2. Cutting and Forming Steel

Steel stock is supplied in standard shapes and it requires working to turn it into useful items. Various methods are used to cut and shape stock material into components. Welding or mechanical fastening is then used to join components to form the desired structure.

The process of cutting and shaping performs a philosophical change to stock material. It is no longer just a piece of material, but a component of the structure, and it now needs to be treated as such. If the final structure is made of a large number of different components, each needs to be identified to distinguish it from the others.

AS 4100 requires, that all structural steel shall be identified. As a minimum, each piece stock material should be marked with its specification and grade or a colour code. Where traceability is required, it also needs to be marked with the heat and plate number. Prior to cutting from stock material, components should be marked with their identification and (where specified) heat and plate numbers. The normal method used to identify a component is by its fabrication drawing number and piece mark, and it is not normal to transfer the material grade. Where there are a number of identical items that have to be uniquely identified (such as weldments), each is given a sequential number by the fabricator. Where specified, the transfer of marks should be witnessed by an inspector.

Processes for transforming stock material to a component include cutting, forming, joining, heat treatment and finishing. The cutting and forming processes are described in this section. Heat treatment is described in the next section and joining processes are described at length later in this volume. Finishing processes (painting and galvanising) are not included in this publication.

The people that do the marking out, cutting, forming and tack welding of structural steel are traditionally boilermakers, and they will have undertaken trade training in boilermaking. The tradesman welder would undertake his task independently. Today apprenticeships in Metal Fabrication have replaced boilermaking and welding. As well as vessels and structure, these tradespeople are trained to undertake pipe assembly. They also are trained to weld, and so develop multiple skills.

2.1. Mechanical Forming

Most components are cut from stock material without any shaping. Some require mechanical forming or plastic working to create the desired shape.

Processes used to shape ingots or blooms into stock material such as plates, bar and rolled sections are known as primary forming processes and involve heavy, usually compressive deformations and are usually undertaken hot. These processes include rolling and extrusion and cause a major change in the thickness and shape of the material. The analysis of these processes is different to the secondary forming processes and is beyond this publication.

The processes used to form stock material into components are secondary forming processes. They include forging, but this is done by specialist forgemasters and the fabricator is only rarely involved in it. Wire drawing and deep drawing are also secondary forming processes, but are beyond the scope of this book.

The forming processes the fabricator commonly uses could be described as contouring in that there is not intended to be any change in thickness. The processes used are predominantly bending: press bending, roll bending and spinning. These are usually performed cold, but some specialist fabricators may undertake hot forming. Shearing and machining can also be considered to be forming processes as they involve plastic work.

2.1.1. Forming Equipment Design

Most fabricators have rolls to bend flat bars, sections or plates into curved components such as cambered beams or vessel shell plates. These rollers use three-point bending to create the required curvature. Roll bending differs from the rolling of ingots in that there is no reduction of thickness.

Bending presses are used to form dished plates, such as those for spherical vessels, and for bending the ends of curved members that cannot be rolled. Presses are also used to form sharper bends, for example to stiffen plate edges.

Pure bending is only achieved in an ideal arrangement, and real bending equipment will generate frictional forces. Sometimes tension is applied along the length of the material.

