there are no efficient testing methods available. The present study focused on gathering as many as possible data on lack of fusion. It was found with which welding processes they were likely to occur, where they were located, and what their properties were. The indications of lack of fusion were studied using different non-destructive testing methods. Testing was carried out on butt-welded joints obtained in gas-shielded welding with a consumable electrode. In addition to non-destructive testing methods, metallographic and mechanical tests were used too. It was to be found why non-destructive testing methods were inefficient in lack of fusion detection.

IIW-Thesaurus keywords: *Lack of fusion; Defects; Welded joints; Butt joints; Fillet welds; MAG welding; Arc welding; Gas shielded arc welding; GMA welding; Nondestructive testing; Ultrasonic testing.*

1 INTRODUCTION

In non-destructive testing of welded joints, the imperfections found should be adequately identified. In order to assess the acceptability of a weld it should be found which imperfection is shown by the indication, where it is located, how often it occurs, and to which degree it weakens the welded joint. X-ray and ultrasonic testing methods make it possible to detect some of the imperfections in the weld itself such as non-metallic inclusions and pores. A lack of fusion defect, however, is hard to identify because no efficient testing method is available for its detection. This may be a consequence of its structure and location. The lack of fusion defect is, namely, a weak reflector of ultrasonic waves and a weak generator of X-ray indications.

The weld quality is assessed with reference to the size of the indication obtained with a non-destructive testing method. In routine testing it is often wrongly assumed that the size of an indication corresponds to the size of the imperfection. We may be misled by the standards in which acceptance criteria are the number and size of imperfections [1]. Weld assessment, however, seems more reliable using the standards in which the acceptance levels are defined with regard to the size and type of indication characteristic of individual non-destructive methods [2, 3]. There are also some other comparative methods [DAC (Distance – Amplitude – Curve), AVG (Abstand – Verstearkung – Groesse)] with which an acceptance criterion is the size of indication.

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In many cases the assessment based on the size of an indication does not indicate the actual weld quality. The type of imperfection shown by the indication and the degree to which the weld is weakened should be known. Consequently, each indication should be analysed carefully and its characteristics determined.

A typical case of a wrong assessment of the weld quality based on an indication is the lack of fusion defect. The non-destructive testing methods show it as a minor imperfection the size of which is usually acceptable. But the lack of fusion defect is in fact a two-dimensional defect characterised by considerable weakening of the welded joint.

In the literature descriptions of general principles of characterisation of echoes in ultrasonic testing are available [4, 5]. Some cases of the characterisation of indications in austenitic pipeline testing [6], welds in nuclear power stations [7] and the characterisation of lack of penetration [8] are described too. No papers, however, can be found on the characterisation of the indications produced by lack of fusion.

2 MICROSTRUCTURE CHARACTERISTICS OF LACK OF FUSION

For efficient identification of defects, the structure of a defect, the weld structure, the boundary between the weld and the parent metal, and the position of individual runs should be known.

Lack of fusion is a planar defect. In the weld there can be a lack of side-wall fusion, i.e., between the parent metal and the weld metal, as well as a lack of inter-run fusion, i.e., between the adjoining runs. It occurs in both butt welds and fillet welds. A lack of fusion usually occurs internal to the weld. It rarely reaches the weld-root surface and it never reaches the weld-face surface. Positions of typical lack of fusion defects in butt and fillet welds are shown in Figure 1.

