Selecting the Correct Steel Grade: Part 1

Steel is a remarkably versatile construction material and has so many uses within modern agricultural and industrial buildings. In addition to the structural frames, which are usually made from hot-rolled carbon steel, galvanized cold-formed steel is often used for the purlins, cladding rails and the roof and wall cladding, while steel bolts hold the structural elements together and reinforcing mesh prevents the concrete slab from cracking. This versatility is due to the unique combination of properties that enable steel to be formed into useful shapes, while possessing sufficient strength to withstand the heaviest snow or strongest winds. Despite this, steel is usually regarded as a commodity to be bought at the lowest price possible from wherever it is available, often with little thought to the precise specification required for a particular job or the potential consequences of getting it wrong.

The aim of this article is to shine a light on the hidden metallurgy within the humble steel beam or column and explain the how its properties determine its suitability for certain applications. Most engineers recognise the importance of specifying the correct steel strength, although 'washing machine' grade (commonly known as DX51) still finds itself used in structural applications, but how many engineers think about fracture toughness or specify the correct steel sub-grade? What about weldability or the impact of heat treatment or other fabrication processes on the steel's properties? All of these issues should be considered routinely, but this is seldom the case in practice.

Steel composition

At its most basic, steel is an alloy of iron and a small amount of carbon (up to 1.67% by mass) plus small quantities of other elements. As the carbon content is increased, so the strength increases but the ductility reduces and it becomes more difficult to weld. By keeping the carbon content low and adding other elements, steel manufacturers are able to maintain the desired strength without losing ductility, but with other potential disadvantages. The steel composition is, therefore, a critical factor to consider when selecting the appropriate steel grade for a particular application. In practice, this is dealt with by a complex classification process resulting is a range of steel 'grades'. BS EN 1993-1-1 contains a list of suitable steel grades for structural applications, such as beams and columns, along with the corresponding product standard for the steel, e.g. BS EN 10025 for structural steel. Provided that the engineer specifies the steel to the appropriate grade and the steel manufacturer makes it to the corresponding product standard, there should be no need to consider the composition any further. If, however, there is any doubt regarding the grade, for example if it is not clearly stated on the documentation or there is no mention of the product standard to which it was manufactured, the engineer should check the stated composition on the mill certificate against the composition prescribed in the standard, e.g. does it conform to BS EN 10025 S355? It is worth noting at this point that hot rolled steel sections should be supplied with a CE mark, which should include the necessary information.

Steel properties

Specifying the steel to BS EN 10025 will ensure that it is suitable for structural applications, while specifying the correct grade, e.g. S355, will ensure that it has the correct strength. However, there are three other properties that need to be considered:

- Ductility
- Fracture toughness
- Weldability

When steel is loaded in tension it follows the stress-strain relationship shown in Figure 1. Initially, the steel stretches in a reversible elastic fashion and carries the load without permanent deformation or damage. This is the state that all structural steelwork should remain in throughout its working life. If, however, the stress reaches the yield strength of the steel (f_y in Figure 1), plastic deformation will begin to occur as the steel stretches with no corresponding increase in load (the horizontal portion of Figure 1). Importantly, the load is maintained in this condition. If steel in a structural frame started to yield, the rafters would sag, but would not collapse at this point. The extent to which a material can plastically deform without failing is known as its ductility, and it is this property that ensures what when steel structures become overloaded they give plenty of warning before collapsing. Beyond the plateau, the steel actually becomes stronger through a process known as work hardening before reaching its maximum tensile strength (f_u) and, ultimately failing. The difference between the load at which the material begins to yield and the failure load provides a very useful safety margin in the case of an engineer’s miscalculations or the overloading of the frame by exceptional storms or snow drifts.

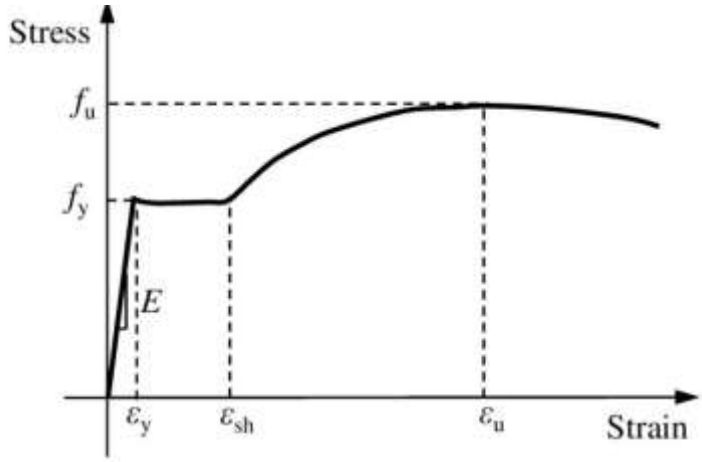

Figure 1 Stress-strain curve for carbon steel

Although steel can generally be regarded as a ductile material, its ductility is dependent on a number of factors including temperature and rate of loading. For example, a standard sample of S275 JR structural steel loaded slowly at 20°C will be ductile in nature, but the same piece of steel at -40°C loaded suddenly is likely to suffer a brittle failure. Such steel would therefore be unsuitable for use as a crane stop or crash barrier in cold climates. The difference between the brittle and ductile failures is related to the amount of energy that the steel can absorb during the fracture process and this property is referred to as the material’s fracture toughness. It was a lack of understanding of this basic principle that led to the tragic loss of the Liberty ships and numerous failures of bridges, marine and offshore structures.

The standard way of measuring the steel’s fracture toughness is with a test known as the Charpy V-notch test. In this test, a small sample of steel with a 10 mm square cross section is given a 2 mm deep V shaped notch on one side. The sample is then placed in a test machine in which a pendulum is swung at the sample to break it. Having passed through the sample, the pendulum rises to a level corresponding to its resultant energy after the impact. Subtracting this value from the initial energy of the pendulum gives the amount of energy absorbed by the fracture process. By repeating the test for a range of sample temperatures, a picture can be built of the suitability of the steel for various applications. As a general rule, any sample absorbing 27 Joules of energy or more at a given temperature, may be regarded as being ductile at that temperature, while samples that absorb less than 27 Joules are brittle.

The third property, weldability, is related to the composition of the steel and is measured by the steel‘s Carbon Equivalent Value (CEV). This is a measure of the combined content of carbon, manganese, nickel, chromium, molybdenum, vanadium and copper. The CEV determines the welding procedures that need to be followed in order to obtain a reliable weld. All weld procedures must, therefore be qualified by a maximum CEV and should not be used beyond this limit.

Engineering practice

In practice, engineers have too little time to become amateur metallurgists every time they wish to specify a piece of steel. Fortunately, the Eurocode design standards and the material product standards have dealt with the metallurgy and present the engineer with a relatively simple specification procedure. At the heart of the method is a list of suitable steel grades and their product standards, e.g. BS EN 10025 for hot-rolled open sections. All of the structural steel grades begin with the letter ‘S’, e.g. S355. By selecting one of these grades, the engineer can be sure that the steel is suitable for fabrication (i.e. weldable) and suitably ductile for structural use. The number following the S is the nominal steel strength, e.g. 355 N/mm^2. Note that this is not the necessarily the design strength of the steel f_y, since this also depends on the thickness of the steel. The issue of brittle fracture is dealt with by the use of sub-grades, e.g. S355 J0, which refers to a steel type that absorbs at least 27 Joules of energy in the Charpy V-notch test at 0°C. The selection of the appropriate sub-grade takes into account a number of factors including the proposed service temperature and will be considered in greater detail in Part 2 of this article.

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