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Fundamentals of flame straightening.

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Flame straightening is a process technology with which deformation in welded structures can be eliminated quickly and without impairing the material. The following description focuses on the basic principle of flame straightening, the equipment and gases required, and flame straightening techniques for different materials.

Contents

01. Introduction

Automatic flame straightening solution

Welding and other manufacturing processes where heat is introduced will leave stresses in the metal during the subsequent cooling, causing distortion or warping. Flame straightening is an efficient and long-established method of correcting the distorted parts.

Flame straightening is based on the physical principle that metals expand when heated and contract when cooled. If expansion is restricted, compressive stresses build up and result in plastic deformations if the temperatures are high enough. Upon cooling, the plastic deformations remain.

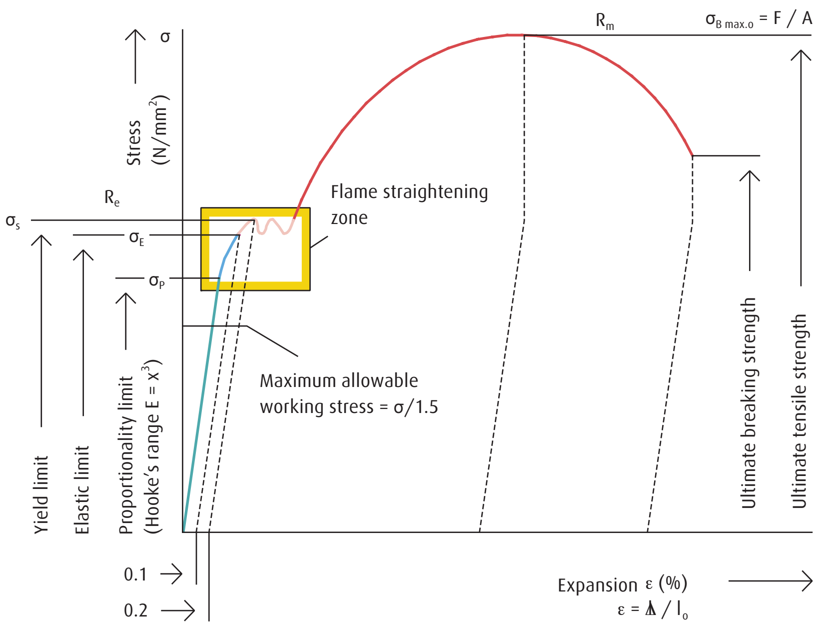
In practice, an oxy-acetylene flame is used to rapidly heat a well-defined section of the workpiece. Upon cooling, the metal contracts more than it could expand when heated and any resulting distortions can therefore be straightened out. Suitable materials include steel, nickel, copper, brass and aluminium.

Although various fuel gases can be used, the highest flame temperatures and intensities for rapid heating are achieved with acetylene and oxygen.

The choice of appropriate equipment depends on the type and thickness of the material. In principle, thin sheet metal and plate in thicknesses of up to 25 mm can be straightened with a standard torch, which is available in most workshops. For straightening of large plates, such as decks and deck houses on ships, adjustable attachments with three or more single-flame nozzles are available, mounted on a small wheel car for easy movement across large surfaces. For thicker material, use our LINDOFLAMM® special torches.

02. Stresses – forces – shrinkage

Figure 1: Stress-strain diagram based on mild steel



The term "stress" is often misinterpreted in discussions about flame straightening and is used to generate a certain anxiety amongst users. In flame straightening, stresses which are located in the component are overlaid. Investigations have shown that flame straightening reduces the residual stresses in the component.

What are stresses and how do they occur?
If a component is exposed to external forces, forces are generated in each sectional plane. The portions allotted to the unit area of the cross-sections which have not yet been deformed are called stresses. They occur whenever forces of differing magnitudes impact on a component and when plastic deformation is not possible.

What effect do stresses have?
Stresses affect the plastic deformation and/or internal stress state of the component (for sensitive materials, there is a risk of stress corrosion).

How can stresses be influenced?
Stresses can be influenced by dimensional corrective measures such as thermal and/or mechanical treatment.

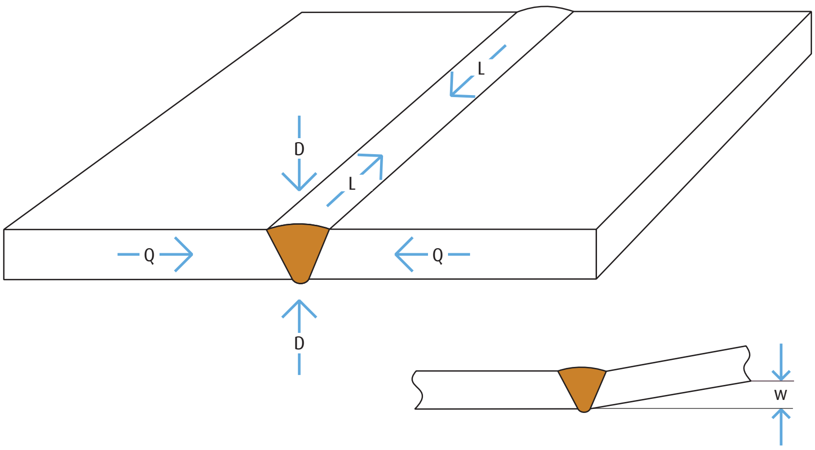
How can stresses be utilised?
Stresses can be used to stiffen component sections and/or to reduce dimensional deviations when exposed to loads.

The deformation mechanism in components is comparable for welding and flame straightening. For both applications, locally restricted thermal input takes place, which then leads to the expansion of the heated zone.

Cold areas next to the heated zone restrict expansion, leading to upsetting in the heated zone.

In order to facilitate plastic deformation of the heating zone, the yield limit of the material, which is slightly above the elastic limit, must be reached. To achieve this, a force is required to build up a stress in relation to the component contour which induces the "flow process" upon exceeding the elastic limit. These interconnections are represented in Figure 1.

Figure 2: Types of shrinkage during welding



Components which do not distort or only slightly distort after the welding joint has cooled down are exposed to higher residual welding stresses because the shrinkage stresses have not led to deformation of the component.

Later, these stresses may be relieved by dynamic loads or by machining. This can then lead to subsequent undesired deformation.

Stresses which are relieved after welding and cause deformation indicate minimal residual welding stresses. The components remain stable.

During welding, 4 shrinkage stresses occur, which can be seen in the distortion depending on the level of stiffness.

In order to influence residual welding stresses, parameters such as the welding process, the seam volume and the energy applied per unit length of weld must be considered. Follow-up plans after welding must be compiled and fulfilled.

For subsequent stress reduction, the following recommendations should be taken into consideration:

1) Thermal processes:
   - → Low-stress annealing in a furnace
   - → Flame heating
   - → Heating element heating
   - → Inductive heating

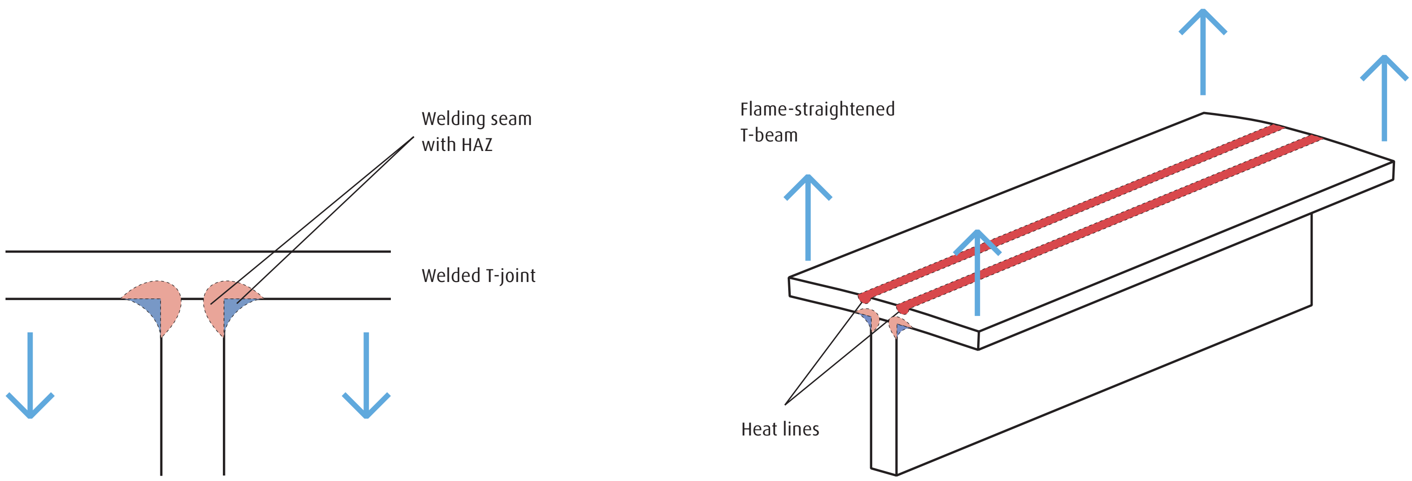
2) Mechanical processes:
   - → Non-recurrent mechanical overload
   - → Vibration relief
   - → Hammering
   - → Shot peening
   - → Flame relief
   - → Flame straightening

Flame straightening is classified as a mechanical process because the resulting expansion causes external forces to impact on the workpiece which then produce stresses in the component.

Plastic deformation takes place in the workpiece above the elastic limit. The result is irreversible deformation.

03. Thermal impact on the workpiece

Figure 3: T-joint – welded and flame-straightened



When components are welded together, the material tries to expand due to the heat input. The cold areas prevent this expansion and the material is upset. As the weld metal cools down, it shrinks, as does the material in the heat-affected zone (HAZ). The overlay of these shrinkages causes the component to distort.

In flame straightening, the elimination of such a distortion takes place in a similar way, by means of heat induction into the component, but in contrast to welding, in a different place. Component sections which are too long are heated specifically. Locally restricted upsetting then results and causes a dimensional change during the cooling process.

These processes can be explained using a T-joint as shown in Figure 3. First, double-sided fillet welding takes place, in which the welding seams and heat-affected zones in the web area as well as the flange area shrink and lead to an angular distortion within the flange.

Flame straightening using the heat line method takes place on the opposite side of the fillet weld, at those points at which the flange needs to be shortened. The number of heat lines required and their length depends on the distortion, the dimensions and the residual stress condition of the workpiece.