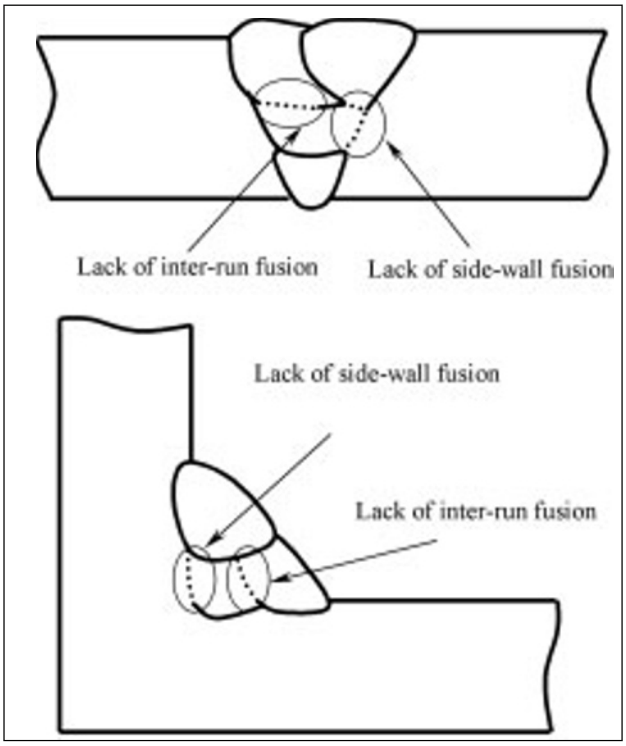


Figure 1 – Typical lack of fusion in butt and fillet welds

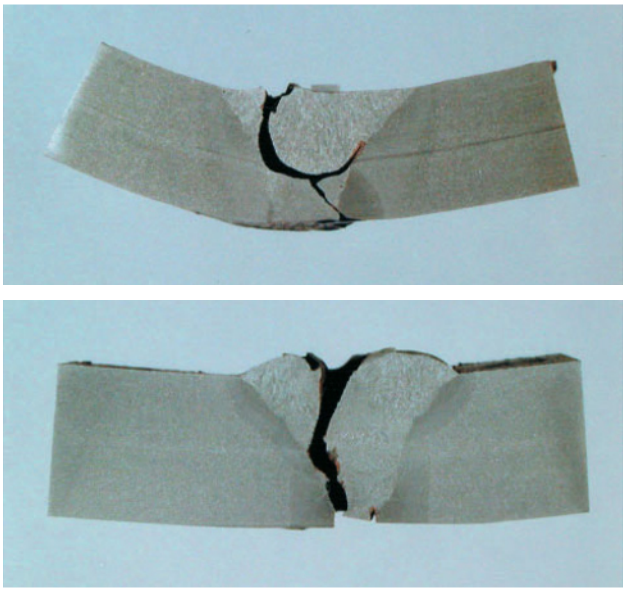
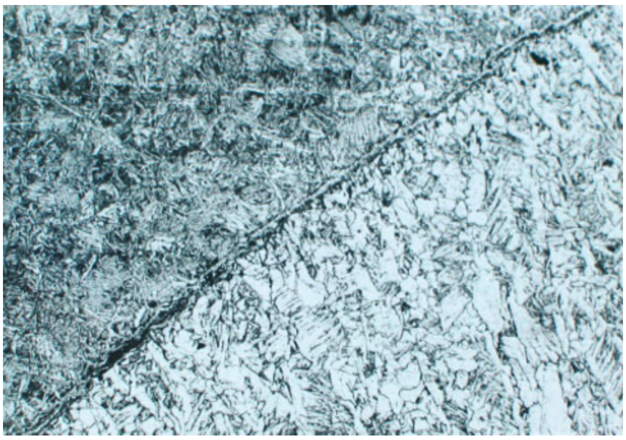


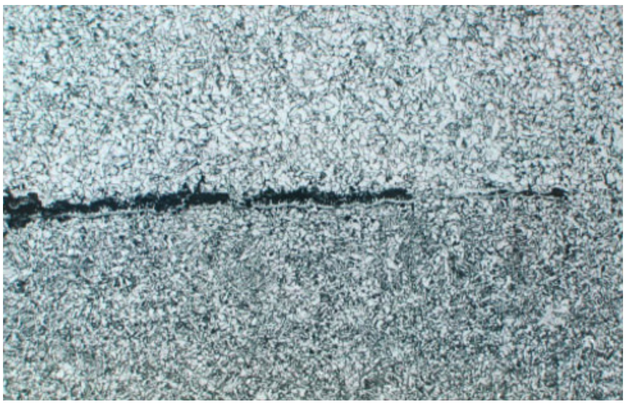
Figure 2 – Appearance of fractures due to lack of fusion in welds

The test pieces for testing were systematically collected. Metallographic methods were used to test a multi-layer MAG butt weld on steel that failed during mechanical testing. A typical weld fracture due to the presence of lack of fusion is shown in Figure 2.

