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METHOD FOR REDUCING DEFORMATIONS IN LARGE BEAMS

METODA ZA SMANJENJE DEFORMACIJA VELIKIH GREDA

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- flame straightening
- large beam deformations
- steel structures
- welding quality

Abstract

This study offers a method for using flame straightening in civil engineering with limitations that are far higher than suggested by the steel manufacturer. In the process of flame straightening, when working with steel structures, a small portion of an element or structure is heated to the straightening temperature to cause geometrical changes. Many factories manufacturing steel structures employ flame straightening procedures. In numerous instances, the economic feasibility of repairing steel structures without flame straightening is not achievable. The purpose of the study is to demonstrate how flame hardening affects the material microstructure. The basic idea that metals shrink when cooled and expand when heated is the basis of flame straightening.

Ključne reči
- ispravljanje plamenom
- deformacije velikih greda
- čelične konstrukcije
- kvalitet zavarivanja

Izvod

Prikazan je metod za ispravljanje plamenom u građevinarstvu, sa daleko većim ograničenjima u odnosu na ona koja predlaže proizvođač čelika. U procesu ispravljanja plamenom, kada se radi sa čeličnom konstrukcijom, mali deo elementa ili konstrukcije se zagreva do temperature ispravljanja da izazove geometrijske promene. Mnoge fabrike koje proizvode čelične konstrukcije koriste proceduru ispravljanja plamenom. U brojnim slučajevima, ekonomska izvodljivost popravke čeličnih konstrukcija bez ispravljanja plamenom je neostvariva. Svrha studije je da se pokaže kako otvrdnjavanje plamenom utiče na mikrostrukturu materijala. Osnova za ispravljanje plamenom leži u ideji da se metali skupljaju kada se ohlade i šire kada se zagrevaju.

INTRODUCTION

The method's basic idea is to use local heating firmly restricted to the area where clamps are used to prevent the material from expanding extensively (Fig. 1).

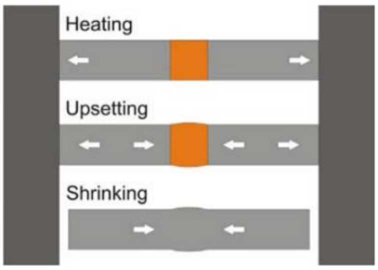

Figure 1. The principle of flame straightening, /1/.

The concept takes into account that metals expand when heated and contract when cooled, being the basis for flame straightening. This well-known technology involves heating metal structures with a flame up to a temperature that straightens while simultaneously limiting their ability to expand. The heating areas are clearly defined. Even though flame straightening has been a common technique for producing steel structures for a long time, there is insufficient understanding of how heating affects the material structure, particularly in high-strength steel structures. Without precise knowledge it is difficult to evaluate the expected influence of the heat source performance, heating time, temperature, extent, etc. Flame straightening methods cannot be utilised with the well-established and refined cooling time concept according to EN 1011-2, which can be used to offer a good estimate of expected mechanical properties of the joint, based on the calculation of the cooling time from arc energy (heat input).

Two different types of flame straightening can be distinguished based on the heating intensity. Heating the surface layer to a partially (usually up to 30-35 % of the whole cross-section) in relation to the structure's overall cross-section is one often employed technique. In this instance, the cooling rate is usually high, and the heat input rate is small in relation to the workpiece material thickness. In the other situation, a relatively high heat input and a low cooling rate can be anticipated when the workpiece whole cross-section is heated locally, /1/. The influence of flame straightening on material properties cannot be regarded anything less substantial than that of welding, since the steel is heated over a relatively large area and depth.

The non-expandable material experiences compressive stress upon heating, which results in localised expansion of the material thickness in the heated region (expanding of the material). As a result of contraction forces in the material, cooling allows the material to relax and take on the required shape. The portion shortens in heated areas because the expansion that would have occurred during the heating phase is stopped.

In real terms, cold base material in nearby places produces a barrier to the local expansion of the heated material during flame straightening, which causes negligible local deformations that arise in this area of the material. The part takes on the required shape because of the compressive forces that develop when the locally heated area cools.

