STAINLESS STEEL
INFORMATION SERIES

sassda
southern africa stainless steel development association

THE FABRICATION OF STAINLESS STEEL

Stainless steel is seldom used as plain unworked sheets, bars or sections and is normally formed into complex shapes, often to optimize its their properties and/or cost. The fabrication of stainless steel occurs in several ways:

- Cutting to shape or a manageable size for subsequent fabrication
- Cold forming or deep drawing
- Machining, drilling, tapping and other similar processes.
- Welding and joining

As these are relatively complex topics they will be separated and covered individually in the next several modules.

These processes are all strongly influenced by the physical and mechanical properties of the various types (or families) of stainless steel, which have been covered in earlier modules of this series, and it is suggested that these be read in conjunction with the next modules.

The module on Welding of Stainless Steel was also the topic of a previous module and will not be re-visited here.

THE CUTTING OF STAINLESS STEELS

The main types of cutting are mechanical cutting and thermal cutting. The first three sections of mechanical cutting are strongly affected by the mechanical properties and work hardening characteristics of the various grades.

MECHANICAL CUTTING

SAWING

- High quality blades of High Speed Steel should be used. Sharp teeth are essential.
- An emulsion of soluble oil is used as a cutting fluid. More dilute emulsions are needed for cutting austenitic (300 series) steels to improve the cooling rate.
- All grades of stainless steel, both wrought and cast, can be sawn.

The sawing of austenitic grades (300 series) and duplex grades is made more difficult by the high rates of work hardening experienced.

In these grades the cut must be initiated without any riding of the saw on the work, a positive feed pressure must be maintained, and no pressure, drag or slip should occur on the return stroke.

HAND HACKSAWING

Generally used for random cutting of light gauge material, small diameter bar, tube and pipe. A blade with a wavy set is preferable. For thin gauge sheet and thin wall tubes a fine 32 teeth per 25 mm blade is necessary. As the thickness of the material being cut increases, the coarseness of the blade should be increased to 24 teeth per 25 mm.

POWER HACKSAWING

Cutting fluid should be flooded on the cut to maximise the cooling, particularly in cutting the austenitic and duplex grades.

More than one tooth should be in contact with the work at all times. This necessitates small pitched blades for cutting thinner gauges and small diameters. As the material thickness or diameter increases the tooth spacing should increase to give better clearance and to minimise chip packing:

Up to 6 mm thick/diameter
6-20 mm - 10 teeth per 25 mm
6-10mm thick/diameter
20 - 50 mm - 10-8 teeth per 25 mm
10-25mm thick/diameter
>50mm – 4-6 teeth per 25 mm

SHEARING

Stainless steel has greater strengths than low carbon (mild) steel. The tendency of austenitics and duplex grades to work harden has a significant effect on the shearing of stainless steel.

More power is therefore required, and it is necessary to de-rate the shear (guillotine) against its nominal capacity, which is usually given in terms of the thickness of low carbon steel that they are capable of shearing.

Indicative de-rated capacities are as follows:

Low carbon (mild) steel
10 mm thick material
Utility ferritics (3CR12)
7 mm thick material
Ferritic stainless steels (e.g. 430)
7/8 mm thick material
Austenitic material (e.g. 304, 316)
5/6 mm thick material
Duplex material (e.g. 2205, 2101)
5/6 mm thick material

Cutting speeds and feeds	Strokes/ minute	Feed per Stroke
Wrought Utility Ferritic Stainless Steel - 3CR12	90	0,15mm
Wrought Ferritic Stainless Steel	90	0,15mm
Wrought Martensitic Stainless Steel (Harder) Wrought	75	0,15mm
Martensitic Stainless Steel (Softer)	100	0,15mm
Wrought Austenitic Stainless Steel	80	0,15mm
Cast Ferritic Stainless Steel	75	0,10mm
Cast Austenitic Stainless Steel	65	0,10mm

All steel is assumed to be in the annealed (softened) condition metal. The molten products are removed by the gas jet.

PLASMA GASES

Many gases can be used in a plasma-arc torch, provided they do not have an adverse effect on the tungsten cathode or the metal being cut. The efficiency of the gas in terms of the thickness and the speed of cut depends on its thermal conductivity as a plasma at the high temperatures.

