Properties of quality class steel

David Brown of the SCI discusses the specification of steel with improved through thickness properties. It should be noted that steel with through thickness properties (so-called "Z grade") is only needed in high risk situations.

Steel with improved through thickness properties is often referred to as "Z grade", although the formal description is 'Quality class'. The "Z" is simply because the dimensions in-plane are "x" and "y" and out-of-plane, through the thickness of the material, is the "z" direction. The word "improved" is important, as steels to the EN 10025 Standards will generally have resistance to stress in the z direction. The common arrangement used to demonstrate the potential need for improved through thickness properties is shown in Figure 1 – tensile stress is applied through the 'incoming' plates, leading to possible lamellar tearing in the 'through' plate. Lamellar tearing is when the steel in the 'through' plate separates internally.

Internal tearing may be occur due to areas of inclusions or impurity which can be detected by ultrasonic testing, or when through thickness loading causes tearing to propagate between micro imperfections. Micro imperfections cannot readily be detected by ultrasonic testing, but would be revealed by through thickness testing to EN 10164.

Material specification

Steel may be examined for the two types of imperfections mentioned above by specifying certain options at the time of order. Within EN 10025, which covers the steel sections and plate normally used in construction, options 6 and 7 apply to plate and sections with parallel flanges respectively, and require the steel to be examined for internal defects by ultrasonic testing. If through thickness properties are required, this must be selected by specifying option 4, which is testing in accordance with EN 10164. For rolled sections to EN 10025-2, clause 7.3.3 indicates that option 4 can only be specified for sub-grades J2 and K2.

If through thickness testing to EN 10164 is specified, this automatically includes ultrasonic testing to EN 10160 (for plate) or EN 10306 (for sections) as applicable, so there is no need to separately specify option 6 or 7.

Through thickness testing

Through thickness testing to EN 10164 requires samples cut from the plate (or section) to be subject to a tensile force in the z direction until the sample fractures. The test is examining the capacity of the steel to 'neck' before fracture, which is a measure of material ductility in the z-axis. The samples are machined to have a circular cross section, typically of 6 mm or 10 mm diameter, with a "headed" portion of the form shown in Figure 2, so that it can be gripped in a testing machine. EN 10164 specifies where the samples are to be taken – typically at 1/3 of the web depth and 1/3 of the flange outstand (measured from the tip).

The obvious question relates to the testing of thin material – how can this be prepared in such a way to be gripped in a testing machine? For thin material, extension pieces are welded to the sample. Because welding will change the material properties locally, the original sample must be at least 15 mm thick. To minimise the effect of the welding, EN 10164 suggests that extension pieces be friction welded to ensure the heat affected zone is minimised. Fracture in the weld or heat affected zone invalidates the results. Extension pieces are mandatory for samples up to 20 mm thick, optional for samples between 20 and 80 mm thick, and cannot be used for samples thicker than 80 mm.