The manner in which the materials behave during flame straightening differs with respect to their properties and according to their thermal expansion behaviour. Materials with high expansion coefficients have the tendency to expand severely during the heating phase. This expansion is restricted, however, and causes particularly severe upsetting. The shrinkage is correspondingly distinctive. Table 1 provides an overview.

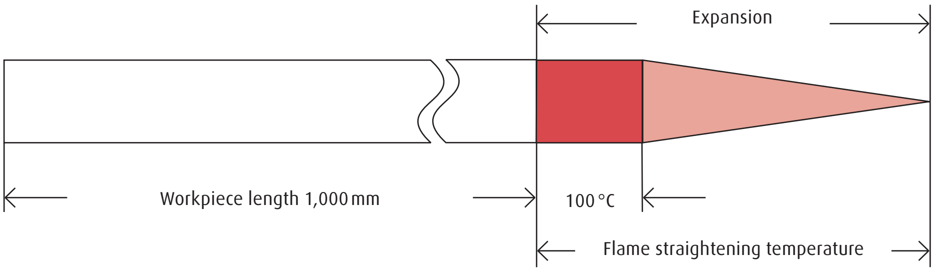


Table 1: Expansion behaviour of different materials

Material	Example	Expansion coefficient α (mm/m K)	Expansion (mm)
Mild steel Boiler steel Rail steel	S235JR S355J0 P265GH 16Mo3 13CrMo4-5	0.011 – 0.014	1.3 9.1
Fine-grain structural steel TM steel	S355N S890QL S355M S460M	0.012 – 0.015	1.4 8.8
Nickel-based materials	2.4360 [NiCu30Fe] 2.4602 [NiCr21Mo14W] 2.4856 [NiCr22Mo9Nb]	0.010 – 0.014	1.2 8.7
Austenitic stainless steel	1.4404 [X2CrNiMo17-22-2] 1.4301 [X5CrNi18-10] 1.4541 [X6CrNiTi18-10]	0.016 – 0.019	1.7 12.3
Aluminium: Pure aluminium		0.020 – 0.024	2.6 7.8
Aluminium: Non-age-hardening wrought alloys suitable for welding (Soft)	EN AW-3103 [Al Mn1] EN AW-5754 [Al Mg3]		2.6 9.8
Aluminium: Non-age-hardening wrought alloys suitable for welding (Hard)	EN AW-5083 [Al Mg4,5Mn0,7]		2.6 6.5
Aluminium: Age-hardening wrought alloys suitable for welding	EN AW-6005A [Al SiMg(A)] EN AW-6082 [Al Si1MgMn]		2.6 4.6
	EN AW-7072 [Al Zn1] EN AW-7020 [Al Zn4,5Mg1]		2.6 6.5
Copper	0.018 – 0.019		1.8 12.6

04. Principle of flame straightening

In flame straightening, the component is precisely and locally heated to the material-specific flame straightening temperature at which plastic deformation occurs. As a result of restricted thermal expansion, the deformation remains. During cooling, the workpiece is shortened around the deformed portion, leading to the desired change in length or shape.

Three factors bring about flame straightening (Figure 4):
heating – upsetting – shrinking
In contrast to mechanical deformation with a press or hammer with which the workpiece sections are elongated (lengthened), the use of a flame always leads to the shortening of the heated zone of the component.

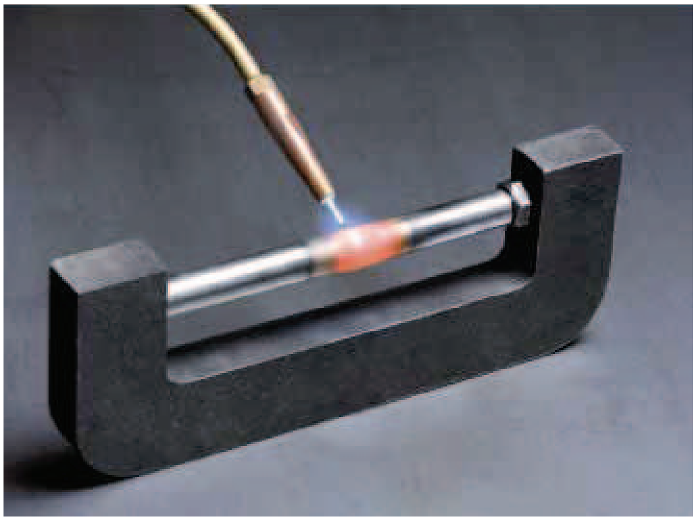
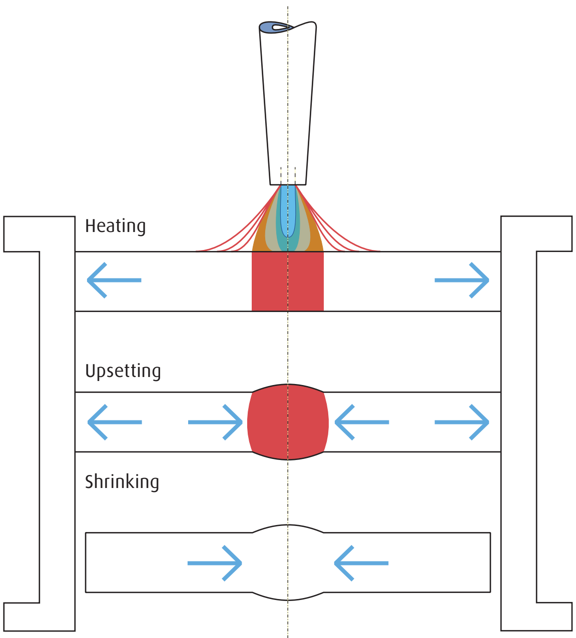


Figure 4: Principle of flame straightening



05. Which materials can be flame-straightened?

All materials suited for welding can be flame-straightened without difficulty if the material's specific properties are taken into consideration, as is common practice in welding.

The elastic modulus and therefore also the strength of every metallic material drops as the temperature increases. In turn, its ductility increases (see Figure 5).

Using the material S355 as an example, it becomes clear that flame straightening temperatures > 650 °C make little sense. An increase by a further 300 °C from 650 °C to 950 °C doubles the heating time and is neither helpful nor necessary.

When heating limited sections of the component to a plastic temperature range, the material flows and is upset as a result of restricted expansion.

Different materials require correspondingly differing flame straightening temperatures (Table 2).

Figure 5: Yield limit and elongation at break for mild steel (S355)

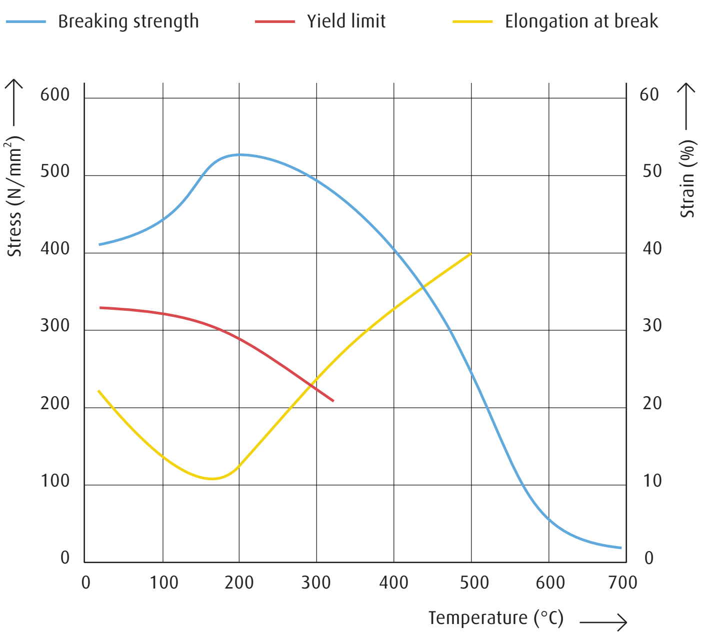
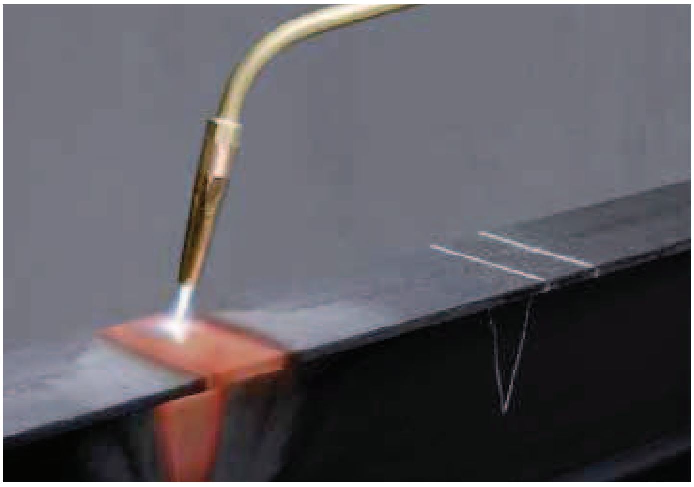


Table 2: Flame straightening temperatures of different materials

Materials		Specification	Alternative specification	Flame straightening temperature [°C]
Mild steel		S235JR		600 ... 800
		S355J0		
Boiler steel		P265GH		
		16Mo3		
		13CrMo4-5		
Fine-grain structural steel		S355N		550 ... 700
		S890QL		
TM steel		S355M		
		S460M		
Nickel material		2.4360	NiCu30Fe	650 ... 800
		2.4602	NiCr21Mo14W	
		2.4856	NiCr22Mo9Nb	
Austenitic stainless steel		1.4404	X2CrNiMo17-12-2	650 ... 800
		1.4301	X5CrNi18-10	
		1.4541	X6CrNiTi18-10	
Aluminium	Pure aluminium			150 ... 450
	Non-age-hardening wrought alloys suitable for welding	EN AW-3103	AlMn1	300 ... 450
		EN AW-5754	AlMg3	
		EN AW-5083	AlMg4,5Mn0,7	150 ... 350
	Age-hardening wrought alloys suitable for welding	EN AW-6005A	AlSiMg(A)	150 ... 200
		EN AW-6082	AlSi1MgMn	
		EN AW-7072	AlZn1	150 ... 350
		EN AW-7020	AlZn4,5Mg1	
Copper				600 ... 800

06. Fuel gas for flame straightening



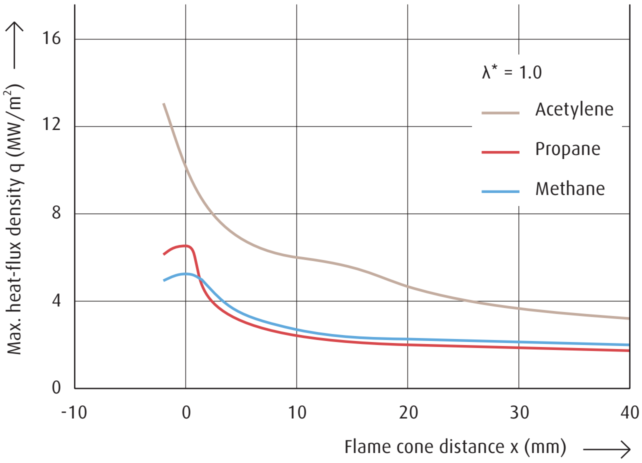
Heat wedge

In flame straightening, component sections must be precisely and locally heated to flame straightening temperature in a very short time. This is only possible if the workpiece surface is provided with a high heat-flux density in a very restricted space. The oxy-acetylene flame with its intensive primary combustion offers this high heat-flux density. Fuel gases whose thermal influence is greater when transferring heat from large-area secondary combustion are not suitable for flame straightening. Here, acetylene differs from slow-burning gases such as propane and natural gas (Figure 6 a).

