Plate bending

Scope

This Guidance Note gives general information on procedures used for cold bending of steel plate produced (to BS EN 10025) by the reversing or coil plate mill processes. The effect of the procedures on the metallurgical and other material properties of the plate is discussed.

The intention is to clarify the metallurgical effects which can occur, to advise engineers on important product quality considerations and to describe the effect on overall performance.

Stress relieving processes are not covered.

General

The bending of plate offers the bridge designer considerable flexibility in forming tailor-made structural shapes including troughs, arches, girder haunches etc. The degree of bending will vary depending upon the particular geometry required.

Plate may be cold bent for structural applications by a number of fabrication techniques, but the most commonly used methods are the use of a press brake and roll forming.

A press brake is a machine that bends a sheet of metal in a straight line by pressing a knife-edged tool down onto the sheet; the sheet is pressed into a lower tool of appropriate shape. Press brakes are extremely flexible in terms of application and are available in a variety of sizes and capacities. Within the UK there are a small number of specialist fabricators who have machines capable of bending up to 12 m (along the bend axis) though shorter lengths up to 8 m are more common.

Roll forming is a process in which flat metal plate or strip is fed through a series of rolls and is progressively formed to a given shape. It is a continuous high volume manufacturing process and so is less suitable for conventional bridge steelwork. The roll forming process is usually carried out by building product manufacturers (rather than fabricators) on relatively thin gauge coil, due to limitations on roll capacity, typically less than 6 mm in thickness.

If non alloy structural steel is to be cold bent during the fabrication process, then consideration should be given to specifying the quality as suitable for cold forming, in accordance with clause 7.4.2.3 of BS EN 10025-2. That clause requires that the quality be designated by the symbol C at the time of ordering (e.g. grade S355J2C+N). BS EN 10025-2 also provides, in Table 11 of the Standard, information on minimum values of inside bend radii for 'cold flanging' of plate, depending upon the grade and thickness. Table 11 refers only to thicknesses less than 30 mm, since it is in this range that the vast majority of applications for cold bent plate lie. It should be noted, however, that the C designation in practice needs only to be specified where very tight centreline bending radii are involved, i.e. close to the limits in Table 11.

BS EN 10025 [1] is published in several Parts, specifying fine grain steels, steels with improved corrosion resistance and high yield steels in the quenched and tempered condition. Each of the Parts specifies forming limitations and options which can be implemented at order stage to purchase steels with suitable properties for forming.

Previous standard practice permitted cold bending of steel to an internal radius of not less than twice the metal thickness (i.e. a centreline bend radius of 2.5t). Experience indicates that no problems have been encountered when such a limit is placed on steels for use in bridgeworks.

It is important to note that the criteria relating to cold bending given in the existing product standards relate only to the 'suitability' of the material for this purpose, but give no guidance as to the resulting material properties. This point is often overlooked by design engineers, who invariably assume that the properties remain unaffected and in accordance with those for the original undeformed plate.

Simple bending theory indicates that the bending of plate to a centreline radius of 2.5t induces a surface strain of 20% (close to the ultimate tensile strain) i.e. the material can be bent without tearing. It is important to realise that the cold bending process can alter the *local* material properties, and that the steel manufacturer should be made aware, at the time of order, if the plate is to be cold bent.

The major effect on material properties of cold bending relates to the Charpy toughness (more specifically the transition temperature), and to the material ductility perpendicular to the axis of bending.

Toughness

Steel plate which has been cold bent suffers a general reduction in toughness which is evident by an increase in Charpy transition temperature, due primarily to the initial straining and subsequent strain ageing process. Note that it is the *transition* temperature which is affected rather than the upper shelf toughness.

The effect of temperature shift is included in the calculation of maximum permitted thickness values and toughness quality in BS EN 1993-1-10 [2]. For example, at a surface strain of 20%, the reference temperature T_{Ed} is reduced by 60°C (i.e. $\Delta T_{\varepsilon\mathrm{cf}} = -60°$).

These shifts in the steel Charpy transition temperature are, however, surface layer effects only and are limited to a very localised area.

Ductility

Cold bending to tight radii will cause the yield strain to be exceeded in the outer fibres of steel plate. The effect is to locally work harden the steel in these outer layers resulting in an increase in the yield strength (with a consequent reduction in the ultimate to yield strength ratio) and a reduction in elongation at failure. The reduction in material ductility applies mainly to the parallel direction with respect to principal cold straining; reductions in the transverse direction are much less significant.