Three samples are tested and in each case the reduction ▶24

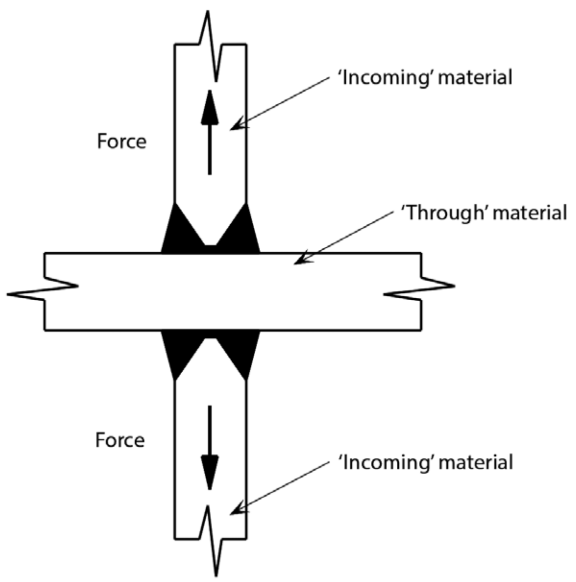


Figure 1 – Cruciform joint

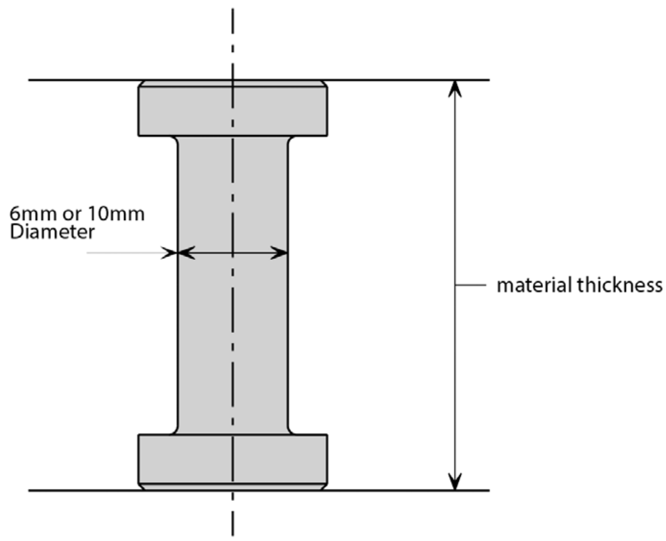


Figure 2 – Testing sample profile

▶22 of area when the sample fractures is given by:

$$\frac{S_o - S_u}{S_o} \times 100$$

where S_o is the original cross sectional area,
S_u is the minimum cross sectional area after fracture.

Both the average and individual results are needed to define the quality class in accordance with Table 1.

Quality class	Reduction of area in %	
	Minimum average value of three tests	Minimum individual value
Z15	15	10
Z25	25	15
Z35	35	25

Table 1: Z Quality class

Eurocode requirements

A procedure to determine if improved through thickness properties are required is given in Section 3 of BS EN 1993-1-10. Readers should note that there is little enthusiasm in the UK for this procedure, and alternative guidance is given in PD 6695-1-10. Despite the UK position, the guidance in BS EN 1993-1-10 establishes important principles, reinforced by the PD. The Eurocode notes that:

- The strain through the thickness of the material arises as welds to the surface (see Figure 1) cool and shrink. If that shrinkage is restrained by other stiff parts of the assembly, it is clear that the possibility of lamellar tearing increases,
- Larger welds increase the possibility of tearing,
- Thoughtful weld detailing can reduce the risk, for example by avoiding fusion faces which are parallel to the surface of the steel,
- The sulphur content in the steel is important – lower levels improve the through thickness properties of the steel.

The procedure in BS EN 1993-1-10 is essentially a scoring system based on a number of contributing factors. Criteria that increase the risk are awarded a higher score, those that reduce the risk given a lower or negative score. The required Z quality class (Table 1) must be greater than the summation of the individual scores. Some examples illustrate the features of the system:

A fillet weld throat 5 mm scores zero, a throat of 14 mm scores 6. The table includes fillet welds up to a 35 mm throat with a score of 15, but would be unusual, one hopes!

Welds where the fusion faces are not parallel to the surface (Figure 3a) score -25 (indicating that these are not a problem). Welds made to the surface of the steel (Figure 3b) score 5, or 8, depending on the detail.

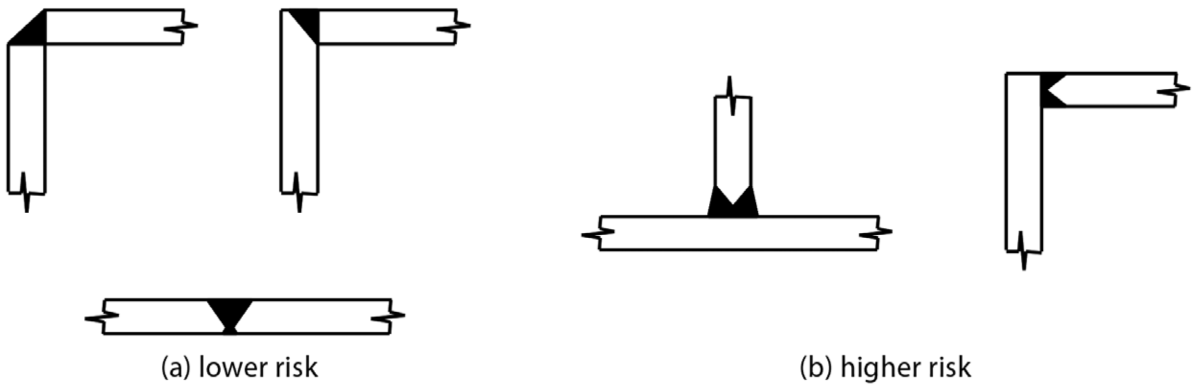
Thicker material, which provides more restraint, scores between 2 for 10 mm material and 15 for 70 mm material.

Perhaps surprisingly, the degree of restraint offered by other portions of the assembly is not so significant – a score of zero for low restraint to (a mere) 5 for high restraint. The most significant contributions are therefore the weld size, the thickness of the material and the joint type.