By raising the oxy-acetylene ratio, the output of the flame can be increased considerably (Figure 6 b). The optimum flame setting is therefore of decisive importance in flame straightening.

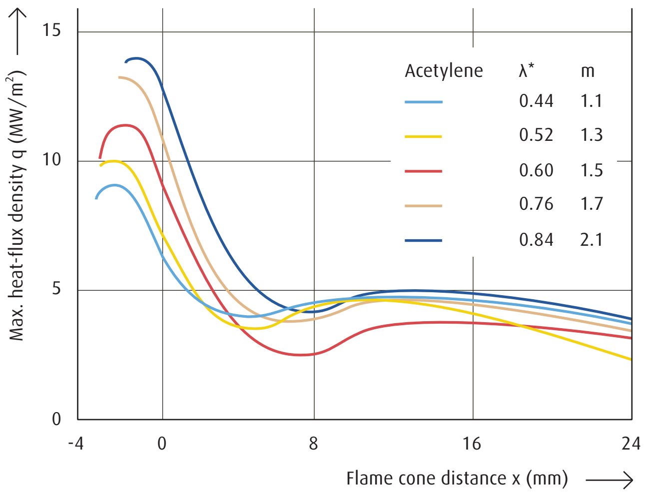
Proper and correct flame straightening is only possible with an oxy-acetylene flame!

Figure 6 a: Heat-flux density of different fuel gases



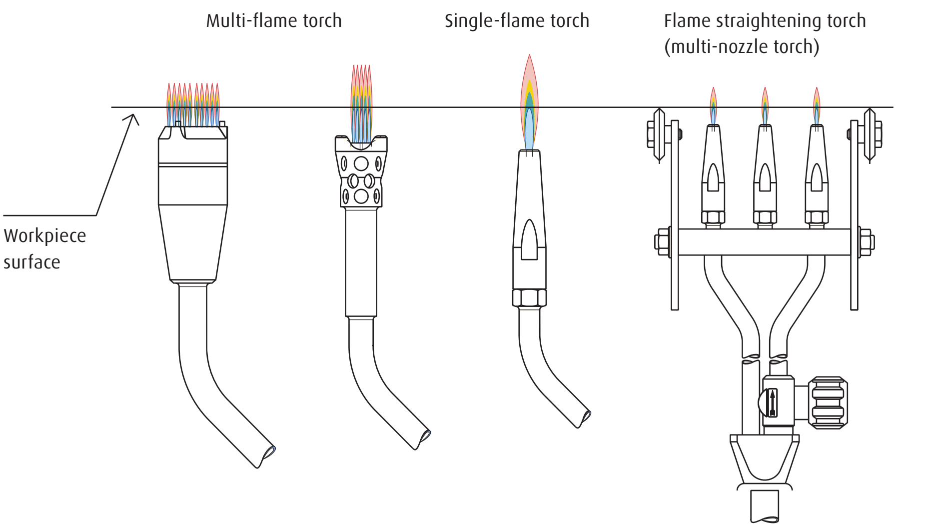
$$\lambda^* \text{ (oxidation ratio)} = \frac{\text{m (neutr.)}}{\text{m (stoich.)}}$$

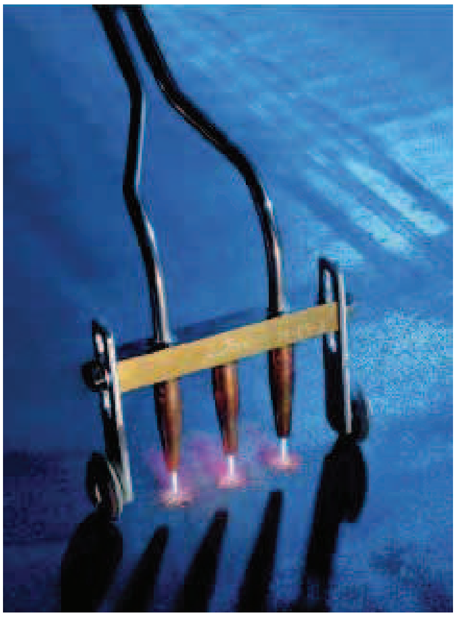
Figure 6 b: Heat-flux density of acetylene



07. Torches for flame straightening

Figure 7: Torches for flame straightening





7.1. Designs of flame straightening torches

The classical flame straightening torch is the oxy-acetylene single-flame torch which is generally used in oxy-fuel technology (Figure 7).

For special operations, e. g. for rectifying angular distortion in a welded metal structure or removing buckling in sheet metal, multi-nozzle torches have proven to be particularly suitable. These devices are based on the conventional single-flame torch with 3 to 5 single nozzles arranged in a row, 30 mm apart, and supplied by an injector. Components with a thickness of > 50 mm can be successfully straightened with large multi-flame torches.

7.2. Selection of flame straightening torches

The choice of suitable torch/nozzle sizes for flame straightening plates, pipes and profiles depends on the workpiece thickness and on the material itself.

In practice, conventional torches designed for a plate thickness range which can be gas-welded have proved best when selecting a suitable nozzle size (Table 3).

Basic guideline for selecting the correct torch:

The workpiece thickness is the criterion for the right choice of torch and is allocated a corresponding nozzle size.

1) Mild, boiler and fine-grain structural steel
Materials with normal thermal conduction:

A welding attachment is selected which is one or two nozzle sizes larger than the torch attachment which would normally be used to gas-weld the workpiece thickness to be flame-straightened.

Example:	Plate thickness	12 mm
	Nozzle size	14–20 or 20–30

2) Austenitic stainless steels
Materials with low thermal conduction:

A welding attachment is selected with the same nozzle size as or one size smaller than the torch attachment which would normally be used to gas-weld the workpiece thickness to be flame-straightened.

Example:	Plate thickness	12 mm
	Nozzle size	6–9 or 9–14

3) Aluminium and aluminium alloys
Materials with very good thermal conduction:

A welding attachment is selected which is at least two nozzle sizes larger than the torch attachment which would normally be used to fuse the workpiece thickness to be flame-straightened.

Example:	Plate thickness	15 mm
	Nozzle size	20–30 or 30–50

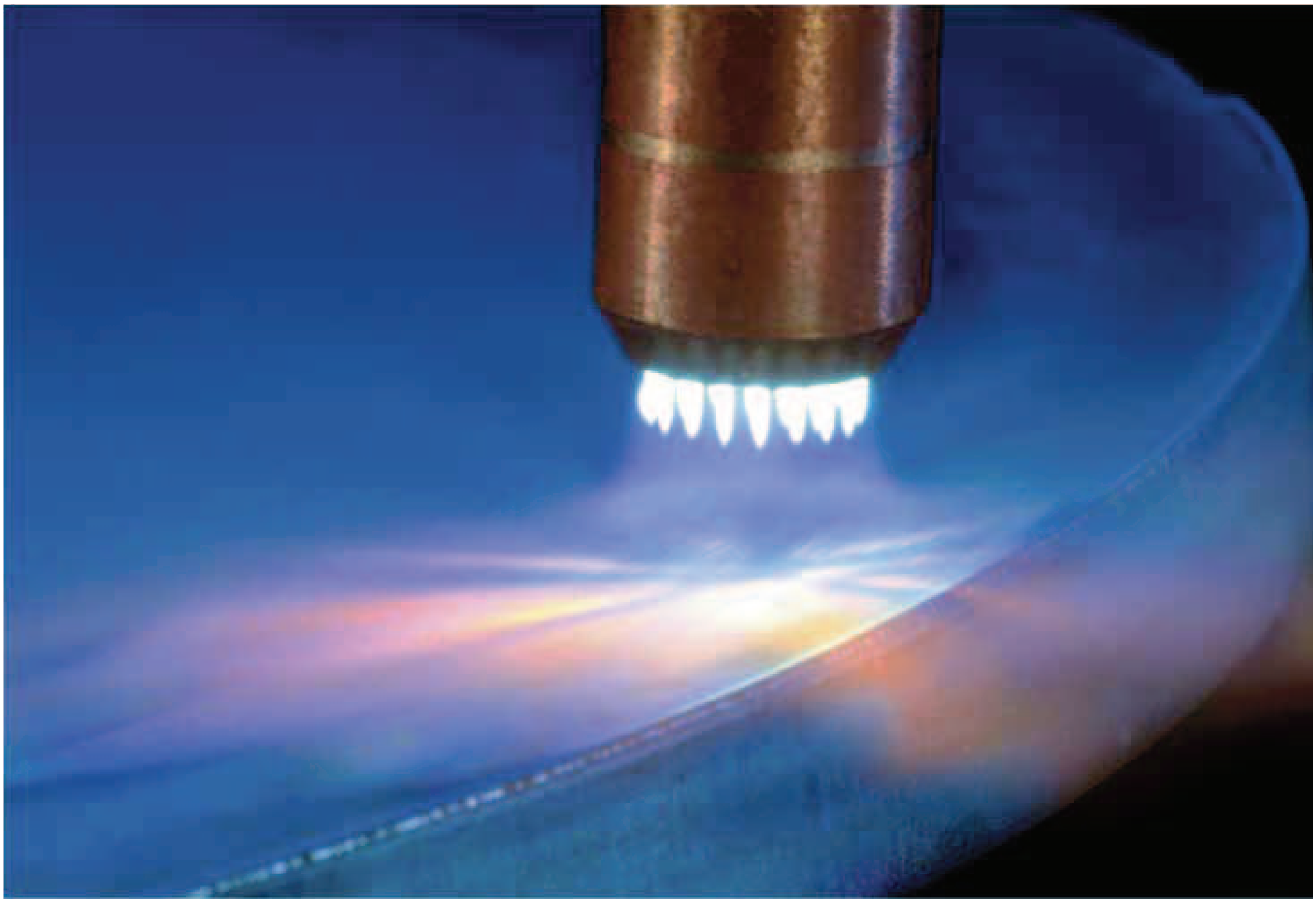
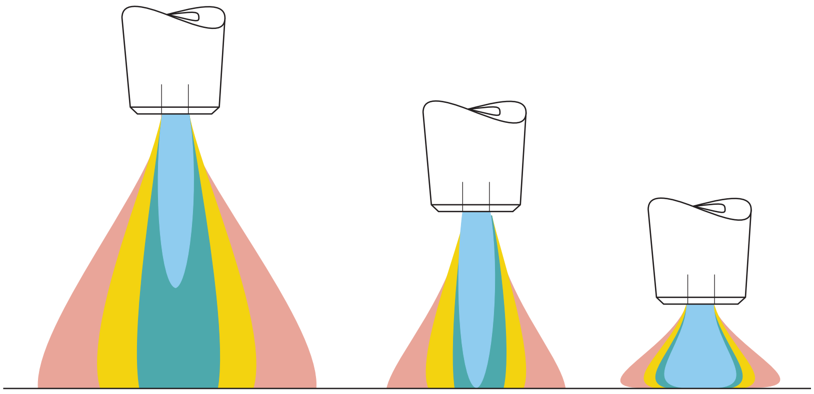