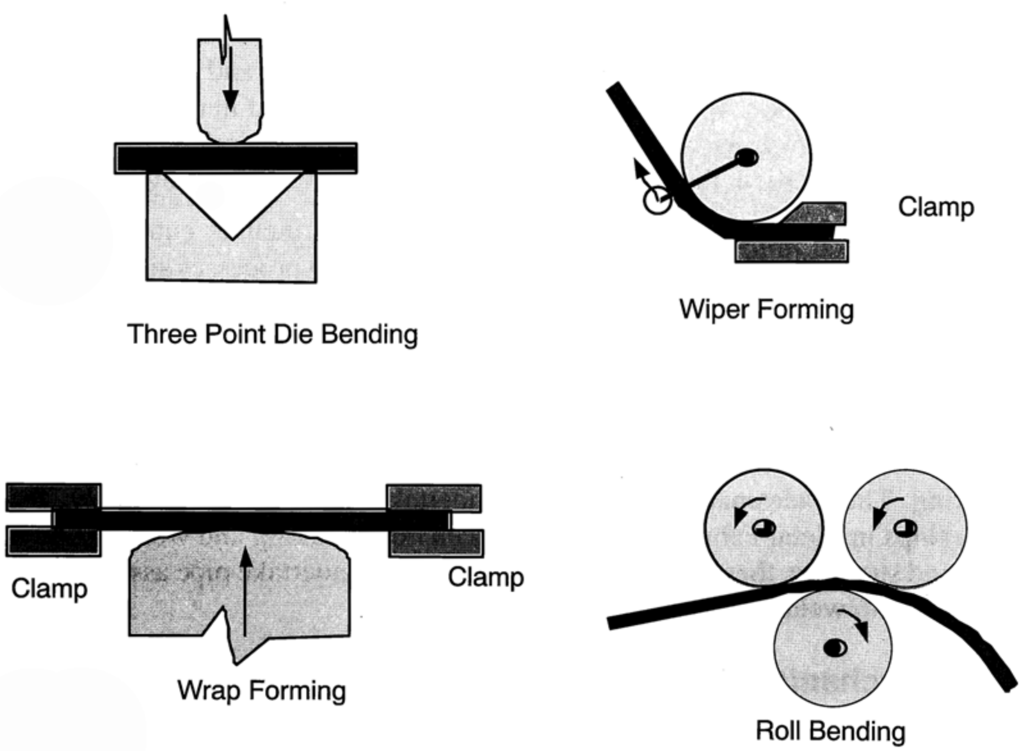

Figure 3 Bending Methods

In practice, four forming methods are used; three-point die bending, wiper forming (draw bending), wrap forming and roll bending. These are shown in Figure 3.

Much bending can be undertaken with standard tools. In other cases, specialised dies are required to handle particular shapes. Where complex sections, such as tubes, tees or angles are to be formed, or complex shapes are required it is necessary to ensure the fabricator has the required equipment. A dialog with potential fabricators at design stage can allow some novel solutions.

2.1.2. Flame straightening

It is possible to use spot heating methods to form simple shapes where the fabricator does not have mechanical working equipment. A spot or area on the inside of the desired bend is intensely heated to create a temperature gradient, and to lower the yield stress in the hot area. Thermal expansion is constrained by the surrounding material or by jigs leading to compressive yielding or upsetting, so that when the heat is removed, the material bends in the required direction. This method of forming is commonly used to straighten distorted components. Australian Standard AS 4100 limits the temperature to a maximum of 650°C for this process to avoid changing the mechanical properties.

2.1.3. Analysis of Simple Bending

In simple bending, the material is subjected to shear forces that create tension on the outside of the bend and compression on the inside. Bending is only in one plane (single curvature), and does not involve dishing. The loads are pure bending, with no frictional or clamping forces leading to longitudinal loads. The material surfaces become circular. For the pure bending formulae of Equations 1 and 3 to apply, the bend radius is large and the deformation elastic.

The highest tensile strain is on the outside of the bend, and in uniform material, over-bending failure will invariably occur at the outside of the bend. The inside of the bend is in compression and at some point inside of the material, there is a plane where no strain occurs. This is known as the neutral plane or neutral axis. In pure bending of plane sections, the neutral axis is in the centre of the section. Figure 4 shows the situation.

The strain at any point a distance z from the neutral axis is determined from Equation 1.

$$Strain = \frac{Extension}{Length} = \frac{z\theta}{r\theta} = \frac{z}{r} \quad \text{Equation 1}$$

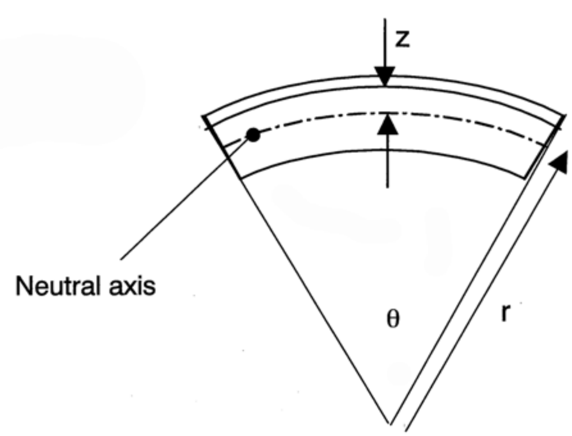

Figure 4 Pure bending

If the section is a plate and it is assumed the neutral axis is in its centre, Equation 1 can be written as Equation 2. In this formula, S is the percentage maximum tensile strain, t is the thickness, R_f is the final outside radius and R_o is the initial inside radius.