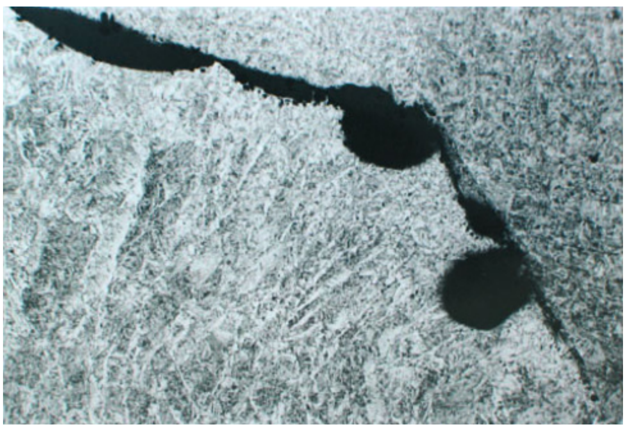
Figure 3 shows microstructures of four typical lack of fusion defects. The least detectable type of lack of fusion is a sharp transition from one structure to the other [Figure 3 a)]. Another type of lack of fusion is shown in



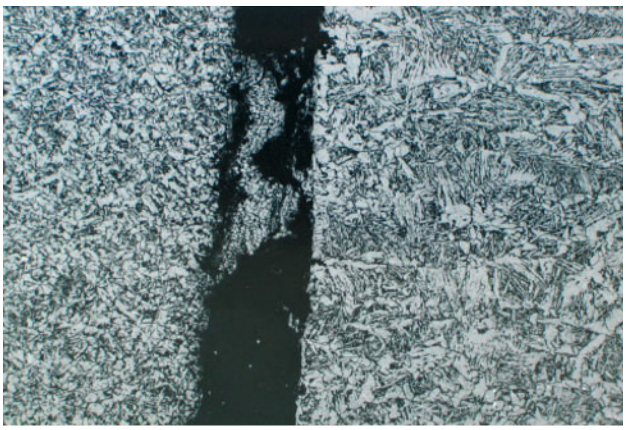
a) Joint line as a straight line



b) Thin oxide layer between the weld and the parent metal



c) Non-metallic inclusions at the line of joining



d) Void between the weld and the parent metal

Figure 3 – Microstructures of typical types of lack of fusion, $\times$ 100

Figure 3 b). There are microscopic, plane-distributed oxides between the runs. In the lack of fusion defects there is a concentration of larger non-metallic inclusions [Figure 3 c)]. The surfaces that lack weld fusion may be separate. Voids similar to cracks occur [Figure 3 d)].

The cases shown indicate that the lack of fusion defects may have different structures. They may appear as a weak joint similar to a brazed or adhesion-bonded joint containing neither voids nor inclusions. Such a type of lack of fusion defect cannot be detected by non-destructive methods.

Lack of fusion was studied in typical butt MAG welds. It was found that lack of fusion occurred at the lower ends of the weld face and a middle bead, and at the sides of the root bead and the middle bead. The research results are schematically shown in Figure 4.

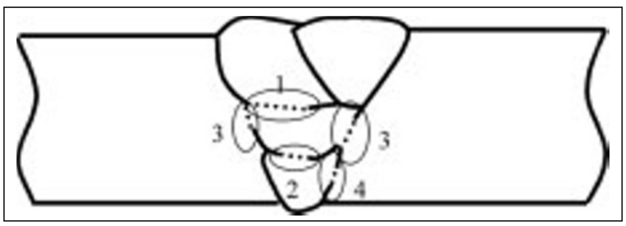
3 DETECTABILITY OF LACK OF FUSION

The lack of fusion defects containing either inclusions or voids, however, have better chances of being detected by ultrasonic or X-ray testing.

With regard to the detectability by non-destructive testing, lack of fusion defects may be classified into two groups, i.e., the ones comprising voids or non-metallic inclusions and detectable with NDT methods, and those free from discontinuities. The latter are structural defects that are not detectable by NDT methods.

