Surface inspection of welds

No. 6.02

Scope

This Guidance Note applies to all welds in structural steelwork for bridges. It covers the surface inspection of welds using non-destructive techniques, either magnetic particle testing or, to a lesser extent, penetrant testing. Visual inspection and measurement of fusion welded joints after welding is covered in GN 6.06, and sub-surface inspection is covered in GN 6.03.

Magnetic particle testing

Magnetic particle testing or inspection (usually abbreviated MT or MPI) is a method of detecting surface or near-surface discontinuities or imperfections in ferro-magnetic materials by the generation of a magnetic flux within a component, and the application of suitable ferromagnetic particles to its surface so as to render the imperfection visible. In principle, the steel surface (including the weld) is magnetized to induce a magnetic flux within the material; the distribution of this flux is disturbed by the presence of imperfections which cause some flux leakage from the surface of the steel. The magnetic field is usually produced by low voltage magnetizing currents introduced into the steel between two electro-magnets, as shown in Figure 1.

Figure 1 *Setup for MPI*

Magnetic powder or flaw detection ink with ferromagnetic particles is applied to the surface whilst magnetized. The ferromagnetic particles are attracted and retained by the flux leakage and thus delineate the imperfection. Imperfections are measured and assessed against the workmanship standard and unacceptable imperfections are declared defects.

Magnetic particle testing can detect cracks, non-metallic inclusions and other imperfections on or near the surface of the steel. The sensitivity of the inspection is not greatly impaired by the presence of foreign matter in the imperfection, and it is possible to inspect components that have been treated with a non-magnetic coating up to 50 μm thick. Maximum sensitivity is achieved when the imperfection lies at right angles to the magnetic field, but is not reduced below the effective level if the imperfection is orientated at an angle of up to 45° from the optimum direction. To obtain the best sensitivity the magnetic field has to be passed in two directions at right angles to each other, in separate operations. Surface cracks produce the sharpest delineation, whilst imperfections just below the surface produce less well-defined indications, making interpretation of test results difficult. Abrupt changes in geometry (sharp corners, edges, excessive surface roughness) and change in magnetic permeability in the heat affected zone of the weld may give indications that can be mistaken for defects.

Note that many specifiers prohibit the use of current flux prods. Electro magnets are now favoured because they eliminate the potential of arcing to steel that exists with current flux prods.

Penetrant testing

Penetrant testing (abbreviated to PT) is a process for detecting certain imperfections open to the surface.

The basis of penetrant testing is that liquid penetrant applied to the surface to be examined enters (through capillary action) any crack or imperfection open to the surface. After a period of soaking, the surplus liquid is removed, either by washing or application of a solvent (depending on the type of penetrant), and a developer is applied. This causes the liquid left in the crack to be drawn to the surface and make it show visibly. Usually colour-contrast dye penetrant is used, rather than fluorescent penetrant. Wide cracks produce a seepage or spread of the penetrant, whilst fine cracks often appear as a series of dots in line which in time may link up to give a continuous line. Rounded surface imperfections are easily recognizable because of the penetrant spread.

It should be noted that some of the materials used can be toxic, and that adequate control of effluent has to be provided.

Scope of inspection
The standard applicable to the execution of steel structures, including bridges, is EN 1090-2 (Ref 1). Workmanship, inspection and testing requirements are defined according to the ‘execution class’. EN 1090-2 states that EXC3 could be specified for bridges and common practice supports this.

For new welding procedure specifications, a more stringent testing regime is applied to the first 5 joints tested to establish that the WPS produces conforming quality welds when implemented in production.

Visual examination is always required, followed by an amount of supplementary non-destructive testing (NDT) specified in EN 1090-2 clause 12.4.2.2 and Table 24. Table 23 in the Standard defines minimum hold times after welding before supplementary NDT takes place. The extent of testing for surface and internal imperfections is given for various joint types and Execution Class.

The execution standard also provides for the project specification to identify specific joints for inspection together with the extent and method of testing. This is to accommodate more stringent examination when fatigue strength requirements are higher.

Where partial inspection is specified, EN 1090-2 also states that sampling should cover as widely as possible, joint type, material grade, welding equipment and the work of the welders.

EN 1090-2 refers to withdrawn standard EN 12062 (Ref 2) for the selection of methods of non-destructive testing, the selection of lengths to be tested where partial or percentage examination is specified and guidance on additional testing where non-acceptable indications are revealed. The Standard is a dated reference in EN 1090-2 and reference should be to that edition. However the normative references within EN 12062 are undated and have all been superseded and therefore the latest edition of the relevant standard applies. EN 12062 is superseded by EN ISO 17635 (Ref 3) and this is likely to be included in a future revision to EN 1090-2. The two standards are very similar in content and for clarity it would seem sensible to use the up-to-date version in this text.