Guidance in PD 6695-1-10

The UK guidance is that through thickness testing is expensive,

Figure 3: Joint types



often unnecessary, and should only be specified in 'high-risk' situations. High-risk situations, illustrated in Figure 4, are identified as:

- Tee joints with butt welds where the thickness of the 'incoming' material is greater than 35 mm, or if fillet welded the throat is greater than 35 mm (again, a notable fillet weld!)
- Cruciform joints with butt welds where the thickness of the 'incoming' material is greater than 25 mm, or if fillet welded the throat is greater than 25 mm (still notable!)

In these high risk situations, the specification of quality class Z35 is recommended. If Z35 material cannot be readily obtained, then the sulphur content should be limited to 0.005%. This is significantly lower than the maximum specified in BS EN 10025-2, which is typically 0.03%.

In addition, weld volume should be minimised by avoiding over-specification – which is sensible advice in all situations. Both the designer and steelwork contractor can contribute here: the designer by not specifying conservative forces for the connection design and the steelwork contractor by making a careful choice of joint preparation.

PD 6695-1-10 notes that steel with low sulphur levels is likely to have improved through thickness properties (Z25 or even Z35) as a matter of course. The sulphur levels which have such a significant influence on through thickness properties may be verified by looking at the mill certificates. The PD also lists a series of practical measures to reduce the risk of lamellar tearing. These measures are primarily for the steelwork contractor and reflect the contributions to the overall risk score noted above. Practice to reduce the risk includes:

- Avoiding weld details where the fusion face is on the surface of the material.
- Managing the assembly of fabricated items to reduce restraint on subsequent welds.
- Minimising shrinkage of the welds by process control.
- Ordering steel with lower maximum sulphur levels, or purchasing steel from suppliers known to produce 'cleaner' steel.

Conclusions

In Western and other developed countries, steel is likely to be 'clean' (low sulphur), the steelwork contractors undertaking complex welding of large assemblies are likely to be highly experienced and the welding operations will be managed by a Responsible Welding Coordinator (an essential individual for the production of CE Marked steelwork). In these circumstances improved through thickness properties need only be specified for the high risk situations noted above.

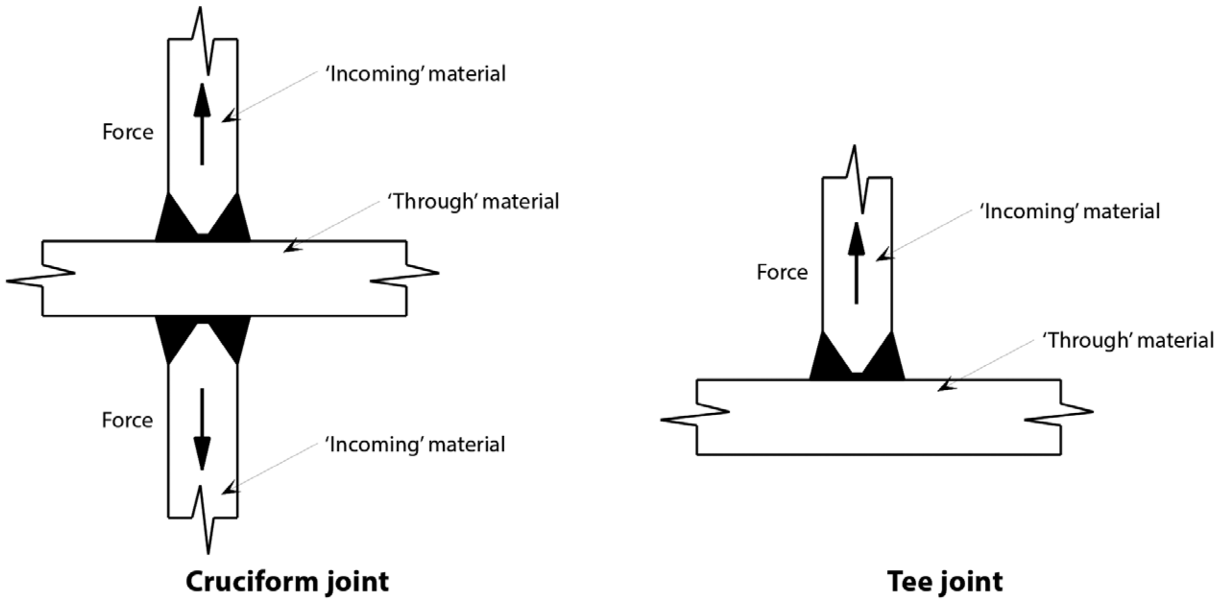


Figure 4: 'High risk' situations