

Guidance Note 3.02

Through thickness properties

Scope

This Guidance Note gives advice on the need for steel with improved 'through thickness properties' and on the selection of an appropriate quality class where such steel is needed.

Steel is an anisotropic material

Steel plate and sections are produced by a process of rolling, and the mechanical properties that the material attains are influenced by the working of the metal as it cools. Sections are rolled from a compact 'bloom' (a large rectangular piece of steel) into a very long element; any inclusions and non-uniformities in the metal are essentially linear in nature. Plate is rolled from slab, but there is a degree of cross rolling as well as rolling in the longitudinal direction; any inclusions and non-uniformities are therefore essentially planar in extent and parallel to the surface of the plate. The mechanical properties of the material are therefore not the same in all directions; the material is anisotropic.

Material properties for steel sections are specified by reference to test specimens aligned longitudinally in the section. It is presumed that transverse properties (e.g. for bending of the flange) are at least equal to the longitudinal properties. Properties normal to the plane of the flange or web are not specified in the ordinary technical delivery conditions (e.g. in BS EN 10025-2 [1]).

Tensile strength properties for plate are specified by reference to transverse test specimens, unless the plate is less than 600 mm wide, when they are longitudinal. Impact toughness test specimens are usually aligned longitudinally. Again, no properties normal to the plane of the plate are specified in the ordinary technical delivery conditions.

The tensile strength out-of-plane (perpendicular to the surface) is more susceptible (than the in-plane strength) to the influence of rolling imperfections, particularly in plates.

There are two levels of imperfection or defect that affect out-of-plane behaviour:

- macro imperfections - thin layers of inclusion or impurity, extending over an area
- micro imperfections - numerous very small inclusions, usually of sulphides.

Macro defects are termed 'laminations' or 'laminar defects'. Their presence and extent can be checked by ultrasonic testing. Acceptance levels are given in BS EN 10160 [2]. This type of defect is not the subject of this Guidance Note.

Micro imperfections are significant when the material is subject to through-thickness loading, because they can lead to 'lamellar tearing' as a tear propagates from one inclusion to the next. Since the inclusions are small they cannot readily be revealed by ultrasonic testing, but their effect may be assessed by carrying out through thickness tensile tests in accordance with BS EN 10164 [3].

Generally, the requirement for 'through thickness properties' is therefore understood to be a requirement for one of the three quality classes of improved deformation properties (Z15, Z25, Z35) defined in BS EN 10164.

Evaluation of deformation properties perpendicular to the surface - BS EN 10164

It is stated in BS EN 10164 that the reduction of area in a through thickness tensile test is a good general guide to the lamellar tear resistance, i.e. the risk of lamellar tearing decreases with increased reduction of area. Steel normally manufactured to the BS EN standards (e.g. BS EN 10025-2) generally has a modest tear resistance (i.e. a modest reduction of area), but this property is not specified or measured. The invoking of BS EN 10164, as a supplement to the product standard, implies that the

steel will have improved deformation properties, as a result of additional steelmaking procedures. These *improved* properties may be specified in terms of a minimum reduction of area in a transverse tensile test; three quality classes are defined, Z15, Z25 and Z35, corresponding to 15%, 25% and 35% average reduction in area at failure, respectively.

The need for steel with improved through-thickness properties

There should be very little need to specify steel with improved (guaranteed) through-thickness properties in typical bridge steelwork, unless the joint details are unusual. The tear resistance of steels from modern steel-making plants is sufficient for most applications. If the source of the steel material is uncertain and/or the manufacturer's or supplier's certification is incomplete and, especially, if the application is one of those recognised to be critical in this respect, testing to BS EN 10164 should be called for. The result will indicate in which category the material lies and its suitability for the application can then be assessed.

'Through thickness properties' would, for example, be needed where there is significant load carried through a cruciform detail, or where pieces are welded in positions where they are constrained against weld shrinkage. Good design of connections should ensure that there are rarely any such details.