Table 3: Selection of torches for flame straightening

Workpiece thickness			Nozzle size for flame straightening	Gas consumption	
Mild steel	Stainless steel	Aluminium and its alloys		Acetylene	Oxygen
mm	mm	mm		l/min	l/min
1–2	2–3	1–2	1–2	2.5	2.8
2–4	3–4	2–3	2–4	5.0	5.5
2–5	5–8	2–4	4–6	8.3	9.2
4–6	7–12	3–5	6–9	12.5	13.8
5–7	10–18	4–8	9–14	19.2	21.1
6–12	15–30	5–10	14–20	28.3	31.2
10–16	25–50	8–15	20–30	41.7	45.8
15–25	> 50	10–20	30–50	66.7	73.3
20–40	> 50	15–30	50–100	125.0	137.5
Multi-nozzle torch (3 nozzles)					
5–15	8–20	5–10	2–4	15.0	16.5
10–30	15–40	8–25	4–6	25.0	27.5
15–40	20–50	12–35	6–9	37.5	41.3
1–300	1–300	1–300	Specialised torch	2–333	2.2–366.3

08. Flame settings and flame guidance for the straightening operation

Figure 8: Flame cone distance and formation



During the heating process, attention should not only be paid to the level of the flame straightening temperature, but also to the flame setting and guidance in order to meet the material's specific properties.

In flame straightening, a rigorously burning oxy-acetylene flame (high flame exit velocity) is exclusively used, which can be set to neutral, excess oxygen or excess acetylene depending on the material.

The heat output and heat dissipation within the workpiece must be proportional to each other. Should it be necessary to heat lower-lying workpiece sections when flame straightening mild, boiler and fine-grain structural steel, or if the entire workpiece section needs to be completely heated through, it makes sense to work with a somewhat "standoff" flame cone (Figure 8, left).

Typically, an experienced flame straightener will use a "contact" flame when working with these steels, i. e. the tip of the flame cone touches the workpiece surface (Figure 8, centre).

An "impinging" flame cone is used if only the surface needs to be heated. In this way, the heat transfer is improved in comparison to the "contact" flame cone. It is necessary to work rapidly (Figure 8, right). The risk of surface damage (burning, overheating) is very high for this type of flame guidance and should be taken into consideration.

Austenitic materials, on the other hand, are flame-straightened with a minimal distance between the flame cone and the workpiece surface, but always with an oxidising flame (Figure 8, left). If excess acetylene (reducing flame) is used along with long exposure at high temperature, carbon can be "picked up" forming chromium carbides on the grain boundaries, possibly leading to intergranular corrosion and reduced corrosion resistance.

To accommodate the low melting temperature of aluminium materials, the distance between the flame cone and the workpiece surface is even greater, compared to austenitic materials. All mild, boiler and fine-grain structural steels are straightened with a neutral or, even better, an oxidising flame (up to 30–50 % excess O_2). Austenitic stainless steels, on the other hand, always require ample excess oxygen (up to 50 %) in order to counteract the additional carbon output of a neutral flame.

A reducing flame is selected when flame straightening aluminium, with a slight excess of acetylene (< 1 %). When using an oxidising flame, the workpiece surface reacts, leaving a grey discolouration in the heated area. A slight excess of acetylene does not damage the surface.

In flame straightening, three flame settings are used for the different types of flame guidance, i. e. distance between tip of flame cone and workpiece surface (Table 4).

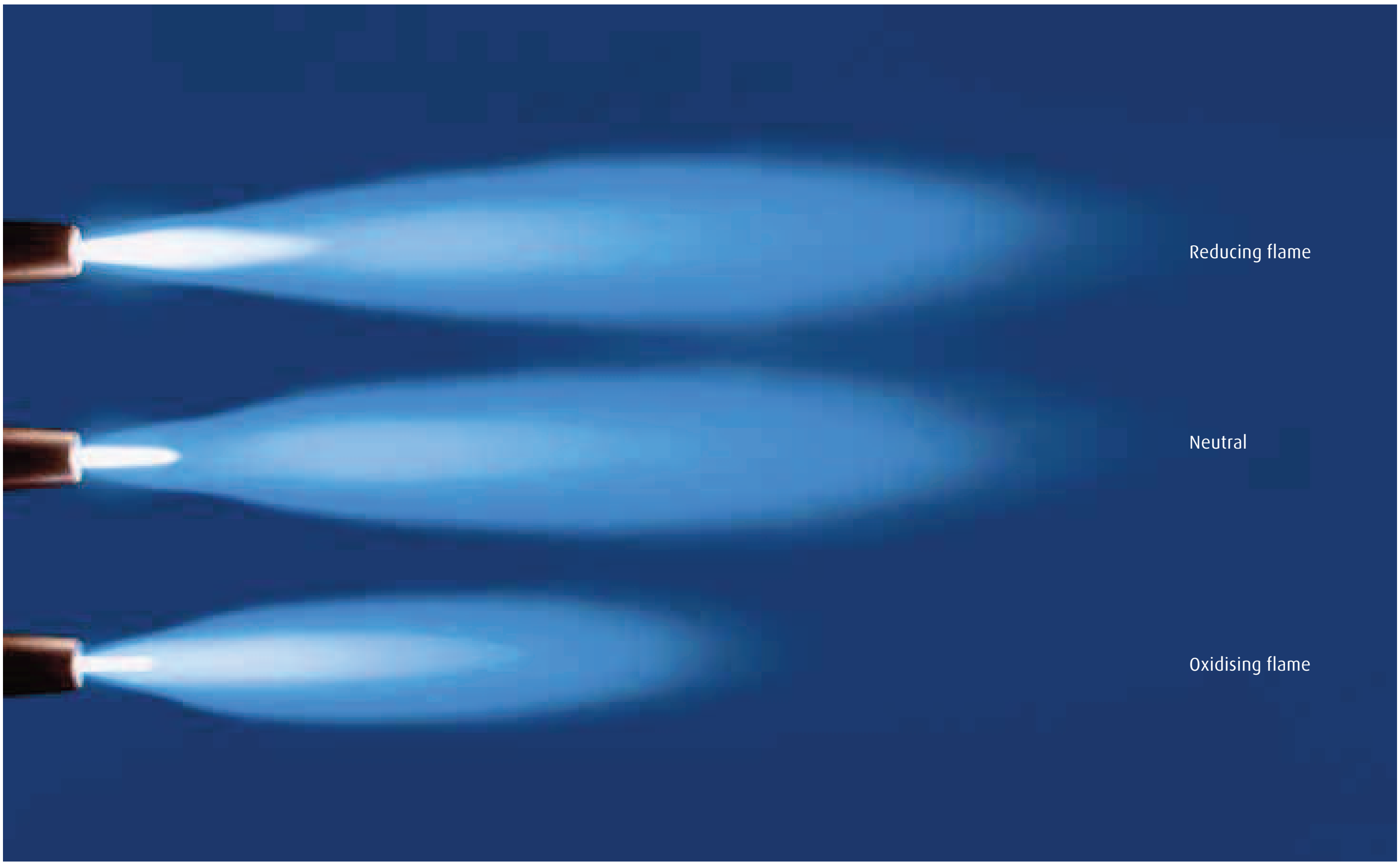
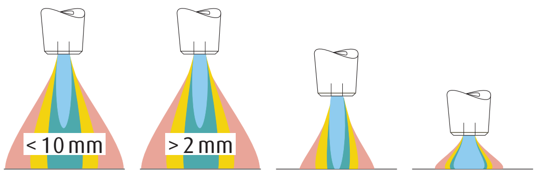


Table 4: Flame settings and guidance for flame straightening

– Unsuitable – – Impermissible • Possible + Acceptable + + Correct

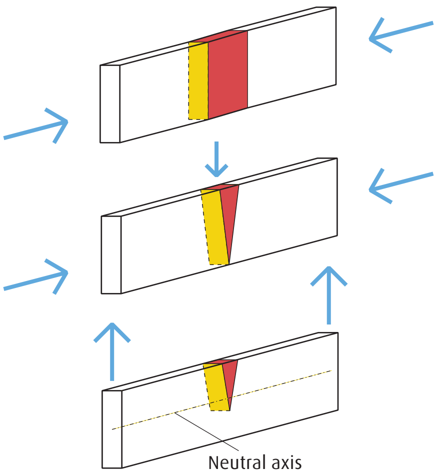


Material	Flame setting				Flame guidance Distance flame cone to workpiece			
	Excess							
	C_2H_2 0 < 1 %	Neutral	O_2 30 %	O_2 50 %	< 10 mm	> 2 mm		
Mild steel	–	•	+	+ +	Heating of edge zone*			
Fine-grain structural steel	–	•	+	+ +	– –	–	+	+ +
TM steel	–	•	+	+ +				
Boiler sheet metal	–	•	+	+ +	Heating of lower-lying zones*			
Rail steel	–	•	+	+ +	+ +	+ +	–	– –
Austenitic stainless steel	– –	–	•	+ +	+	+ +	–	– –
Duplex steel	– –	–	•	+ +	+	+ +	–	– –
Aluminium	+ +	–	– –	– –	+ +	+	–	– –
Aluminium alloys	+ +	–	– –	– –	+ +	+	–	– –

*Box highlighted in blue refers to mild steel, fine-grain structural steel, TM steel, boiler sheet metal and rail steel.