The traditional gases used for the cutting of stainless steels are the inert gases argon, nitrogen, hydrogen and helium. Argon is easily ionized but has a low thermal conductivity at high temperatures. Nitrogen has better thermal conductivity and is therefore added to enable the cutting of thicker material. Hydrogen has a high thermal conductivity, and therefore should be utilized for improved cutting capabilities and efficiencies of thick material (over 12 mm). Mixtures of any two, or all three of these gases are usually employed. Helium also has a high thermal conductivity, but is seldom used because of its high cost.

The use of nitrogen under conditions employing high arc currents can lead to the formation of relatively large amounts of nitrogen dioxide - a brown gas. This is highly poisonous, and all due precautions should be taken.

Active gases such as carbon dioxide (CO2) and compressed air can also be used. The use of such active gases requires torches and nozzles specifically designed for their use.

CO2 is used in conjunction with N as the plasma gas, the CO2 performing the function of an annular shielding gas.

Compressed air may be used alone as the plasma gas, and the plasma arc temperature is complemented by the exothermic (heat generating) reaction which takes place, thus reducing the electrical energy required.

Active gases are claimed to induce change in the chemical composition of the surface layers of the cut-edge, which could affect the corrosion resistance. This should be borne in mind, and such edges should be dressed to ensure corrosion resistance equivalent to the parent material. In general terms the use of active gases is limited to thicknesses up to approximately 30 — 40 mm, after which their cutting efficiency falls off, usually requiring the use of nitrogen/h mixed plasma gases, which are necessary for such thicknesses.

Selection of the appropriate gas is often machine-dependent, and should be discussed with your machine supplier.

The width of the kerf tends to be greater than that obtained by conventional oxy-gas cutting of carbon steels. The kerf width is affected by parameters which include stand-off distance, electrode positioning within the nozzle, electrode shape, method of electrode dressing/grinding, nozzle size, cutting speed and thickness of material being cut.

Further, a kerf angle is a typical feature. If process parameters are not carefully controlled this angle can increase to an unacceptable degree. The kerf angle should be less than 5°, and can be reduced to 1°. The cut edge should be smooth, clean, and have a very small heat affected zone (HAZ) adjacent to the cut edge.

Depending on the type of thickness of material to be cut, the following are the main variable parameters:

- Arc Current (amps)
- Plasma Gas - flow rates and mixture ratios
- Nozzles - size, shape and design which affect the
- Cutting speed and quality of cut
- Width and shape of cut.

LASER CUTTING

This utilises the vast amount of heat liberated when a Laser Beam (intense monochromatic light) strikes the workpiece. The heat is sufficient to melt or vaporise even the most heat resistant refractory materials.

The cost of the equipment is relatively high but the efficiencies gained by the speed of the process, the ability to achieve tight nesting of components and the limited heat effect on the cut edge has now made laser cutting the preferred cutting process for many applications.

Although laser energy has been used for quite some time, recent improvements in beam quality has extended the capability of lasers, to that of fast high quality precision cutting up to 12mm thick stainless steel. These high speeds are attained via high powered (8Kw) laser systems which generate temperatures beam temperatures in excess of 35 000°C.

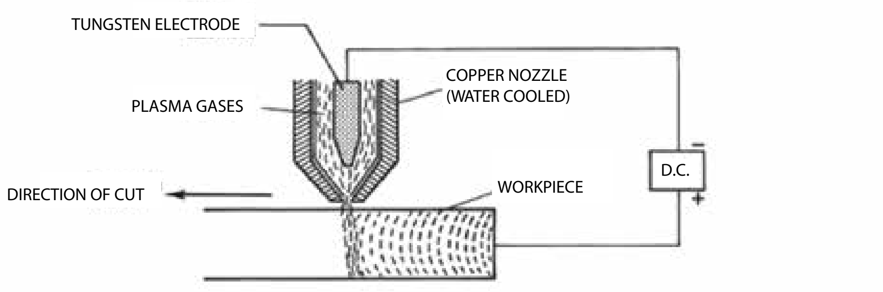
A laser beam is a high energy heat source that can be focused to a very small spot, thus achieving extremely high power densities.

Laser cutting has the advantages of very high speeds, narrow kerf widths, high quality cut edges, low heat inputs and minimal workpiece distortion. The process can cut any material and can easily deal with stainless steels. It can only be automated and thus integrated into a programme controlled system for optimal use.