X-ray and ultrasonic testing methods are available for the detection of lack of inter-run fusion and of side-wall fusion. With lack of fusion reaching the surface in fillet welds, magnetic and penetrant testing methods are used.

The X-ray method is not suitable for detecting lack of fusion. The inclusions shown in Figure 3 c) (mag.: $\times$ 100) look large but they are too tiny to be registered by a radiographic film. There are some chances to detect a lack of side-wall root fusion defect passing on to lack of penetration shown as a dim line or a slight shadow on the radiographic film. The inter-run lack of fusion being perpendicular to the direction of X-rays cannot be detected. An X-ray film will show only large inclusions and oriented in the direction of radiographing (Figure 5). That the X-ray method is not the most reliable one



1 Lack of inter-run fusion (weld-face run)
2 Lack of inter-run fusion
3 Lack of side-wall fusion (in the middle)
4 Lack of side-wall fusion in the root

Figure 4 – Typical lack of fusion found in butt welds

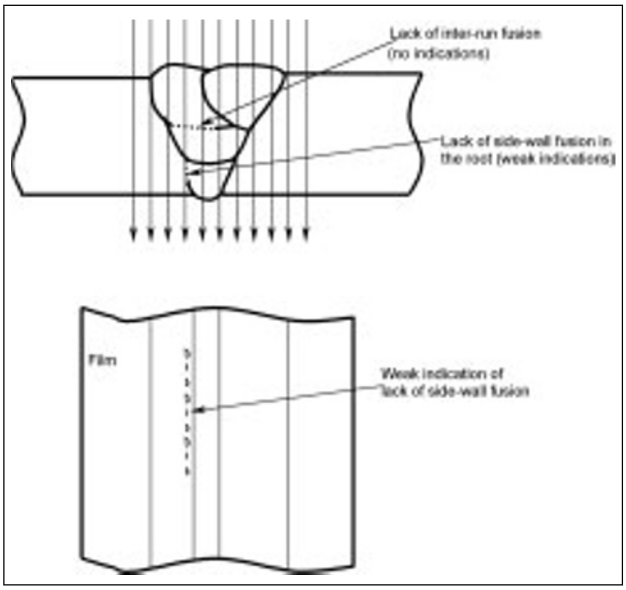


Figure 5 – Radiographic examination shows lack of side-wall fusion but no inter-run lack of fusion

shows a case of failure of a longitudinal weld at a pressure vessel that was examined and assessed as acceptable, and yet it failed [9].

It is the ultrasonic testing method of all the non-destructive methods available that seems to be the most efficient in lack of fusion. An adequate testing unit, a selection of an adequate method and a careful analysis of all indications permits the detection of some types of lack of fusion. The ultrasonic method, however, is not totally reliable. Because of a specific structure and unfavourable position of some types of lack of fusion they cannot be detected by ultrasonic testing. The indications given by some lack of fusion defects are, namely, so weak that no attention is paid to them. In some cases limitations are imposed by the geometry of a product or the weld thickness.

Lack of fusion being a planar defect, inclusions and voids are arranged in planes from which ultrasonic waves are supposed to reflect well; therefore, it is difficult to understand why this defect is so hard to detect. This fact may be ascribed to the structure of the lack of fusion defects. At boundary planes there is a number of tiny defects a single one of which does not represent a major obstacle to ultrasonic waves. Under loading, they link up to produce a major discontinuity in a material.

The position of lack of fusion defects is unfavourable when it comes to ultrasonic testing. Lack of side-wall fusion defects are found at the boundary between the parent metal and the weld metal making an angle with the surface ranging between 25 and 45°. When smaller incident angles are used, weak echoes are obtained. Lack of inter-run fusion is parallel to the workpiece surface, which is not favourable. Ultrasonic waves will reflect in a way that the echo propagates into the material and the receiver cannot not register it [10, 11]. In such cases it is more suitable to employ the tandem testing method.

The application of ultrasonic testing is limited also by the workpiece thickness. It is known that ultrasonic testing is not suitable for testing welds thinner than 8 mm. This means that for the welds that thin there is no efficient non-destructive testing method available. Manufacturers of pressure vessels frequently employing such joints are therefore avoiding the application of shielded-gas welding since in this case lack of fusion is very likely to occur.