It is worth noting the conclusion of a study carried out by TWI for TRRL in 1991 [4]: "The review and survey of industry have shown that the principal factors controlling lamellar tearing are well understood, and that instances of this form of cracking in bridge construction are currently very infrequent." The report goes on to say that with the advent of options that offer "a range of through thickness tested grades, there is a risk that such steels will be specified in situations where they are not strictly necessary, thus adding unnecessarily to the overall cost". Refinements in steelmaking since 1991 are likely to have further reduced the instances of tearing.

Avoidance of lamellar tearing

The main cause of lamellar tearing is very high out-of-plane stresses due to restraint of weld shrinkage. Tearing will usually appear during or soon after cooling of the welds; tearing due to applied load occurs rarely,

unless tearing has already been initiated, or lamellar defects are present.

The best way to avoid tearing is therefore to avoid details that induce high out-of-plane stresses. Where they cannot be avoided, it is recommended to check by ultrasonic testing locally around any critical details *after* welding, to ensure that there are no tears or defects.

Details that avoid the risk of lamellar tearing

A simple corner butt weld can lead to tearing if the weld preparation is to the wrong plate. See Figure 1.

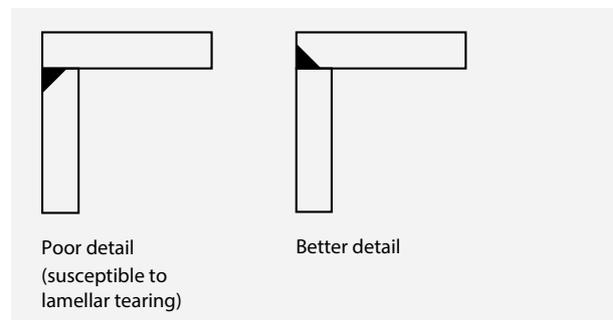


Figure 1 Corner weld details

When the upper plate in Figure 1 is prepared (as in the right-hand detail), the preparation cuts across most of any lamellar defects.

If a cruciform detail is needed (for example when there are integral crossheads), consider running the thicker web plate through and weld the thinner to it, as in Figure 2. The thinner web is unlikely to require very large welds and thus should not require consideration of through-thickness. In any case, try to remove the need for full penetration welds; fillet welds and partial penetration welds are less likely to give rise to problems.

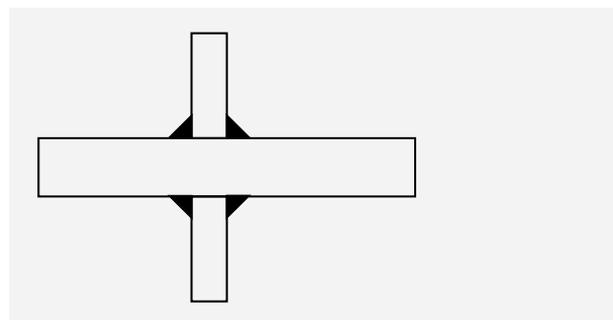


Figure 2 Cruciform detail

If a full penetration butt weld detail is needed (perhaps because of its better fatigue classification), there is again a lesser risk of tearing if the thicker plate is passed through; then no requirement for through thickness properties need normally be specified. See Figure 3.

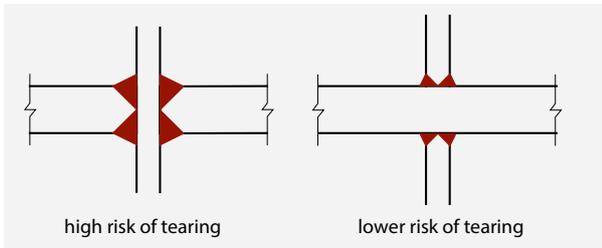


Figure 3 Cruciform details using butt welds

Specification of steel with improved deformation properties

Specifying a quality class to BS EN 10164 will ensure that the steel supplier provides a fine grained steel, with a sulphur level lower than that normally encountered with 'ordinary' structural steels. In addition to the usual properties, the steel will have a 'guaranteed' level of through thickness ductility.

However, steel with improved deformation properties should only be specified if the designer perceives a risk of lamellar tearing. Such a perception should be made after taking a balanced view, not simply as a belt-and-braces safe option. The advice in this Note should aid the designer to make a reasoned judgement.