09. Basic heating methods for shortening and bending components

Figure 9: Type of heating and deformation



Type of heating	Deformation
Symmetrical heating through the entire cross-section	Shortening of the entire component
Unsymmetrical heating through the entire cross-section	Shortening and bending of the entire component depending on the position of the heating zone
Unsymmetrical heating of the cross-section to the neutral axis or just beyond	Bending of the component

Component sections which are locally heated are upset when thermal expansion is restricted in the heated zone. The position of the upsetting point within the workpiece determines the change in shape (Figure 9).

9.1. Centric or symmetrical heating for shortening

If a component is heated evenly to flame straightening temperature across the whole workpiece thickness, the entire heated zone is upset, provided that expansion was adequately prevented during the heating process. In this case, the workpiece is shortened by the upset volume. This is referred to as symmetrical or centric heating (Figure 10, left).

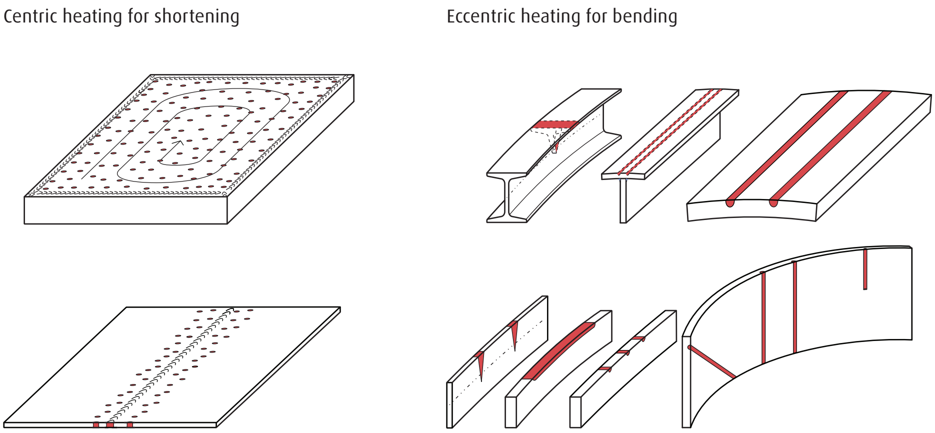
Greater residual welding stresses are reduced depending on the position of the welding seams in relation to the flame straightening point.

9.2. Eccentric or unsymmetrical heating for bending

If heating the component only encompasses the workpiece area close to the surface on one side, upsetting only occurs inside the heated zone.

The section of the workpiece thickness which remains cold typically restricts thermal expansion. In this way, components can be selectively and accurately bent. This is referred to as unsymmetrical or also eccentric heating (Figure 10, right).

Figure 10: Position of heating for shortening and bending



Residual welding stresses present in the component are relieved and overlaid by shrinkage stresses as a result of flame straightening. Stress peaks in the component are reduced.

It is not unusual to observe that the selection of unsuitable torches or imprecise heat guidance can cause the workpieces to be shortened as well as bent although only one type of deformation is desired.

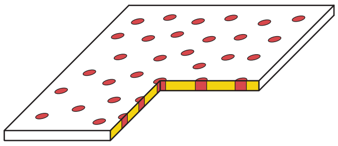
Using torches which are too small over a prolonged period of heating can, under certain circumstances, lead to undesired heating through. There is no heat build-up as a result and thus no localised upsetting. The desired deformation of the component does not take place.

10. Heating techniques for flame straightening

Figure 11: Heating techniques for flame straightening

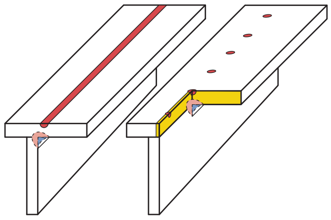
Heat spot

e. g. straightening buckled plates



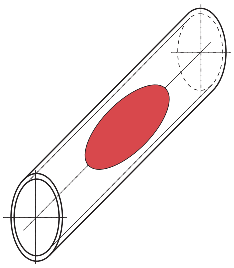
Heat line

e. g. straightening bends and one-sided built-up welds



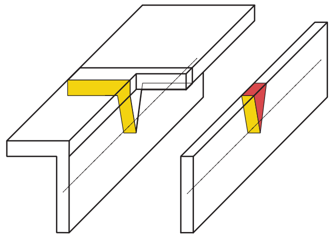
Heat oval

e. g. straightening pipes



Heat wedge

e. g. straightening profiles and narrow metal plates



Depending on the component and the level of deformation, different heating techniques are used to achieve the best possible straightening result (Figure 11). With the exception of heat spots, the heating patterns should be drawn on the component so that an overview of the heating which needs to be carried out is provided.

10.1. Straightening thin sheet metal with heat spots

Heat spots (Figure 12) are preferable when flame straightening buckled thin sheet metal. The heat spots are arranged irregularly on the sheet metal surface. Linear rows of heat spots lead to larger shortening zones which can cause the formation of folds.

The workpiece is heated through the full thickness to achieve extensive shortening of the plate.

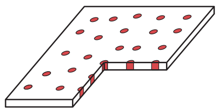
Contrary to the recommendation regarding torches for mild steel, torch sizes corresponding to the plate thickness are used for thicknesses up to 3 mm to obtain the smallest possible heat spots. The heat spots produced by larger torches, with a bigger spread flame, are too big.

Many small spots are substantially more effective than only a few large ones. The latter cause additional buckling in the sheet metal plane.

Plates which are open on one or more sides can only be flame-straightened with a closed clamping system. There must always be a completely enclosed field. Every stiffening element and every welding seam serves as a field boundary. Plates which are too large must be

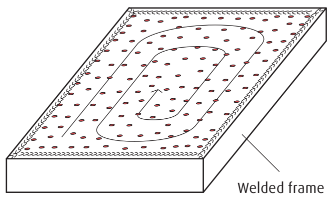
Figure 12: Heat spots in plates

Heating through



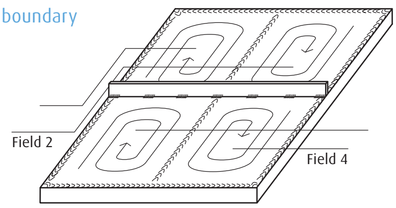
Implementation
Small spots heated through, if possible with dolly and hammering.

Clamping



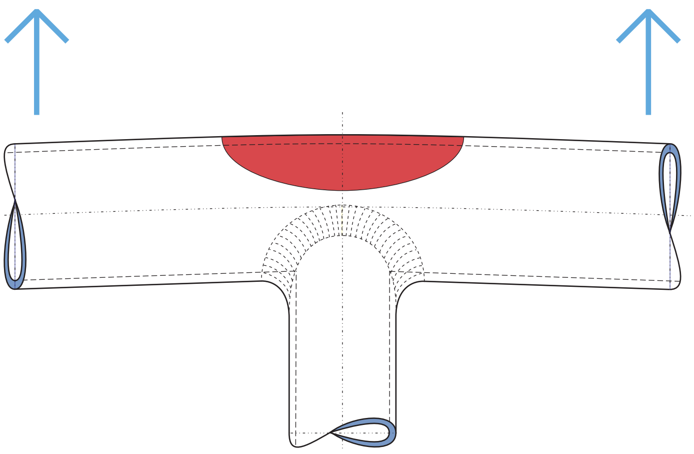
Restriction of expansion with closed clamping. Spots are set on plate, from the clamping device (welded frame) in spirals towards the centre of the plate.

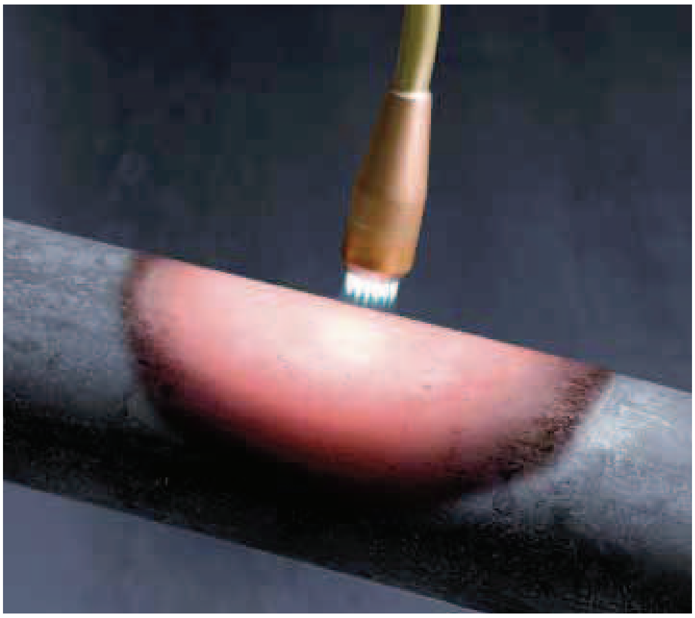
Field boundary



Subdivision of larger fields into several smaller fields. Every welding and tacking seam counts as a field boundary. Additional stiffening may be necessary. Spots are set in fields individually as illustrated for “clamping” above.

Figure 13: Heat oval





subdivided into several smaller fields if necessary, for example by tacking on stiffening elements.

The spots are set on the plates consistently from the outside to the inside. In this way, the field is processed in spirals, starting at the clamping frame and working towards the centre of the field.

To maintain smooth workpiece surfaces, heat spots are applied with a suitable hammer (slightly spherical). A flat-shaped dolly is used from the back during hammering to provide counter support. The hammering tool and the dolly must be adapted to the material to be straightened.