4 PREPARATION OF THE TESTING PROCEDURE AND CHARACTERISATION OF INDICATIONS

The efficiency of testing is affected not only by testing itself and an analysis of indications obtained, but also by the preparation and review of welding data.

The preparation for testing includes a careful review of the relevant welding procedure specification (WPS). The WPS indicates the welding process used, edge preparation, and welding parameters. It is advisable to consult a report on the welding procedure testing. Macroscopic testing provides information on a weld structure. Based on these data an assessment is made to determine whether there is a risk of lack of fusion in the weld. It should be taken into account that lack of fusion occurs in gas-shielded welding with a consumable electrode. The risk of lack of fusion should be considered in welding of high-strength steels since in this case the energy input is limited. There is a higher risk of lack of fusion if the angle of preparation is narrower, or in welding downwards. Attention should be paid to lack of fusion in mechanised and automatic welding processes.

If it is suspected that there might be lack of fusion in a weld, the testing procedure should be adapted accordingly. A sketch of weld sequence is recommended. The points susceptible to the occurrence of lack of fusion shall be marked. A suitable testing technique and parameters such as angle of incidence, direction of testing, and sound frequency shall be selected. Attention should be paid to the points where lack of fusion may occur.

The ultrasonic waves shall be directed towards the boundary between the parent metal and the weld, taking into account the position of the edges of the parent metal prepared for welding, and that of individual runs. Thus echoes may be received from the un-melted side walls of the parent metal making an angle ranging between 20° and 40° or from individual runs situated in the middle and having a spherical shape. The preparation for testing and characterisation of indications are shown in Figure 6.