The disadvantages of laser cutting versus plasma cutting lie in the thickness limitation; however, with the development of higher powered Laser systems these limitations will soon be overcome.

In all cutting operations carried out on stainless steels the following points are important:

- No contamination by ferrous (iron or steel) material or particles should take place.
- Mechanically cut edges will naturally form the corrosion resistant passive film. The formation of such a passive film on cut edges will be enhanced by a chemical (acid) passivation treatment with Nitric Acid.
- Thermally cut edges may be affected in terms of chemical composition and metallurgical structure. Removal of affected surface layers by dressing is necessary so that impaired areas of mechanical and corrosion resistant properties do not exist.
- Any heat impaired surface adjacent to the cut edge must always be restored to full corrosion resistance by pickling and passivation of this narrow zone. SS



Schematic illustration of Plasma Arc Cutting with a Transferred Arc without lubrication. However, the use of a lubricant reduces the power required, and also improves tool life. Lubricants that can be used include emulsifiable chlorinated waxes/oils, wax based pastes, soluble oils and soap plus borax.

Clearance between the punch and the die is important. For the thinnest gauges of material, a minimum clearance of 0.025mm per side is suggested. For thicker sheet the clearance per side should be between 5% and 10% of material thickness, and for plate thicknesses the clearance per side may be increased to 15% of the material thickness.

Blanking, perforating and punching are severe applications, involving both shock and abrasion. A range of tool steels may be utilized, depending on the aspects of the particular job, and the production quantity required. Proper heat treatment by quenching and tempering must be employed to develop the necessary combination of properties, i.e. hardness, wear resistance and toughness.

For example, in a job where the punch is subject to a high level of shock, it is preferable to reduce the hardness (which will necessitate more frequent dressing and sharpening), rather than experiencing frequent breakage of the punch.

Suggested tool steel, rated in an indicative order for increasing severity of application and increased tool life are:

- Oil Hardening, Non-Deforming Steel (1% C, 1-1.5% Mn, 0.5% Cr, 5% W)
- Cold Work Tool Steel (1%C, 5%Cr, 1%Mo)
- High Carbon High Chromium Cold Work Steels (1.5% C, 12% Cr, 1% Mo or 2% C, 12% Cr, 1% Mo)
- Carbides (generally not suitable for use under conditions involving high impact).

Dimensions and the spacing of pierced holes are important.

In the ferritic and duplex grades, the hole diameter should not be less than the material thickness. In the case of austenitic grades minimum possible hole diameters are possible:

The distance (spacing) between holes should not be less than ½ x the hole diameter edge to edge (i.e. 1½ x hole diameter centre to centre). The edge to edge distance should also not be less than the material thickness. These minimum distances may have to be increased for holes approaching smallest possible diameters. If progressive (stepped) tooling is being employed the edge to edge spacing between holes has to be increased to 1½ - 2 times the material thickness.

The material being worked should be firmly held, especially when holes approaching the minimum diameters (necessitating slender punches) are being produced. Any vibration set up in the material being worked tends to cause jamming of the punch on the withdrawal stroke, which can cause punch breakages. The sheared edges of holes or blanks produced from austenitic grades will be work hardened. This affects subsequent forming operations such as bending, as cracks may initiate from such work hardened edges. This may be overcome by mechanically removing the work hardened surface layers, or by annealing the pieces.

ABRASIVE CUTTING

Abrasive discs, rotating at high speeds, can be used for both cut-off operations on relatively small section sizes, and for straight line cutting of sheet and thin plate material (often called an angle grinder) The use of aluminium oxide (Alumina) discs is recommended. Cut-off operations can be done wet, using a soluble oil emulsion. Rubber-based discs are used.

Random straight line cutting of sheet and thin plate is normally done dry. Vitrified or resinoid-bonded discs are used.

Care must be exercised not to induce excessive over-heating of the cut edge.

Dedicated discs (uncontaminated by cutting of carbon steels) must be used.

WATER-JET CUTTING

This is also referred to as abrasive jet cutting. The process employs fine abrasive particles that are carried through a nozzle in a highly pressurised jet of water. The high capacity pumps that are necessary use large amounts of water and power. Such a jet can cut through both non-metallic and metallic materials, and is capable of cutting >100mm thick stainless steel. There is no heat affected zone (HAZ) nor alteration to the metallurgical structure of the work-piece. The finished cut has a high quality surface finish but kerf angle can be a problem in thicker cuts. Contours and bevels can be cut. Not generally economically effective for thin gauge sheet, but stack cutting is possible.

