Thermal cutting of structural steels

No. 5.06

Scope

This guidance note relates to the thermal cutting of structural steels in the fabrication of bridge steelwork and covers the flame and plasma processes. Laser cutting has gained some popularity in ship building for cutting relatively thin material, but there are considerable health and safety problems in controlling and containing the cutting beams. It is seldom used in bridge construction at present.

The flame cutting process

The process functions on the principle that a jet of pure oxygen is directed at a surface that has been preheated to its ignition temperature. The material in the path of the jet is oxidised and ejected, resulting in a cut. Figure 1 shows a diagrammatic view of this process.

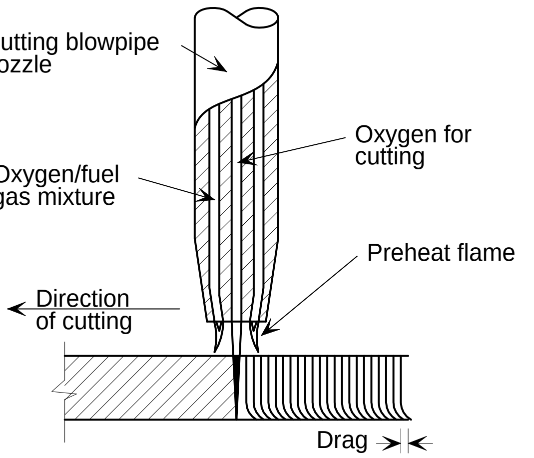

Figure 1 *Flame cutting of metal*

The process does not function on all metals; the following conditions must be satisfied:

- The ignition temperature of the metal must be lower than its melting point. (The ignition temperature is the point at which the metal will ignite in pure oxygen.)
- The melting point of the oxide must be lower than the ignition temperature of the metal so that the oxide can be ejected from the cut by the force of the oxygen jet.
- The heat generated by the oxidation reaction must be high to perpetuate the cut, while the thermal conductivity of the metal must be low in order to contain that heat.

These conditions are satisfied by structural steels.

The plasma cutting process

In plasma cutting, gas is transformed into plasma when it is heated, which results in extremely high temperatures of up to 27,000°C being generated. Figure 2 shows a diagrammatic view of this process.

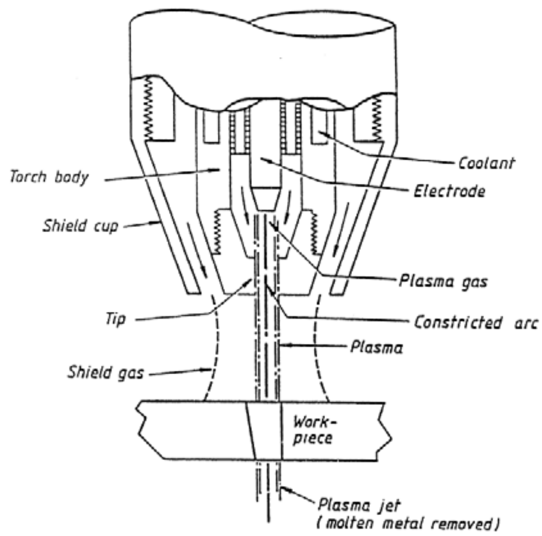

Figure 2 *Plasma cutting of metal*

The plasma arc cutting process severs metal by means of this highly constricted arc jet, which has sufficient energy and force not only to melt the metal but also to eject the molten material. Because melting rather than oxidation produces the cut, plasma cutting can be used to cut any metallic material. It requires no preheat and produces minimal distortion in the material being cut.

Plasma cutting has been in use for bridge construction for a number of years. Cutting speeds are relatively high, and the cut surface tends to be harder than the equivalent flame cut surface. Cutting is normally carried out under water, to limit the production of ozone and oxides of nitrogen. It also reduces the noise and light emissions.