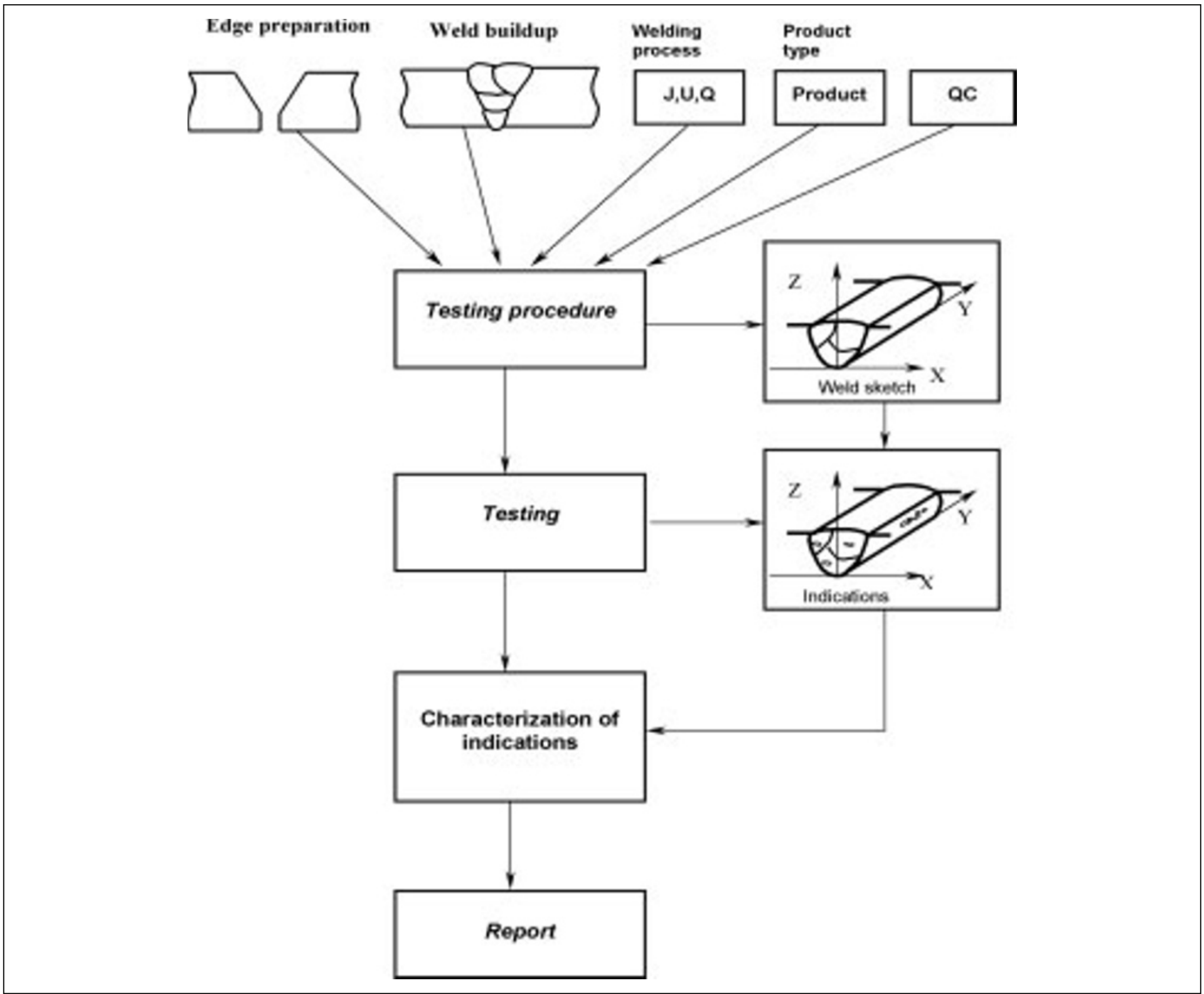


Figure 6 – Flow chart of testing procedure and characterization of indications

The weld shall be carefully examined from both sides using the selected technique. Attention shall be paid to all indications, although at first sight they do not appear to be major defects. The points providing any kind of indication shall be marked at the sketch and examined from several directions. The angle of incidence, the frequency, and the method sensibility shall be varied. For the examination of some inter-run lack of fusion defects the tandem technique is quite suitable.

All the indications obtained shall be systematically analysed. Attention shall be paid to the amplitude curve, dynamics of occurrence, and the distribution of the indications in space. The lack of fusion defects occurring in the weld may have different shapes and sizes. Major discontinuities in a material can easily be detected. They are, however, harder to detect when they comprise a number of minor discontinuities and stuck surfaces containing no voids or oxides.

In the detection of lack of fusion, attention should be paid to smaller, yet repeated indications. The position, size and orientation of the imperfections detected shall be carefully determined. The sketch of the weld already prepared is helpful in determining in which parts of the weld the defects are occurring most frequently. The position and distribution of the imperfections detected in space should be accurately determined.

Lack of fusion should not be taken for minor porosity because the latter is an acceptable imperfection. Major three-dimensional inhomogeneities, such as pores and non-metallic inclusions can easily be identified and distinguished from lack of fusion. If lack of fusion, however, is taken for incomplete penetration or cracks, this is of no consequence because the latter imperfections are as unacceptable as lack of fusion.

5 CONCLUSIONS

Lack of fusion is a planar defect that considerably weakens the welded joint. In ultrasonic examination it emits weak signals. It is a weld defect hard to detect and identify. The study has shown that lack of fusion is likely to occur at the lower sides of the weld-face run and the intermediate run and at the side walls of the root run and the intermediate run.

The metallographic examinations performed showed that the lack of fusion defects were of different structure. A sharp line of joining indicates lack of fusion. There are microscopic face-distributed oxides. Non-metallic inclusions concentrate in the lack of fusion defect. There are voids similar to cracks. They can appear as a weak joint similar to a brazed one or an adhesive-bonded one containing no voids or inclusions.

With reference to the chances of detecting lack of fusion with the non-destructive methods, the lack of fusion defects can be classified as those comprising voids or non-metallic inclusions and detectable by the non-destructive testing methods, and those showing no discontinuity in the material.

Of the non-destructive testing methods available, ultrasonic testing seems to be the most efficient method of detecting lack of fusion. A suitable preparation, a selection of an appropriate technique, and a careful analysis make it possible to detect some types of lack of fusion. They are, however, harder to detect when they comprise a number of minor discontinuities and stuck surfaces containing no voids or oxide.

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