THERMAL CUTTING

In conventional oxyacetylene cutting the metal is first heated by the flame, then an excess of oxygen is supplied. This causes exothermic (heat generating) reactions that generate the heat necessary to melt the oxides formed, which are then removed from the cut by the velocity of the gas jet.

Stainless steel, having a high level of chromium, cannot be cut by simple oxy-cutting methods due to the refractory nature (very high melting point) of the chrome oxide that is formed.

Modified or other methods therefore have to be employed.

POWDER (FLUX) CUTTING

A fine iron-rich metal powder is sprayed into the oxyacetylene gas flame. When this burns in the oxygen stream a great amount of heat is generated, sufficient to melt the refractory chrome oxide and, in addition, a diluting effect also takes place. The molten material is removed from the cut by the velocity of the gas stream enabling cutting to proceed.

This process is not really suitable for cutting stainless steel as it severely contaminates the cut edge, and should only be used with due consideration.

ARC CUTTING

The extremely high temperatures developed in electric-arc processes will melt all metals, thus enabling them to be cut.

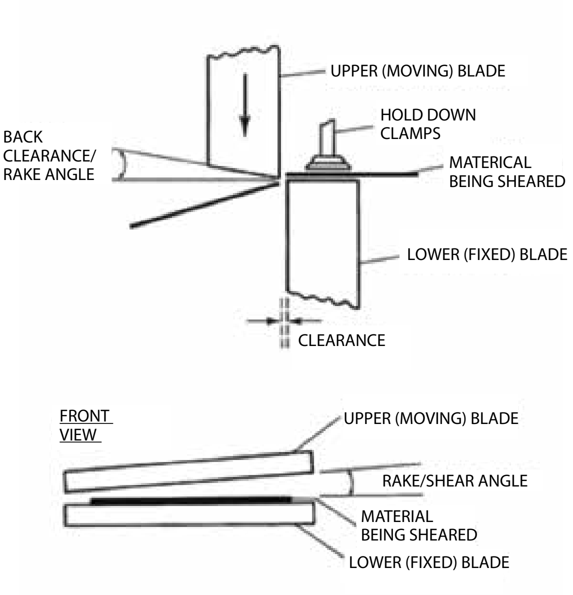
Many modifications of the process exist. Different electrodes can be used, with or without gases, either to promote or prevent the oxidation of the metal being cut. The two commonly used processes are air carbon-arc cutting and oxygen-arc cutting.

These processes are not really suitable for cutting stainless steel as they severely contaminate the cut edge, and should only be used with due consideration.

PLASMA ARC CUTTING

This is a form of electric arc cutting. It is possibly the most common thermal cutting process used on thicker gauges of stainless steel.

Plasma forming gases are constricted and passed through an arc chamber, the arc supplying a large amount of electrical energy. This ionizes the gases and they exist as a plasma, a mixture of free electrons, positively charged ions and neutral atoms. Extremely high temperatures are attainable (up to 30 000°C). Therefore, cutting depends solely on temperature and not on chemical reaction. The constricted plasma arc heats and melts the metal in the cut due to the effect of the electron bombardment, and the transfer of energy from the high-temperature, high-energy gas to the



Schematically shows the Shearing parameters and mechanical set-up

Utility ferritics (3CR12) and ferritic stainless steel tends to fracture after being cut through approximately half their thickness. In this respect they are similar to carbon and low alloy steel.

Austenitic stainless steel is typified by a high ductility and hence a greater resistance to fracture. A greater degree of penetration therefore needs to take place before fracture occurs. The clearance setting of the blades is important. For shearing thin gauge sheet, a clearance of 0,025 mm to 0,050mm is suggested.

Duplex has very high strengths and therefore needs higher power.

Closer clearance tends to induce blade wear, whereas larger clearances allow the material being sheared to drag over to an excessive degree, resulting in excessive wear of the blades and a poor cut.

As the material thickness increases the clearance should be increased accordingly and adjusted to best suit the specific piece of equipment being used, consistent with minimum roll over, burr height and distortion (camber, twist and bow).