Quality of cut surface

In order to achieve a good quality cut the following parameters require control:

- The cutting speed;
- The distance from the cutting nozzle to the work piece;
- The cutting nozzle size and condition;

- The pressures of the heating fuel gas and oxygen (flame cutting);
- The pressure of the cutting oxygen (flame cutting);
- The power setting (plasma cutting).

The overall degree of control of the movement of the cutting head is also very important. This is a matter that has improved greatly with modern CNC (computer numeric controlled) equipment, leading generally to a much squarer and more uniform cut than could previously be consistently achieved.

EN 1090-2 (Ref 1) specifies standards of cut surface quality in terms of squareness (perpendicularity/angularity) and depth of drag line (mean height of profile). However, these parameters are only appropriate to laboratory conditions, so the assessment of flame cut surfaces on the shop floor is best achieved by having available samples which have been calibrated to the particular quality requirement, so that they can be used as comparators.

Figure 3 shows three flame cut surfaces. The right hand side shows surfaces slightly weathered and the left hand side shows the effect of blasting with chilled iron grit. All three samples were assessed on their as-cut surfaces in accordance with the provisions of EN IS0 9013 (Ref 2) for depth of drag line. In the upper sample the depth is well within Range 3 and the middle sample is slightly over the limit for Range 3. The lower sample is well above Range 3, but within Range 4.

The Range 4 standard required for EXC3 can be achieved with as-cut surfaces with both processes, but a plasma cut surface is unlikely to comply with the Range 3 squareness standard for EXC4. This would not normally matter except where the surface was required to be fitted to another component.

Individual / isolated defects in the cut surface, such as gouges (see Figure 4) can occur from time to time. These are unacceptable in bridge work and should be dressed out by grinding to a smooth profile. Weld repair of such defects should only be considered as a last resort for deep gouges, and such repairs should always be subjected to surface crack detection after welding.

Drag Lines

Despite controls exercised on the matters listed above, the thermal cutting process tends to lead to the formation of drag lines on the surfaces of the cut. A 'drag line' is defined in BS 499 (Ref 3) as "Serration left on the face of a cut made by thermal cutting", and the standard goes on to define 'drag' as "The projected distance between the two ends of a drag line" (i.e. measure relative to a line square to the material surface - see Figure 1).

When equipment settings are perfectly adjusted, it is possible to produce a cut with an extremely smooth and flat surface, where drag lines are not readily apparent (i.e. the serrations are very shallow, or the 'depth of drag line' is small). However, maintaining all the variables within the bounds that produce this standard, on components of the scale encountered in bridge work, is very difficult, and drag lines are usually evident to some extent.

In Table 8.1 of EN 1993-1-9 (Ref 4) there are fatigue categories for plain members with and without drag lines. Detail 4, category 140, requires that all visible discontinuities are removed while Detail 5, category 125, allows "shallow and regular drag lines". Both of these categories will only govern fatigue life of the member where there are no transverse butt welds, no fillet weld attachments and no drilled holes (all of which are lower categories), and as such the requirement for ground edge surfaces for fatigue reasons is unusual in bridge construction. Note also that the UK NA to EN 1993-1-9 requires special testing and inspection for category 140.

If Detail 4, category 140 is needed in exceptional cases, grinding should only be specified at those locations.

In the past, regrettably, it has often been the case that grinding all cut edges has been specified, with a disregard for the costs that are being added for no benefit in performance. EN 1090-2 defines hardness limits and the SHW clause 1806.4.4 identifies where grinding is necessary.

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Hardness of the cut surface
The main purpose of controlling the hardness of a cut surface is to avoid degrading the properties which control the susceptibility to fatigue and brittle fracture.

Optional limits on the hardness of thermally cut free edge surfaces are given in clause 6.4.4 of EN 1090-2 but they are not a result of direct research into thermal cutting; they have been imported from welding research. The limit for S355 steel to EN 10025 is given as 380 HV10 but there is no mention of the fact that it is not possible to achieve that level of hardness when cutting with plasma.