It is not necessary and not advisable to draw heat spots on the plates. A geometric and too regular arrangement of spots may lead to linear-shaped shrinkage zones which do not produce the desired straightening result. An irregular distribution of spots is more appropriate.

10.2. Heat oval in the construction of piping

Pipes and other rotationally symmetrical workpieces can be easily and effectively flame-straightened.

The main application of flame straightening is to remove deformations which result after connecting branch lines on one side. This deformation is rectified by applying a heat oval on the opposite side of the pipe connection using a torch which has been adapted to the pipe's wall thickness.

The basic guideline is as follows:
The long side of the oval must always be positioned lengthways along the pipe's axis (Figure 13). A heat oval positioned at an angle of 90° has a similar effect to that of a heat wedge which may produce kinking in the pipe.

Depending on the degree of bending, the heat oval is drawn level with the pipe's axis of symmetry and the pipe wall is heated through completely. The heated zone is upset as a result, which then brings about the desired change in shape when cooling down.

Single heat spots or a heat spot row can achieve the required success even with minimal deviations in shape.

Figure 14: Heat line

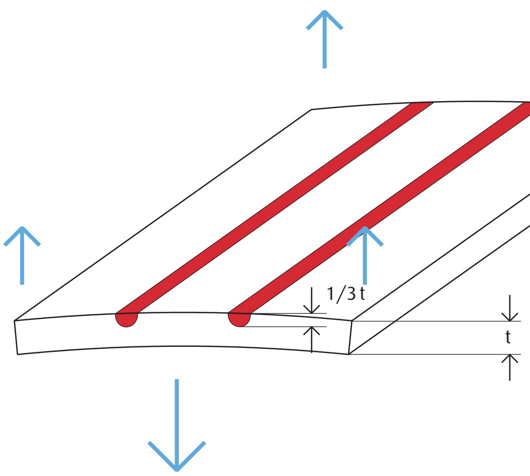
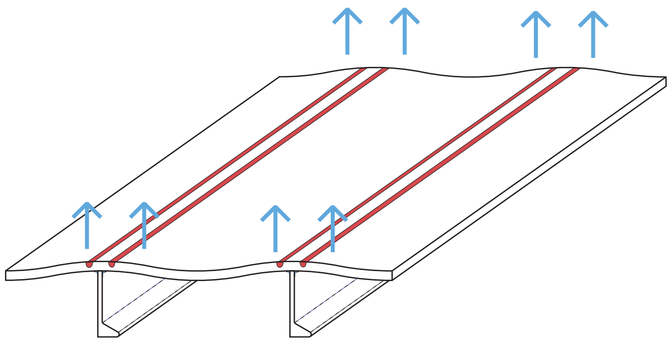


Figure 15: Heat line with 3/2 multi-nozzle torch



10.3. Heat line to remove angular distortion

Angular distortion is the most frequent and most visible form of deformation. In many cases, it can be removed by drawing one or more heat lines in a parallel arrangement on the opposite side of the fillet seam. A heat line (Figure 14) is particularly effective if only 1/3 of the workpiece thickness is heated to flame straightening temperature.

For this purpose, it is absolutely essential that high-performance torches are used which have been carefully adjusted to the thickness of the sheet metal. The depth of heat penetration into the workpiece surface is monitored via the annealing colour of the surface directly behind the flame cone of the straightening torch. To get a feeling for the right feed rate, the flame straightener lifts the torch slightly for a short time. The dark red glow will fade immediately if the flame is optimally set, the distance between the flame cone and the workpiece surface is correct and the feed rate is properly adjusted. If the dwell time is prolonged, the heat penetration into the component will be too deep. The success of the straightening operation will then be reduced.

Multi-nozzle straightening torches which are also referred to as "3/2 and 5/3 multi-nozzle torches" are preferable for removing angular distortion in welded structures and for rectifying buckling in sheet metal panels (Figure 15). The distance between the single nozzles is 30 mm.

The flame setting, the flame cone distance to the workpiece surface, and the feed rate must be carefully coordinated and adjusted. The stabilising wheels or guide runners must be set in such a way that the flame cone does not touch the workpiece and all the single flames have the same distance to the workpiece surface. When adjusting the flame according to specific material properties, the distance between flame cone and workpiece should be 3–5 mm.

For an optimum flame setting and adjusted feed rate, heat zones will result which should clearly show the cold areas between the individual heat lines. The heat lines should be prevented from running into each other as this causes the workpiece to be completely heated through. Eccentric heating does not take place and the intended removal of angular distortion is not achieved.

Multi-nozzle torches are available in the following two sizes:
Size 3 (2–4 mm) < 15 mm plate thickness
Size 4 (4–6 mm) > 15 mm to approx. 40 mm plate thickness

Figure 16: Heat wedge

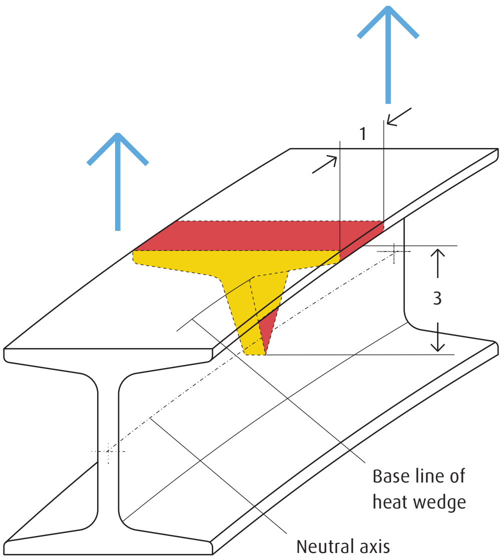
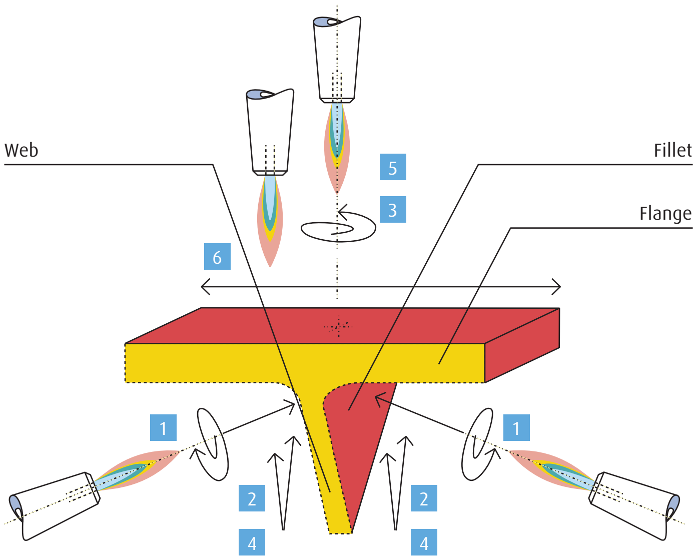


Figure 17: Heat guidance on T-beam



10.4. Heat wedge

The heat wedge (Figure 16) is predominantly used on profiles and upright narrow metal plates if larger deformations need to be achieved in the straightening operation. The component is always evenly heated through to the base line – starting at the wedge tip. It is imperative that the shape and size of the wedge fit the component dimensions. The heat wedge must be sharply delimited, pointed and long.

The ratio (width of wedge base line to wedge height) in the web should be 1:3. The wedge height, depending on the extent of deformation, should be selected in such a way that the wedge tip only just exceeds the neutral axis of the profile. In this way, the stiffness of non-heated material zones is used as a means of restricting expansion. If a greater deformation is required, the wedge shape is drawn further across the neutral axis. The width-height ratio remains 1:3. In this case, additional restriction of the expansion process would favour deformation.

The shape of the heat wedge must be drawn on both sides of the component to ensure, as far as possible, that both sides of the wedge volume are heated exactly opposite each other.

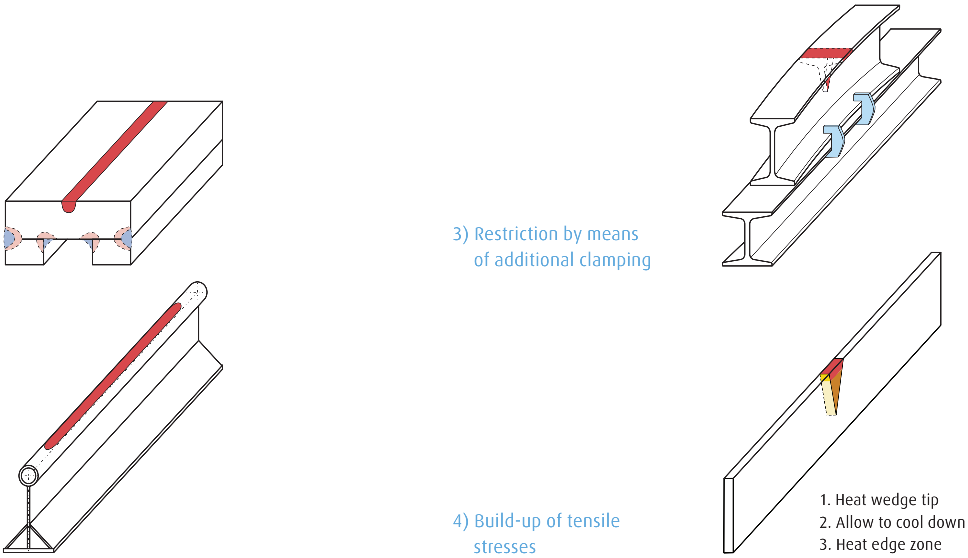
If heating is displaced, a wedge-shaped heating zone cannot be achieved, only an undefined heated workpiece area. This, in turn, does not lead to the desired straightening result.

The procedure for profiles is the same. The heat wedge is drawn on the component. Heating begins in the web from the fillet towards the wedge tip. The dwell time for heating the wedge tip must be very brief so that the heat cannot spread too much, in contrast to the fillet. The wedge base line determines the width of flange heating. The fillet area of profiles, the area in which the most material accumulates, is heated most effectively from the top side of the flange (Figure 17).

To prevent steps between the heated flange zone and the non-heated flange areas, it is recommended that the flame temperature be kept somewhat lower in the edge zone of the heated flange.