$$S = \frac{50t}{R_f}\left[1 - \frac{R_f}{R_0}\right] \qquad \text{Equation 3}$$

Pure bending only roughly approximates the real situation in simple bend forming, and then only for large bend radii. Treatment that is more complex is required for tight angle bends, even where yielding does not occur. Once yielding occurs the material rarely behaves the same in tension as in compression and the neutral axis is displaced towards the compression side. Its position will displace more the tighter the bend radius, the greater the material thickness and the higher the work hardening rate. Work hardening complicates the stresses. Once one element work hardens, yielding occurs in the adjacent elements that have less work hardening and a lower yield stress. The maximum tensile strain is therefore always higher than theoretically determined, and is difficult to predict. Equation 3 only applies for pure bending, yet it is used in AS 4458 to determine the limit of simple cold bending.

Pure bending can only occur if there are no longitudinal loads. In practice, the bending equipment grips the material causing longitudinal tension, and this has the effect of moving the neutral axis towards the compression side. The magnitude of the tension force is variable and is dependent on thickness, equipment design and lubrication.

2.1.4. Limitation of Cold Bending

For convenience bend radii are conventionally measured on the inside of the bend and expressed as a factor of T, the section thickness. A 2T bend in a 10mm plate has an internal radius of 20mm (or a diameter of 40mm).

If the bend radius is too tight, failure by cracking on the outside of the bend can occur. The minimum radius is determined by the ductility of the steel. Low strength grades of steel (AS 3678 Grades 200 and 250) are more ductile than higher strength grades and therefore can be bent to tighter radii. Steel standards AS 3678 and AS 3679.1 contain recommended minimum bend radii that are safe for most applications. Minimum bend radii are dependent on the method of manufacture and the steel manufacturer may allow tighter radii for some grades. However, the material standard and manufacturer's recommendations should be used with caution as they usually assume that bending is simple. Where complex bending is being undertaken as described below, the minimum bend radii should be considerably increased.

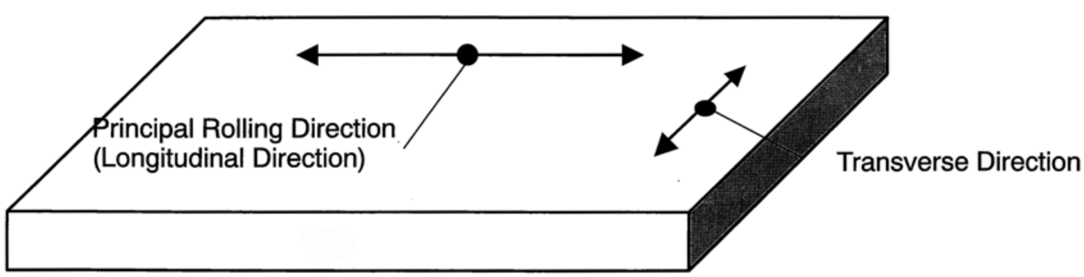

Figure 5 Plate Texture

Long products have a texture induced by the rolling process used in their manufacture. The metallurgical structure and any inclusions tend to be strung out along the length of the product. These materials therefore have better ductility parallel to the principal rolling direction, and the recommended bend radius when the bend axis is in the transverse direction is smaller than if it is in the longitudinal direction.

Cold bending should not be performed at temperatures likely to result in brittle failure. The temperature of the material before bending should be more than 15°C for most thicknesses, but preheating thicknesses of over 20mm to 75°C is recommended to avoid brittle failure.

2.1.5. Complex bending

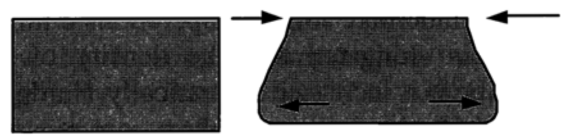

Figure 6 Deformation of a Bar Cross Section on Bending

Roll bending of plate can be assumed to approximate the simple bending circumstances described above, but other situations are more complex.