When flame-cutting, slower cutting speeds help to reduce surface hardness and most fabricators use cutting speeds below those recommended by equipment manufacturers for this reason. Excessively slow cutting speeds result in a rough and irregular cut surface as the preheating temperature gets too close to the melting point of the material.

Plasma cutting has a narrower "window" of settings that will produce straight clean dross-free cuts so there is little that can be done to adjust the process to reduce the hardness of the cut surface. Bridge parts such as webs, flanges, stiffeners and cover plates up to 30 mm thick are routinely cut using plasma, and hardness values for S355 steels cut by this process typically lie between 400 and 600 HV10.

Research carried out in the US and by Corus in the UK has shown that this increased hardness has no effect on fatigue resistance. There are indications however from a small number of impact tests carried out by Corus on small un-notched specimens at -100°C that it slightly reduces the resistance to brittle fracture. There are practical difficulties however with obtaining impact results from un-notched specimens, so the amount of data available is not sufficient for a proper quantitative comparison to be made. This reduced resistance is also confirmed by the fact that untreated plasma-cut surfaces tend to crack when cold-formed.

Machine plasma cut edges have therefore been exempted in particular cases from the edge hardness limits in Table 10 of EN1090-2. The exemption, detailed in SHW clause 6.4.4(2), is restricted to certain steel grades and Quantified Service Categories, and only applies where the edge surface is free of stress-raising features and will not subsequently be cold-formed. It is also a requirement that the hardness does not cause difficulties with the preparation of the surface for corrosion protection.

Where a hardness limit specified in Table 10 is applicable, the processes that are likely to produce local hardness (thermal cutting, shearing, punching) shall have their capability checked. The check of the capability of the processes shall be as specified in 6.4.4. The procedures for checking the capability of the processes should observe a similar discipline of drafting, testing and certification as for welding procedure specifications.

Suitable surface for sprayed metal
A note at the end of clause 10.2 of EN 1090-2 warns that thermally cut surfaces are sometimes too hard for blast cleaning to achieve the specified surface roughness and might therefore have to be ground. Grinding will ensure that a suitable blast profile can be achieved to enable sprayed metal coatings to adhere. There are, however, two other and equally valid methods of achieving adhesion; they are:

1) After general blast cleaning with chilled iron grit, thermally cut faces are blasted with alumina grit. This provides a sharp profile on harder surfaces, suitable for the application of flame sprayed aluminium or zinc.
2) Use of the electric arc method of spray application. This achieves adhesion values in the order of four times that of the more common flame spray process in the case of sprayed aluminium; it can therefore tolerate a lesser blast profile to achieve the required adhesion. If an applicator or fabricator proposes to use this technique it is advised that he should be asked to demonstrate the resulting adhesion levels by test. In the case of sprayed zinc, however, the process offers no increase in adhesion.

Adhesion testing of sprayed metal
The SHW 1900 series (Ref 6) calls for adhesion trials in the form of pull off tests on sample plates of the same grade as the parent plate being coated. A successful procedure trial on this basis gives little indication of the adhesion performance on thermally cut sur-

faces. If there is an adhesion problem the probabilities are that it will be on a thermally cut surface.

Specifiers would be well advised to supplement the provisions of SHW clauses 1910 and 1915 by requesting a method statement for the application of sprayed metal to the flame cut surface of the thickest material anticipated in the particular project, and a procedure trial in the form of a pull-off test on such a cut surface.

Production tests for adhesion on thermally cut surfaces are best carried out by grid test, as defined in BS EN ISO 2063 (Ref 7).