11. Restriction of thermal expansion

Figure 18: Possibilities for restricting expansion



1) Restriction by means of own weight

2) Restriction by means of own stiffness

3) Restriction by means of additional clamping

4) Build-up of tensile stresses

Upsetting the straightening point after heat input is the prerequisite for successful straightening. If the component is not stiff enough to restrict thermal expansion during the heating operation, additional measures need to be taken so that upsetting can start as soon as the heating process begins. Additional restriction of thermal expansion in components with insufficient stiffness is critical for successful straightening (Figure 18).

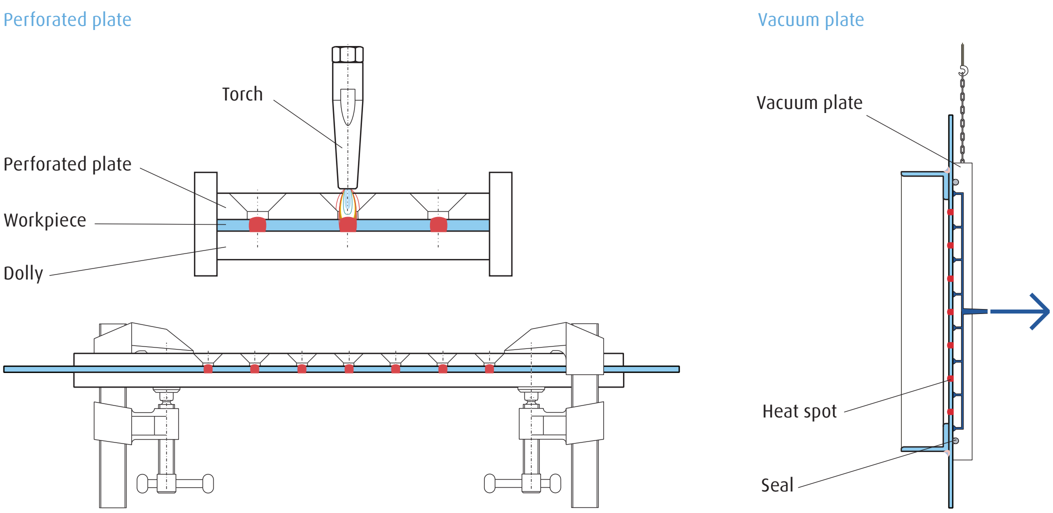
Flame straightening can also be performed faster and more effectively on thicker cross-sections by additionally restricting expansion.

When using mechanical devices to restrict expansion, it is important that the workpieces are not distorted. These auxiliary devices should not stretch or tauten, but merely hold the workpiece in place. The application of excessive distortion forces can cause kinks in the flame straightening zone of the component.

Using areas in the edge zone of a flame straightening pattern which initially remain cold is particularly helpful. For example, a heat wedge is typically heated from the wedge tip towards the wedge base line. With this method, the wedge tip is already severely upset during heating since the non-heated edge zone of the wedge base line serves to restrict expansion. The flame straightening procedure is then completed for the wedge tip.

If the upset section of the wedge tip is allowed to cool down to approx. 200 °C while not heating the edge zone, shrinkage forces (tensile stresses) occur in the upset area which support upsetting as the edge zone is heated. In this way, good straightening results can be achieved with fewer and smaller heating patterns. It is possible to apply this method in all cases in which the edge zones can be used to additionally restrict thermal expansion.

Figure 19: Perforated plate – vacuum plate



11.1. Clamping tools for restricting expansion in thin sheet metal

Thin sheet metal and unstable components cannot be flame-straightened without special clamping. Individual workpiece sections are flame-straightened using the classical method (enclosed frame and thorough heating with the smallest possible heat spots from the frame edge towards the centre of the plate). The sheet metal is "tautened" in a similar way to tautening the membrane of a drum.

In serial production, e.g. in the construction of wagons, perforated plates which have been adapted to the size of the individual fields have proved to be effective (Figure 19, left). They force the sheet metal into the desired plane and hold it in place during the heating operation. The size, thickness and distances of the perforated plates depend on the workpiece thickness and the component. The measurements are often based on experience, i.e. empirical values.

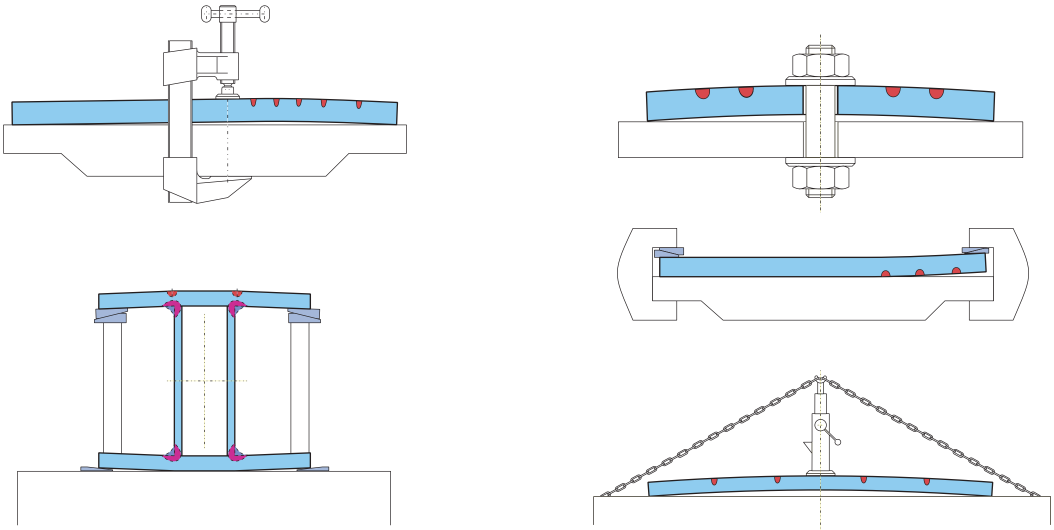
Flame straightening with perforated plates can only work if the sheet metal section to be straightened is supported from the opposite side by a stable plate. In the railway vehicle industry, in which the sheeting of the vehicle cells or the outer shell of the vehicle are primarily made of aluminium materials, magnetic plates are used as dollies to tighten the perforated plates through the aluminium sheet wall and thus force the component into the desired plane.

The spots are set through the recesses in the perforated plate. Flame straighteners do not need to use a particular sequence when setting the spots. Hammering the wart-shaped thickening of the heat spot is not possible and also not necessary.

When using perforated plates, monitoring the flame straightening temperature in aluminium structures can be problematical and virtually impossible to carry out. The flame should therefore be tested on a specimen plate prior to starting the operation. Typically, the time the workpiece is exposed to the flame will initially be determined by counting and later by feeling.

Instead of using a combination of perforated plate and dolly plate, "vacuum plates" have also proved to be effective for relatively thin metal sheets (Figure 19, right). These plates comprise a stable metal sheet on which a rubber seal is sunk into the plate's periphery. The vacuum plate is laid against the metal sheet. By evacuating the space between the two, the area to be straightened on the metal sheet is drawn into the desired plane. The flame straightening operation is performed from the opposite side. Based on practical experience, the flame straightener then determines the number and distance of the heat spots.

Figure 20: Auxiliary devices for restricting expansion



11.2. Clamping tools for restricting expansion in plates, pipes and profiles

Optimum straightening success is assured if expansion in the component is restricted as soon as the heating process begins.

The degree of workpiece deformation due to the ability to move freely diminishes the dimensional change resulting from flame exposure.

If it is possible for the workpiece to move freely, it will be necessary to restrict thermal expansion with suitable resources (Figure 20).

To what extent expansion needs to be restricted depends on the workpiece. If the structure itself is stiff enough, additional restrictive measures may not be necessary.

Suitable resources are:

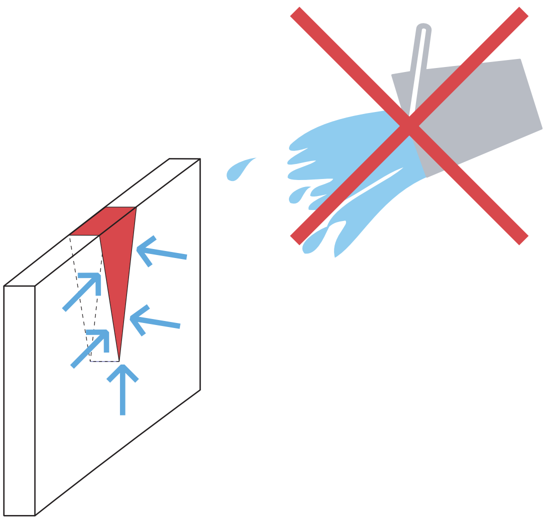
- Heavy screw clamps
- Wedges (steel) and cleats
- Chains
- Hoists and jacks etc.

Unsuitable resources are:

- Normal screw clamps
- Hydraulic lifting equipment
- Ropes
- Weights
- Everything which may yield

12. Cooling after flame straightening

Figure 21: Cooling after flame straightening



The cooling medium and whether cooling is in fact applied depends on the material.

Correct and proper cooling for flame straightening means careful heat dissipation from the edge to the centre of the heating zone. It is absolutely imperative that the cooling process does not cover the entire heated area (Figure 21).

In flame straightening, cooling with water or compressed air after heating does not increase the success rate of the straightening operation. It merely accelerates straightening.

Additional cooling of adjacent areas during the heating process positively influences upsetting and enhances the straightening effect.

If possible, forced cooling after heating should not be applied in flame straightening.

Amongst other things, the following should be taken into consideration:
- Build-up of excess stresses through non-uniform cooling can result in additional distortion
- Formation of hardening structures
- Critical cooling speeds for plate thicknesses > 25 mm
- Exposure of the working area to water

Stainless steels are an exception. For these steels, rapid heat dissipation from the workpiece is required to avoid precipitation and to prevent corrosion. Structural transformation and hardening structures cannot result.

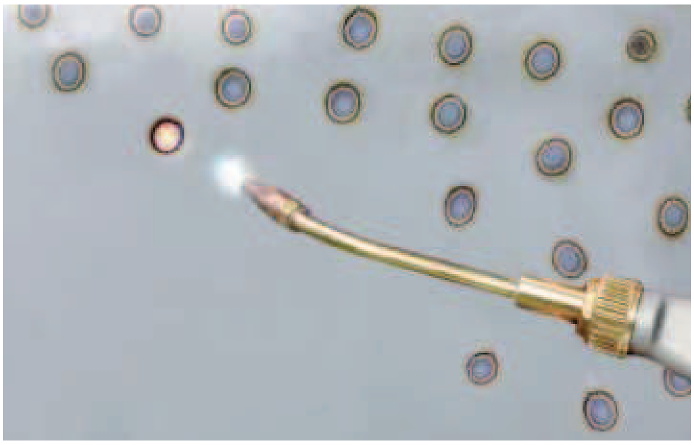
Components made of austenitic stainless steel are generally cooled with an ample amount of water.

