Cold formed sections

The forming process affects the toughness of cold formed sections and their use in external structures. Welding is prohibited near the corners of cold formed sections in certain circumstances. Richard Henderson of the SCI discusses the issues.

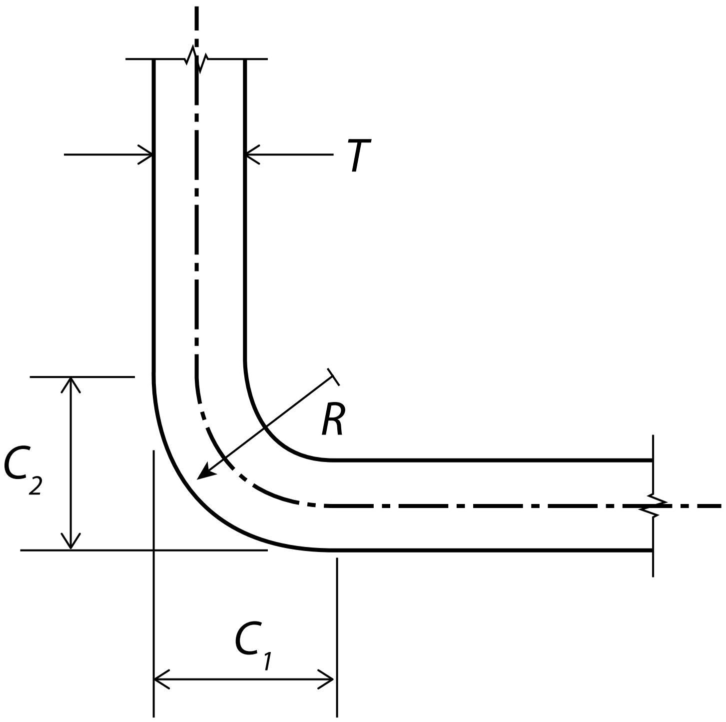

Figure 1: Corner dimensions

The toughness of steel is affected by the extent of strain it has undergone as well as by other factors. This fact is taken into account when determining the limiting thickness for materials using BS EN 1993-1-10. The limiting thickness of plate or hot rolled or hot finished structural sections does not, in general, depend on the extent of strain because such elements are not subject to plastic strain during their use, nor in the course of their manufacture. This does not apply however to cold formed square and rectangular hollow sections, which experience significant strains at the corners of the profile. Neither does it apply to beams which have been pre-cambered by cold bending.

The product standard for cold formed welded structural hollow sections, BS EN 10219-1:2006 requires that for square or rectangular sections, the test pieces for impact testing are taken either longitudinally or transversely midway between the corners from one of the sides not containing the weld. The impact values therefore relate to material which is unaffected by cold forming, thus tacitly acknowledging that the forming process affects the material toughness. According to clause 6.7.2 of the product standard, there is no requirement for impact tests for specified thicknesses of less than 6 mm.

The effect of strain during cold forming must be taken into account when determining the limiting thickness of material of a given sub-grade. According to BS EN 1993-1-10 and its UK National Annex, the reference temperature T_{Ed} for determining the toughness of a steel element:

$$T_{Ed} = T_{md} + \Delta T_r + \Delta T_\sigma + \Delta T_R + \Delta T_\varepsilon + \Delta T_{\varepsilon_{cf}}$$

where (T_{md}+ΔT_r) considered together represent the minimum effective temperature of the steel part, ΔT_R is a safety allowance, ΔT_ε is an adjustment for strain rate and $\Delta T_{\varepsilon_{cf}}$ is an adjustment for the extent of strain during cold forming.

The UK National Annex collects together factors affecting the safety of elements and gives an equation for ΔT_R as follows:

$$\Delta T_R = \Delta T_{RD} + \Delta T_{Rg} + \Delta T_{RT} + \Delta T_{R\sigma} + \Delta T_{Rs}$$

where ΔT_{RD} is an adjustment for detail type, ΔT_{Rg} for gross stress concentration, ΔT_{RT} for Charpy test temperature, $\Delta T_{R\sigma}$ for stress level and ΔT_{Rs} for strength grade. The procedure is consistent with $\Delta T_\sigma = 0$.

The temperature adjustment for cold forming is given in clause 2.3.1(2) of the standard as minus three times the percentage strain expressed as degrees Celsius. A strain of 10% would result in a temperature adjustment of –30 °C. This is potentially significant when considering the adoption of cold formed sections.

The strain resulting from cold forming SHS or RHS tubes can be determined from the limiting dimensions in the product standard as follows. Consider the corner of a box section as shown in Figure 1. The external corner profile is determined in the product standard by measuring dimensions C_1 and C_2 or R.

The length of the centre line is the original length before forming. For one corner, the centre line length is:

$$L = \frac{2\pi}{4}\left(R - \frac{T}{2}\right)$$

The outside length after forming is $\frac{2\pi}{4}R$

The change in length $\Delta L = \frac{2\pi}{4}R - \frac{2\pi}{4}\left(R - \frac{T}{2}\right) = \frac{\pi T}{4}$

The strain is $\frac{\pi T/4}{2\pi/4(R-T/2)} = \frac{T}{(2R-T)}$

The dimensional tolerances on the corner radius for different thickness ranges is taken from the product standard and used to determine the maximum percent strain due to cold forming in Table 1 (over page) by substituting the minimum external radius in the formula for strain.