References

1. EN 1090-2:2008+A1:2011, Execution of Steel Structures and Aluminum Structures, Part 2: Technical Requirements for the Execution of Steel Structures.
2. EN ISO 9013:2002, Thermal cutting - Classification of thermal cuts - Geometrical product specification and quality tolerances
3. BS 499: Part 1:2009, Welding terms and symbols - Glossary for welding brazing and thermal cutting
4. EN 1993-1-9:2005, Eurocode 3: Design of Steel Structures, Part 1.9: Fatigue
5. Manual of Contract Documents for Highway Works, Volume 1, Specification for Highway Works, Series 1800, Highways TSO, 2014
6. Specification for Highway Works, Series 1900, Protection of steelwork against corrosion, 2005.
7. EN ISO 2063:2005, Thermal spraying. Metallic and other inorganic coatings. Zinc, aluminium and their alloys.

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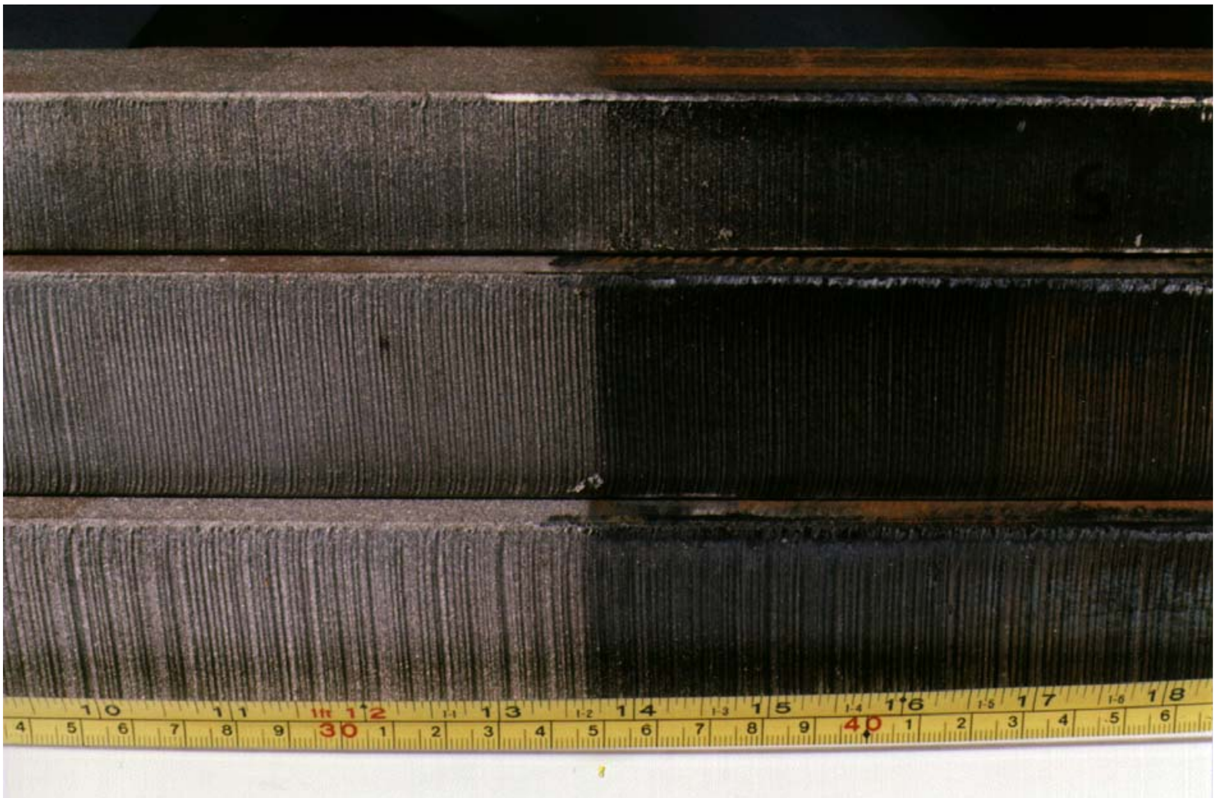

Figure 3 *Drag lines produced by flame cutting*

Figure 4 *Unacceptable isolated defects in flame cut surface*