For unalloyed mild steels, forced cooling does not cause problems.

For fine-grain structural steels starting with S355, abrupt cooling should not be utilised. Here, the recommendations for welding apply.

Components made of aluminium and aluminium alloys can be effectively cooled with water, water spray or compressed air.

13. Flame straightening of different materials



Heat spots on stainless steel

Materials which are suitable for welding can be flame-straightened without difficulties. For improved heat transfer into the workpiece, the oxy-acetylene flame setting should be either hard/neutral or, even better, hard/with excess oxygen or with slight excess acetylene. The flame setting depends on the material to be straightened.

13.1. Mild, fine-grain structural and TM steels

The flame straightening temperature is 600–650 °C (dark red glow). At this temperature, structural change is not possible. Cooling generally takes place in static air. Forced cooling leads to shorter straightening times for thinner and insensitive workpieces.

13.2. High-alloyed austenitic stainless steels

When flame straightening austenitic stainless steel, tools made of the same material must be used.

If the flame temperature "dark red glow" is maintained while straightening such steels, the structural composition of the material will remain unchanged. Due to low thermal conductivity and higher thermal expansion, upsetting and good straightening results are quickly achieved.

Abrupt cooling, e. g. with water, has a positive effect on the workpiece and corrosion resistance. In all cases, the oxy-acetylene flame is adjusted to give an oxidising flame in order to prevent exposure of the workpiece surface to a carbon-excess flame atmosphere.

Incorrect flame straightening at temperatures over 1,000 °C and prolonged maintenance of such temperatures may, under certain circumstances and with a reducing flame, cause the edge zone of the workpiece to carburise.

After the flame straightening operation, oxides must be removed from the surface, or in fact prevented, by etching, grinding or forming while straightening to prevent subsequent corrosion.

13.3. Galvanised components

Hot-galvanised components can be flame-straightened through the zinc coating without impairing their corrosion protection. In this application, the most favourable flame temperature is again "dark red glow". It is, however, not visible on hot-galvanised components. The use of brazing flux, type FH10 (DIN EN 1045), will thus facilitate an easier operation. Its fusing temperature makes it a good temperature indicator and, at the same time, protects the surface from oxidation. Investigations have shown that the heated zinc coating which is protected by the flux becomes denser and serves as an excellent bond to the base material. The oxy-acetylene flame may only impinge on the workpiece surface with a moderate flow velocity. Multi-flame torches are very suitable for this purpose.

13.4. Aluminium and aluminium alloys

A slightly reducing flame is used for these materials. Due to their high thermal conductivity, the torch attachments are larger than those for mild steel. As thermal expansion is twice that of steel, it must, in most cases, be restricted with mechanical resources during heating.

Depending on the aluminium alloy, the straightening temperature is between 150 °C and 450 °C. Within a range of 250 °C to 280 °C (light brown line), it is possible to quickly and easily monitor the flame straightening temperature with a wood chip or to determine the temperature with selected thermo-colour markers.

Electronic contact thermometers are not recommended due to their indication lag. Pyrometers can also not be used due to emission regulations for practical operations.

14. Working procedures for flame straightening

The following sequence of working steps is recommended:

Measuring

First, the reason for the distortion must be determined. Only then can flame straightening be carried out correctly. For deformations, the component measurements help to determine the shape and size of the dimensional deviation. Mark the reference points and record the measuring result on the component.

Determination of long side

With the help of heat input, workpiece sections are merely shortened. Welding seams are already too short. Therefore, never heat directly on welding seams. Thoroughly heated sections as a result of welding should be avoided as the HAZ of the weld area is already upset.

Restriction of thermal expansion

During the heating operation, the workpiece expands at the heated point. In order to obtain optimum straightening results, expansion must be restricted during the heating operation so that the required upsetting of the heated zone is achieved.

Fuel gas (acetylene)

The oxy-acetylene flame is by far the best for flame straightening! The fuel gas/oxygen mixture for flame straightening must impinge on the workpiece surface with a high flow velocity and heat flow density. In comparison to acetylene, other fuel gases such as propane or natural gas require more time for local heating due to their combustion properties, and they develop a larger flame due to the higher fuel gas/oxygen ratio. Areas adjacent to the flame straightening point are thus heated as well. This causes the heated zone to buckle and the straightening result is unsatisfactory.

Choice of torch

The torch size depends on the workpiece thickness and the material to be straightened.

Precise local heat build-up

Correct flame straightening can only be achieved if heat build-up is generated locally and precisely. The heated zones must be kept small. Several small heating patterns are better and more effective than one large figure. Heat wedges applied to the workpiece must be narrow and sharply delimited with a width-height ratio of 1:3.

Upsetting by means of plastic deformation

The heat output must be regulated in such a manner that the flame straightening point reaches the plasticity limit (above the elastic limit). In the plastic temperature range, the material “flows” by restricting thermal expansion. Upsetting then occurs in the heated zone. During cooling, the heated zone shrinks by the upset proportion and expansion restriction has no further function. This becomes visible when, for example, the jacks or wedges used to restrict expansion become loose as cooling progresses. The workpiece deforms.

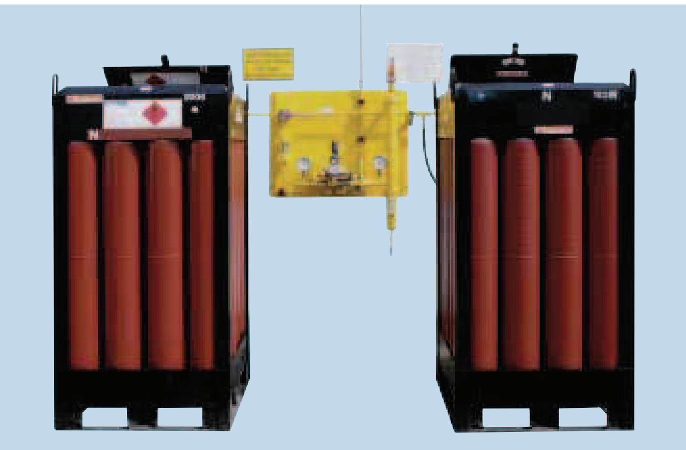
Allowing to shrink until ambient temperature has been reached

Workpieces shrink until they have reached ambient temperature or until a temperature balance is achieved between the flame straightening zone and the adjacent workpiece areas.

Measuring

The success of the straightening operation can only be measured on the component after it has cooled down. Only then can a new straightening point be determined if the agreed tolerance is not achieved.

15. Supply options for all oxy-acetylene processes



Cylinder bundle supply

A single cylinder system combined with an oxygen cylinder facilitates the use of oxy-fuel processes virtually at all times and in all places. Should a single cylinder not be sufficient to supply larger torches, multiple acetylene cylinders or bundles are connected to form a cylinder or bundle battery. For larger volumes, oxygen can be supplied as a cryogenic liquid in portable vessels or tanks.

The operating, monitoring and safety elements of the supply systems meet the latest technological standards and prevailing regulations. They have been adapted to individual requirements.

Delivery as	Type	Contents	Gas withdrawal in l/h		
		kg	Short-term < 20 min	Normal 8 h/day	Continuous > 8 h/day
Single cylinder	40/48/50	6.3/8/10	1,000	500	350
Cylinder bundle (6 cylinders)	46	43.2	6,000	3,000	2,000
Cylinder bundle (16 cylinders)	61	144	16,000	8,000	5,500
Trailer (128 cylinders) 8 bundles		1,152	128,000	64,000	44,000
Trailer (256 cylinders) 16 bundles		2,304	256,000	128,000	88,000

16. Notes on torch operation and safety

Flame straightening is associated with potential sources of hazards, such as fire, radiation and by-products, requiring special care and corresponding safety systems and equipment. Gas cylinders, cylinder bundles and tanks are normally used for supplying gas. They also need to be handled prudently and require appropriate accident prevention measures.

Fire

The safety of any work area can be improved by following good housekeeping practices. All combustible materials should be removed from the area prior to flame straightening. Never flame-straighten in an area containing combustible vapours, flammable liquids or explosive dust.

An approved and regularly serviced fire extinguisher should be kept and maintained close to where work is being carried out.

Process emissions

Fumes that are hazardous to health may occur during flame straightening depending upon the surface condition of the workpiece (e. g. oil and paint). Therefore, it is important to ensure proper ventilation and use.

Gases and gas supply

Gases for flame straightening are supplied in gaseous form in gas cylinders or cylinder bundles, or in liquid form in cryogenic vessels or, as applicable, in a tank. Gas cylinders must always be secured so they cannot fall over as this can cause injury or damage to the cylinder valve.

When gas is being withdrawn, pressure must be decreased to operating pressure, which can be done using the corresponding cylinder pressure regulator and/or point-of-use regulators provided. They must be suited for the respective gas being used and opened slowly in order to avoid a pressure shock that can damage subsequent installations. The cylinder must be resealed when work is finished. Pressure regulators should only be connected and replaced by authorised personnel. Safety valve settings and safeguards should not be changed at all.

Flashback arrestors

A flashback arrestor is a device designed to prevent a flashback from passing from the hose into the cylinder. A flashback arrestor has a sintered flame-arresting element, which acts to extinguish any flame coming into contact with it. Hose check valves are designed to prevent gases from flowing back into the system. They are not designed to stop a receding flame and must not be used in place of flashback arrestors.

Start-up procedure

There are two types of burner designs, based on where the oxygen and fuel gases are mixed; injector-mixed or nozzle-mixed. The start-up procedure depends upon the type of torch, it is therefore important to identify the correct procedure for the torch being used by reading the torch instruction manual.

Fuel and oxygen starvation are responsible for the majority of problems occurring with heating torches. If insufficient amounts of gas are allowed to flow through the nozzle during operation, it will cause backfires to occur. Repeated backfires can cause damage to the nozzle and torch.

Withdrawal rates for fuel gases depend on the size of the cylinder, the contents in the cylinder and the temperature of the cylinder. Never exceed the recommended withdrawal rates.

Please contact Linde for additional safety information.

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