It should be noted that plate supplied for bridge construction typically has elongation values in excess of the commonly required 22% (for thickness between 3 mm and 40 mm) specified in BS EN 10025-2.

It is important to remember that the work hardening effect relates only to the surface layers of a very localised area. Indeed, a significant amount of research carried out on the behaviour of cold formed tubes (formed from coil plate) indicates that performance of the section in bending is at least as good as the hot finished alternative, both in terms of moment of resistance and structural ductility. Similarly, the local reductions in Charpy toughness which occur due to cold bending in the corner areas have little effect on the overall impact performance of the cold formed tube when acting as a structural element.

Use of bent plate

The principal uses of bent plate in bridgework are:

- in flanges of haunched girders
- in webs of curved (in plan) plate girders
- as especially large angle sections (as transverse stiffeners in box girders for example)
- as trough sections in orthotropic decks
- as substitute channel or angle sections in weathering steel

When used in the above situations, the two considerations are the integrity of the steel after bending and the effect on toughness. Precautions to ensure that cracking is not introduced are discussed below. Considerations about toughness can be related to the use of the bent material.

Any reduction in toughness would be most significant if the material is subject to tensile stresses. This could affect thick tension flanges, but use in those situations will usually involve only relatively large radii (10t or more). It is unlikely that any change of quality grade would be necessary for such use.

Use as stiffeners or troughs may involve tighter radii, but the material is usually thinner and the lower value of limiting thickness given by the reduced reference temperature may be sufficient for such applications.

Precautions

The notes below give general practical precautions which will be of assistance to the designer who wishes to utilise cold bent steel plate.

- Ensure that the steel is from a supplier who adheres to a rigorous quality scheme with regular inspections.
- **Always ensure** that the cold bent areas of the plate (particularly edges) are **visually inspected** for obvious defects, e.g. dents or cracks which may act as initiators for fatigue crack growth or propagation by brittle fracture.
- In the case of cold bending heavy plates or thin plates with tight radii for use in critical locations, Magnetic Particle Inspection (MPI) may be considered to ensure no cracks are present in the highly strained corner regions.

The designer may wish to check that the fabricator exercises the following precautions:

- Ensure that the steel deforms smoothly within the press brake, and that the plastic strain is adequately distributed by the tool head.
- Exercise care if plate which has been grit (or shot) blasted is to be cold formed, as the hardening effect may lead to loss of ductility in the surface layers and the formation of localised micro cracking on the tension face.
- Exercise care if pickling and hot dip galvanizing cold bent components, because of an increased risk of incipient cracking.
- Avoid cold bending plate with edge defects (e.g. flame cut edges with visible drag lines (see GN 5.06) or notched edges), or with zones that are locally hardened. Grinding of plate edges may be carried out in order to ensure freedom from micro cracks which could propagate during bending.

Summary

Guidance on the suitability for cold bending relates only to the avoidance of tearing or cracking upon forming; it does not guarantee that the mechanical properties, particularly Charpy transition temperature and material ductility, will remain the same as for the as received plate.

The designer should appreciate that cold bending to tight radii can, in the absence of stress relieving, modify the resulting material properties, but only in the surface layers at localised areas.

No problems should be experienced in ordinary bridgework as a result of cold bending, so long as the steel plate is supplied by a quality producer and advice is sought at the time of ordering about the recommended minimum bend radii for the grade of steel.

References

[1] BS EN 10025: Hot rolled products of structural steels.
Part 1: 2004, General technical delivery conditions.
Part 2: 2019, Technical delivery conditions for non-alloy structural steels.
Part 3: 2019, Technical delivery conditions for normalized/normalized rolled weldable fine grain structural steels.
Part 4: 2019+A1:2022, Technical delivery conditions for thermomechanical rolled weldable fine grain structural steels.
Part 5: 2019, Technical delivery conditions for structural steels with improved atmospheric corrosion resistance.
Part 6: 2019+A1:2022, Technical delivery conditions for flat products of high yield strength structural steels in the quenched and tempered condition.

[2] BS EN 1993-1-10:2005, Eurocode 3: Design of steel structures - Part 1-10. Material toughness and through-thickness properties