When plates are bent, the stresses at the plate centre are in one plane. At the plate edges stresses normal to the plane of bending can develop. Cracking at the edges can occur, particularly if they have a rough profile, and it is recommended flame-cut edges be ground where they may be subjected to high bending strains. Where rectangular bar sections are bent, the edges are likely to deform changing the shape of the cross section as shown in Figure 6. It is likely the material will thin because it is less supported from deformation perpendicular to the plane of bending.

If complex sections are bent, such as angles, channels or tee sections, the position of the neutral axis is closest to the heavier part of the section. If the lighter part is in compression, it is likely to buckle. If it is in tension, it is likely to crack.

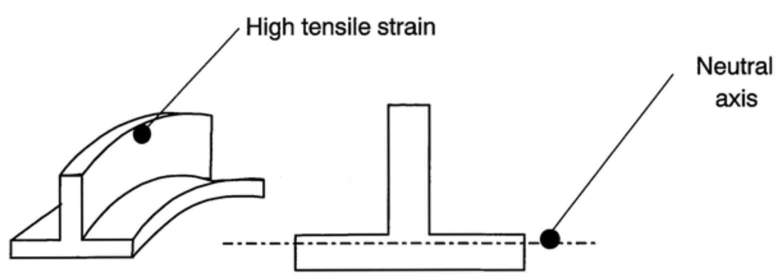

Figure 7 Deformation of a complex section

CHS, SHS and RHS are also frequently bent. In this case the surface inside the bend can buckle or pucker if the bend radius and wall thickness are both small. This can be overcome by tensioning along the tube axis, and specialist pipe bending equipment often has provision for this (draw bending). Purpose-made tube bending machines use the wiper forming arrangement. The former is contoured so that the tube is supported over as much of its area as possible so that it remains circular or rectangular. The tendency for the section to distort (flatten) can also be prevented by filling the tube with a support material such as dry sand or by using an internal mandrel. The minimum bend radius is determined by the tendency for the inside surfaces to pucker and the outer surfaces to thin and is a function of the diameter and wall thickness.

Tubes to AS 1163 are manufactured by cold forming from sheet or plate and welding the edges together. This means the material is already cold worked, and it will have lost some

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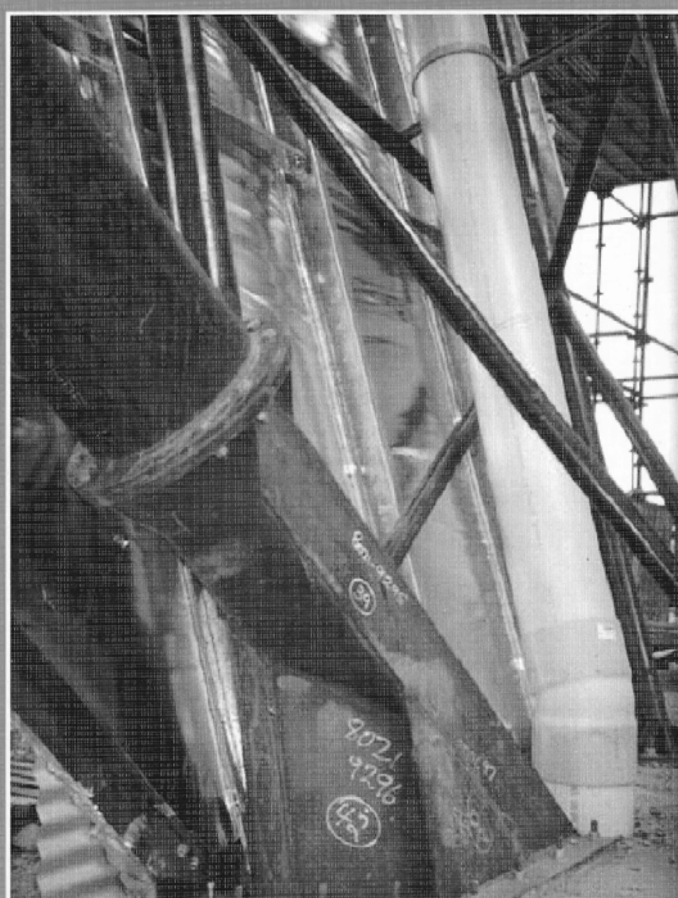

by John Taylor BSc, Sen.MWeldI

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