BS EN 1011-2 [5] provides in its Annex F some guidance on the relationship between the reduction of area in the transverse tensile test and the risk of lamellar tearing in joints of differing restraint. This is presented in tabular form in Table 1.

Reduction in area	Type of joint at risk
Up to 10%	Some risk in lightly restrained T joints, e.g. I-beams
Up to 15%	Some risk in moderately restrained joints, e.g. box-columns
Up to 20%	Some risk in highly restrained joints, e.g. node joints, joints between sub-fabrications
Over 20%	Probable freedom from tearing in any joint type

Table 1 Relationship between reduction in area and risk of tearing

Annex F also contains advice on the best ways of avoiding lamellar tearing problems.

If a designer has concerns in relation to any details, advice could be sought from experienced fabricators prior to contract.

Another simple rule-of-thumb is to expect problems when the size of the attachment by weld to a plate surface matches or exceeds the thickness of that plate.

BS EN 1993-1-10 [6] contains a numerical method for determining the required Z-grade according to the weld size, detail type and level of restraint. However, the UK National Annex [7] indicates that this should not be used. The view of the UK experts is that this method is unduly conservative, required extensive calculations, and would lead to the unnecessary specification of Z-grade material. Instead, the UK National Annex refers designers to PD 6695-1-10 [8], which gives:

- Options for the fabricator.
 - The PD points out that the risk of 'lamellar tearing' can be mitigated by fabrication control measures, notably by procuring material from a modern mill known to produce clean steel.
- Options for the designer.
 - The PD implies that Z-grade material need not be specified for low and medium risk situations. For high risk situations it recommends that designers should specify Z35 quality to BS EN 10164. It defines high risk situations as:
 - In T-joints, when $t_z > 35$ mm.
 - In cruciform joints, when $t_z > 25$ mm

Where t_z is the thickness of the incoming plate for butt welds and deep penetration fillet welds, and is the throat size of the largest fillet weld for fillet welded joints.

Material availability

Requirements for improved through-thickness properties are usually very local in nature. However, steel with improved properties is more expensive and less readily available. If restricted portions of web or flange are specified in such steel, it is likely that only small quantities will be needed on any particular project. This may prove difficult for the fabricator, because the supplier may impose minimum order quantities, with a premium for small quantities. These practical considerations should be recognised by

the designer; *it is better to design details that do not require the use of steel with improved through thickness properties.*

Avoidance of laminar defects

Wherever load-carrying connections are made to the surface of steel, whether transmitting shear or out-of-plane forces, laminar defects should either be absent or of limited extent, irrespective of any need for through thickness properties. For critical details (such as lifting cleats or bearing stiffener connections to a web), ultrasonic inspection can be carried out before fabrication, as a precaution. Specification of a quality class to BS EN 10164 invokes a requirement for ultrasonic inspection as well as for through thickness properties.

References

- [1] BS EN 10025-2:2019, Hot rolled products of alloy structural steels. Technical delivery conditions for non-alloy steels.
- [2] BS EN 10160:1999, Ultrasonic testing of steel flat plate product of thickness equal to or greater than 6 mm (reflection method).
- [3] BS EN 10164: 2018, Steel products with improved deformation properties perpendicular to the surface of the product. Technical delivery conditions.
- [4] Study of through thickness properties of steel for bridge construction, Report 3-4048/3/91, The Welding Institute, 1991 (unpublished)
- [5] BS EN 1011-2:2001 Welding. Recommendations for welding of metallic materials. Arc welding of ferritic steels
- [6] BS EN 1993-1-10:2005, Eurocode 3: Design of steel structures - Part 1-10 Material toughness and through thickness properties, BSI, 2005
- [7] NA to BS EN 1993-1-10: 2005, UK National Annex to Eurocode 3: Design of steel structures – Part 1-10: Material toughness and through-thickness properties, BSI, 2009
- [8] PD 6695-1-10:2009, Recommendations for the design of structures to BS EN 1993-1-10, BSI 2009.