For highway infrastructure projects, the Specification for Highway Works (SHW) Series 1800 was published in August 2014 (Ref 4). This specification interprets and implements PD 6705-2 (Ref 5) and introduces the concept of Quantified Service Category (QSC) to determine the method of non-destructive testing, frequency of testing and the acceptance levels which are different to EN1090-2. See GN 6.01 for further explanation. A project Appendix 18/1 is required to cover any project-specific requirements. It is incumbent on the Designer to determine the relevant QSC and communicate this through Appendix 18/1 or the drawings. The Designer should also avoid overcomplicating the requirements and keep in mind that it is much easier for steelwork contractors to use one category for the project than use multiple different categories and run the risk of misunderstanding or misinterpretation. Guidance on specification of QSC is given in GN 2.12.

Method of non-destructive testing
The method of NDT should be selected from those described in EN ISO 17635. It suggests that penetrant or magnetic particle testing are suitable methods for testing butt and fillet welds for surface imperfections. For bridges in conventional structural steels, MT is the principal method in use by UK steelwork contractors.

The use of MT may also be specified on the tensile surface when plates have been bent, to confirm the absence of surface cracks. In addition, it is used for assessing the integrity of backgouged root areas and excavated repairs.

Penetrant testing is a time consuming process and it is normally used on bridges for testing joints in special machined components or non-magnetic steels, such as austenitic stainless steels, used on feature pieces or perhaps handrailing. It is also used for testing joints in dissimilar materials, for example, austenitic stainless steel to mild steel, although this type of joint should only be used for non-structural elements, such as drains and architectural features.

Magnetic particle testing of welds should be carried out in accordance with EN ISO 17638 (Ref 6) and penetrant testing shall be carried out in accordance with EN ISO 3452-1 (Ref 7). The standards describe the equipment, techniques, surface preparation and viewing conditions necessary to carry out the test. It also describes the information to be included in the test report.

Again, for infrastructure projects carried out in accordance with the SHW Series 1800, the methods of testing are specified in Tables 18/4 and 18/6. The selection of method and frequency of testing is based upon the material thickness and QSC. Table 18/5 provides a method of adjusting the frequency of test depending upon certain criteria, such as how and where the weld was made, the material grade, the QSC and whether the weld is under repair. For example, the proportion of supplementary NDT is adjusted down where there is less risk of imperfection because the weld was deposited using automatic or robotic processes, or adjusted up for higher grades of material, site welds or repair situations.

Acceptance criteria

EN 1090-2 requires that for EXC3 joints the acceptance criteria for weld imperfections is Quality Level B to EN ISO 5817 (Ref 8).

For joints where an enhanced level of quality is required to meet design fatigue strength requirements, EN 1090-2 Table 17 gives additional requirements for EXC4 as Quality Level B+. In addition, the table gives supplementary requirements for bridge deck steelwork. These are more stringent acceptance standards for imperfection types over and above Quality Level B.

Generally the requirements for Quality Level B+ are not practically achievable in routine production. Indeed normal welding procedure and welder qualification tests are not assessed against acceptance criteria at this level. If a higher quality level is required, this should be specified for each relevant joint detail and the extent and method of testing can be selected to detect imperfections and to characterize them.

In the case of highway infrastructure projects carried out in accordance with the SHW, the acceptance criteria are specified in Table 18/9. The criteria are further based on the QSC and the acceptance levels specified in EN ISO 23278 (MT) (Ref 9) or EN ISO 23277 (PT) (Ref 10).

EN 1090-2 suggests that non-conforming welds be judged individually for each case and evaluation should be based on the function of the component and the characteristics of the defect in terms of type, size and location in order to determine acceptability. Reference back to the design codes may be used to support the evaluation.

Surface breaking cracks are not permitted. Other imperfections can be accepted subject to certain limitations on dimension and location which safeguard against the initiation and propagation of cracks in fatigue sensitive areas.

Temporary attachments should be removed and weld areas carefully ground smooth; EN 1090-2 requires inspection of areas from which temporary attachments have been removed to ensure there is no surface cracking. The SHW Series 1800 specifies magnetic particle testing for this and qualifies the basic requirements of EN 1090-2 with respect to QSC and positioning of the attachment and subsequent removal

The designer should be aware that imperfection types, such as internal pores and solid inclusions in fillet welds are not detectable using normal surface examination techniques used in bridgework. See GN 6.03 for further advice on sub-surface inspection.

Repair

Where testing identifies defects, repair becomes necessary. In some cases this might involve a simple localized light grinding or dressing to correct the problem and it is not practical to report these.

For more substantial repairs, which are reported through non-conformance and corrective action procedures, the repair is likely to involve gouging and welding. It is necessary to maintain control by implementing a repair procedure either of a generic nature or specifically developed to correct the problem. In either case, the completed repair area needs re-examination and reporting.

Both EN ISO 17635 Annex C and SHW Table 18/5 provide guidelines or requirements respectively for examination or increased sampling to isolate and identify any recurring problems.

Non-destructive testing personnel

All inspection to ensure the quality of the completed welding should be carried out by appropriately qualified and experienced personnel as required by EN 3834-2 (Ref 11). Non-destructive testing, such as MT should be performed by personnel qualified in accordance with EN 473 (Ref 12) or the later standard EN ISO 9712 (Ref 13).