The nominal suggested clearances for such thicker material are:

- Utility ferritics (3CR12):
  2.5% of material thickness
- Ferritic/austenitic stainless steels:
  3 - 5% of material thickness

To counteract the greater shearing force required, the hold down pressure on the clamps may have to be increased, particularly when shearing austenitic grades. The higher power requirements can, to some extent, be countered by altering the rake/shear angle. A rake of 1 in 40 is a shear angle of approximately ½°. This is the lowest rake that should be used. Small rake/shear angles necessitate higher power/force, but cause less distortion, whereas larger rakes/shear angles (e.g. 1 in 16 or 3½°) reduce the power/force required, but need higher hold down pressure on the clamps and tend to increase distortion.

Blades MUST BE SHARP . Blunt blades increase the roll over, burr height and distortion (camber, twist and bow).

The moving blade should be provided with as large as possible back clearance/ rake angle, without causing chipping of this blade.

For anything but the shortest of production runs, blades made from high quality tool steels, quenched and tempered to possess the correct combination of hardness, strength and toughness.

The following are suggested:

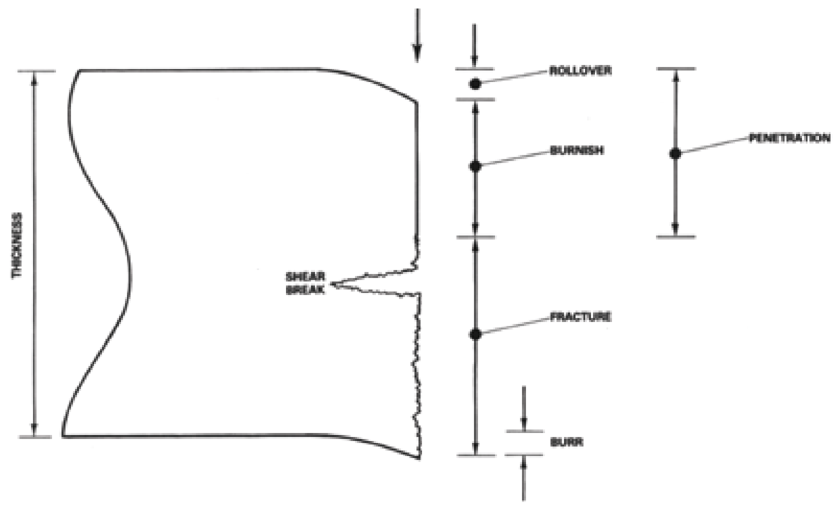
- Some benefits may be obtained by a slight reduction of shearing speed (20 – 25%), but this can tend to increase the distortion of the cut piece.
- Distortion (twist, camber and bow) tends to increase as the width of the cut piece decreases relative to the thickness of the material, and also to a lesser degree as the length of the cut increases.
- Distortion may be minimised by careful planning attention to, and adjustment of, the various parameters as discussed above.

Shear break is a phenomenon often seen with 3CR12 and ferritic stainless steel. It should not be interpreted as a material defect, namely laminated plate. It is more likely to occur if the material being cut is cold (e.g. on a frosty winter morning). The shearing parameters (especially clearance) have a marked effect and particular attention should be directed to these if shear break is experienced. The work hardening effect of shearing is significant in the case of austenitic stainless steel. Subsequent forming (bending) of such edges may lead to the initiation of a crack from the sheared edge. This can be overcome by mechanical dressing of the sheared face to remove the work hardened surface layers, or by annealing the cut pieces.

BLANKING, PERFORATING AND PIERCING

Blanking, perforating and piercing are, in essence, shearing operations, and therefore the various principles and parameters are very similar to those as discussed under shearing. Because of the higher strength levels of stainless steel the equipment must either be de-rated accordingly, or the presses, punches and dies must have greater strength and rigidity to accommodate the additional power required.

Warming the material up to 175°C has the effect of decreasing the power requirements, and this may assist in being able to accomplish a job that is proving to be borderline in terms of machine capacity. Such warming also assists in prolonging tool life The power required may also be reduced by utilising stepped punches and by angular shear on either the punch or the die The angular shear on the punch or die also affects the flatness of the sheet or the blank respectively. Blanking, perforating and piercing operations can be carried out



Schematic illustration of the typical features of a sheared edge