The strain could therefore be as high as 45% for material less than 6 mm thick bent to the tightest radius, giving a temperature adjustment for cold forming of -3 × 45 = –135 °C when determining the limiting thickness. Such an adjustment puts

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Thickness Range (mm)	External corner profile C_1 and C_2 or R	Maximum strain	% strain
$0 < t \leq 6$	1.6T to 2.4T	$T/(2 \times 1.6T - T) = 1/2.2$	45.5
$6 < t \leq 10$	2.0T to 3.0T	$T/(2 \times 2.0T - T) = 1/3.0$	33.3
$10 < t$	2.4T to 3.6T	$T/(2 \times 2.4T - T) = 1/3.8$	26.3

Table 1: Strain due to cold forming

▶26 the relevant temperature well outside the range covered by the tables in BS EN 1993-1-10 and PD 6695-1-10.

The SCI's recent publication P419, Brittle fracture: selection of steel subgrade to BS EN 1993-1-10 addresses the acknowledged conservatism in the standard for structures where fatigue is not a significant design consideration and presents tables of limiting material thicknesses for this circumstance. However, the tables do not extend to the much lower temperatures indicated when considering the adjustments for the high strains resulting from cold forming. SCI has produced values for the relevant temperatures and these are given in Table 2 for S355J2 material (the common steel grade for hollow sections).

As an example consider a cold formed section of steel grade S355J2 with thickness in the range 0 to 6 mm used in an external building environment where fatigue is not a design consideration, with a high design stress ($\sigma_{Ed} > 0.5f_y$), no gross stress concentration and with a welded detail classed as "Welded very severe".

Temperature adjustments are given in Table 3:

From Table 2, the limiting thickness of the cold formed section is 5 mm. Limiting thicknesses for sections in the higher thickness ranges in the product standard are given in Tables 4 and 5 for details classed as "welded very severe" and "welded severe".

Table 5 also applies to a detail which is classed as "welded very severe" and has a design stress of less than $0.3f_y$.

An examination of the sizes in the Blue Book shows that certain sections should not be used if the attributes of a connection detail correspond to those in Table 4. If the detail corresponds to the description in Table 5, there is no restriction on the catalogue sizes which could be used.

The strain involved in cold forming circular hollow sections

Material S355J2	Stress level $0.75f_y$											
Temperature (°C)	-70	-80	-90	-100	-110	-120	-130	-140	-150	-160	-170	-180
Thickness (mm)	54	40	30	32	18	15	12	10	8	7	6	5

Table 2: Limiting thicknesses for low temperatures

Adjustment	$(T_{md} + \Delta T_r)$	ΔT_{RD}	ΔT_{Rg}	ΔT_{RT}	$\Delta T_{R\sigma}$	ΔT_{RS}	ΔT_{ε}	$\Delta T_{\varepsilon cf}$	Total
Temperature (°C)	-15	-30	0	0	0	0	0	-136	-181

Table 3: Temperature adjustments for determining limiting thickness

is much less than that at the corners of square and rectangular sections (about 10% in the worst case) and there is consequently no restriction on the choice of cold formed circular hollow sections, even with the presence of a gross stress concentration.

Designers will also remember that BS EN 1993-1-8:2005 Clause 4.14 and Table 4.2 imposes restrictions on welding near cold formed zones. The table is entitled 'Conditions for welding cold formed zones and adjacent material' and gives maximum thicknesses based on an *r/t* ratio or strain due to cold forming. Unhelpfully, the radius considered in the clause is the internal radius of the corner, whereas the product standard BS EN 10219-2 uses the external radius (external corner profile). The corresponding *r/t* values and limiting thicknesses are given in Table 6 (below right).

The clause therefore prohibits welding within 5 times the wall thickness of the corners of many square and rectangular cold formed sections, unless the steel is "fully killed Aluminium-killed steel (Al ≥ 0.02%)", with limits on carbon (C ≤ 0.18%,), phosphorous (P ≤ 0.02%) and sulphur (S ≤ 0.012%). Alternatively, tests must have been carried out to show that welding is permitted.

Table A1 in Annex A of the product standard indicates the steel is fully killed steel with a minimum 0.02% of total aluminium. The table gives the chemical composition of the steel and includes maximum percentages by mass of carbon (C ≤ 0.22%), phosphorous (P ≤ 0.03%) and sulphur (S ≤ 0.03%). The material therefore satisfies the requirement for fully-killed aluminium killed steel but allows the percentage of carbon, phosphorous and sulphur to fall outside the limits specified in Table 4.2.

This restriction prohibits the adoption of a welded end plate or base plate for most rectangular and square cold formed hollow sections which comply with the product standard but do not meet the tighter requirements for carbon, phosphorous and sulphur in Table 4.2.

Design detail	Thickness range (mm)	Temperature adjustment (°C)	Maximum thickness (mm)
no fatigue; external steelwork, welded very severe, high design stress (>0.5f_y) no gross stress concentration, S355J2H	$0 < t \le 6$	-181	5
	$6 < t \le 10$	-145	9
	10 < t	-124	13

Table 4: Detail classed as welded very severe (equivalent to -30 °C in NA.1)

Design detail	Thickness range (mm)	Temperature adjustment (°C)	Maximum thickness (mm)
no fatigue; external steelwork, welded severe, high design stress (>0.5f_y) no gross stress concentration, S355J2H	$0 < t \le 6$	-171	6
	$6 < t \le 10$	-135	11
	10 < t	-114	16

Table 5: Detail which is classed as welded severe (equivalent to -20 °C in NA.1)

Product standard thickness range (mm)	Product standard tolerances based on *R*	Table 4.2 Corresponding *r/t*	Table 4.2 "worst case" maximum thickness (mm)
$0 < t \le 6$	1.6*T* to 2.4*T*	0.6 to 1.4	not given
$6 < t \le 10$	2.0*T* to 3.0*T*	1.0 to 2.0	6
$10 < t$	2.4*T* to 3.6*T*	*1.4 to 2.6*	6 (out of range)

Table 6: Maximum thickness for welding related to the product standard