Surface penetrating defects

Magnetic particle testing (and also penetrant testing) is normally used to detect surface penetrating cracks and surface breaking porosity in butt and fillet welds. Porosity is created when gas is entrapped in solidifying weld metal, and is a sign that the welding process has not been properly controlled or that the base metal is contaminated or of variable composition. The presence of porosity indicates that there is the possibility of hydrogen in the weld and heat affected zone (HAZ) that may lead to cracking. Porosity may occur as:

- a localized cluster of pores usually resulting from improper initiation or termination of the welding arc;
- a line of pores aligned along a joint boundary, the root of the weld, or an inter-bead boundary caused by contamination that leads to gas evolution within the weld;
- one or two surface imperfections which may be interspaced with many more sub-surface elongated cavities or wormholes (also known as piping porosity).

Cracks occur in the weld and/or base metal when localized stresses exceed the ultimate strength of the material. Generally high residual stresses are present, and crack initiation and propagation is greatly influenced by the presence of imperfections that concentrate stress. Hydrogen embrittlement is often a contributor to crack formation - see GN 6.04 for further guidance. Welding related cracks are generally brittle in nature, exhibiting little plastic deformation at the crack boundaries.

Longitudinal cracks are parallel to the axis of the weld (Figure 2). They can be:

- throat cracks, generally found in the centre of the weld bead and usually, but not always, hot cracks forming upon the solidification of the weld metal at temperatures near the melting point;
- root cracks, generally hot cracks in the root of the weld;
- toe cracks propagating into the base metal from the toe of the weld where restraint stresses are highest; these are hydrogen-induced cold cracks, forming hours or days after the completion of welding (see GN 6.04).

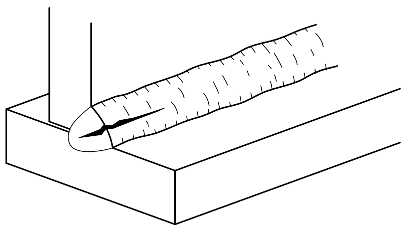

Figure 2 *Longitudinal crack in face of weld*

In submerged arc welds made by semi- or fully automatic welding process, longitudinal cracks are often associated with high welding speeds. In small welds between heavy sections, longitudinal cracks often result from fast cooling rates and high restraint and are usually associated with an inappropriate weld depth to weld width ratio.

Transverse cracks are orthogonal to the axis of the weld (Figure 3). They occur in the weld metal, the base metal or both. Transverse cracks initiating in the weld metal are commonly the result of longitudinal shrinkage stresses acting on excessively hard weld metal.

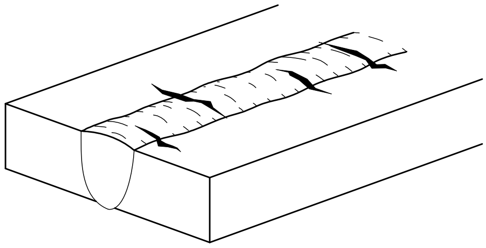

Figure 3 *Transverse surface crack*

Transverse cracks initiating in the HAZ are generally hydrogen cracks.

Crater cracks form in the crater or depression that is formed by improper termination of the welding arc. Usually they are shallow hot cracks in the form of a multi pointed starlike cluster (Figure 4).

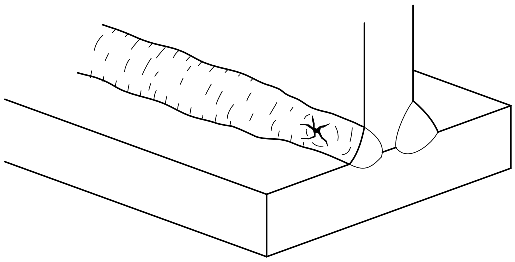

Figure 4 *Crater crack in fillet weld*

For further information on imperfections in metallic fusion welds, refer to EN ISO 6520 (Ref 14).

References

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4. Manual of Contract Documents for Highway Works. Volume 1 Specification for Highway Works. Series 1800 Structural steelwork. Amendment August 2014, TSO.
5. PD 6705-2: 2010+A1:2013 Structural use of steel and aluminium. Part 2: Recommendations for the execution of steel bridges to BS EN 1090-2.
6. EN ISO 17638: 2009 Non-destructive testing of welds. Magnetic particle testing.
7. EN ISO 3452-1: 2013 Non-destructive testing. Penetrant testing. Part 1: General principles.
8. EN ISO 5817: 2014 Welding. Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded). Quality levels for imperfections.
9. EN ISO 23278:2009 Non-destructive testing of welds. Magnetic particle testing of welds. Acceptance levels.
10. EN ISO 23277: 2009 Non-destructive testing of welds. Penetrant testing of welds. Acceptance levels.
11. EN ISO 3834-2: 2005 Quality requirements for fusion welding of metallic materials. Part 2: Comprehensive quality requirements.
12. EN 473: 2008 Non-destructive testing – Qualification and certification of NDT personnel – General principles. *Superseded, withdrawn.*
13. EN ISO 9712: 2012 Non-destructive testing. Qualification and certification of NDT personnel.
14. EN ISO 6520-1: 2007 Welding and allied processes. Classification of geometric imperfections in metallic materials. Fusion welding.