The sheet of metal is heated from the inside out using an oxyfuel flame (often oxyacetylene) at locations where there are curvatures. The heated area is then cooled using a water jet. The wooden hammer is used to straighten the heated points that have been cooled with water, based on the side the heat has caused them to deform. Although at least two workers are needed on both sides of the board, this method is not productive. Since improper heating might cause the sheet to bend even more, the heating technician needs to be an experienced specialist. The water used to cool it thereafter causes a quick oxidation process. Point deformations with varying diameters ranging from 6 to 10 mm will manifest in heated areas and will not go away. As a result, even after grouting and painting, the casings' exterior appearance is not what is intended.

ADVANTAGES AND DISADVANTAGES

Advantages of flame straightening:
- impact on material and its surface is insignificant,
- size of the flame and its setting can be adequately adapted to the workpieces and material,
- flame straightening without applying mechanical force,
- flame straightening is often the only possibility to ‘save’ a component, respectively to bring it to the required shape,
- it is a relatively economical method.

Disadvantages of flame straightening:
- operators require strong qualifications,
- has the effect of lowering mechanical strength,
- causes structural changes,
- may cause carburizing or melting of the material.

Figure 2 shows different types of flames and multi flame straightening burners/torches. While single flame burners are typically used for straightening thin materials, multi flame burners are designed for thick materials, because of material thickness, the energy (heat) needed for reaching the straightening effect is higher and slight dissipation of heat reduces the risk of melting the material surface.

a)

b)

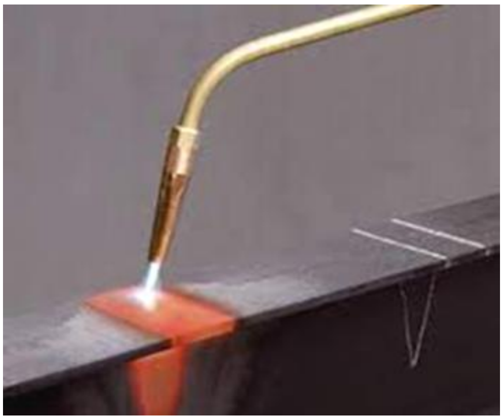

Figure 2. Flame straightening: burners a); torches b).

RECOMMENDATIONS FOR FLAME STRAIGHTENING

For the carbon-, fine-grained-, thermomechanically rolled steel and Al alloys, recommendations are as follows:
- the temperature of the straightening flame is 600-650 °C (bright dark red). At this temperature, structural changes are not possible. Cooling generally occurs in static air. Forced cooling leads to shorter straightening times for thinner and insensitive parts;
- austenitic stainless steels: when flame straightening is performed on austenitic stainless steel, the equipment of the same material must be used. If flame temperature (corresponding to the ‘dark red’ shade) is maintained during straightening, the structural composition of the material will remain unchanged. Due to low thermal conductivity and higher coefficient of thermal expansion, tensioning and straightening are quickly achieved with good results. Sudden cooling, for example, with water, has a positive effect on the workpiece and corrosion resistance. In all cases, an oxyacetylene flame of oxidizing character shall be used to prevent exposure of the surface of the straightening part to an atmosphere of flame with excess carbon. Flame straightening at temperatures above 1000 °C and prolonged maintenance of such temperatures may, under certain circumstances and using a reducing flame, cause carburizing of the marginal area of the part. After the flame straightening operation, the oxides must be removed from the surface, or oxidation prevented, in fact, by pickling or grinding during straightening to prevent further corrosion;
- galvanized components: hot-dip galvanized components can be flame straightened through the zinc coating without affecting corrosion protection. In this application, the most favourable flame temperature is also that corresponding to the ‘bright dark red’ shade. However, the colour is not visible on hot-dip galvanized components, which is why it is recommended to use hard bonding flux type FH10 (DIN EN 1045), which will facilitate an easier process. Its fusion temperature makes it a good temperature indicator and at the same time protects the surface from oxidation. Investigations have shown that the heated zinc layer that is protected from flux becomes denser and serves as an excellent binder with the base material. The oxyacetylene flame can only affect the surface of the workpiece with a moderate flow rate. Multi-flame burners are well suited for this purpose;

- aluminium and aluminium alloys: for these materials, a slightly reduced flame is used. Due to the high thermal conductivity of these materials, torch attachments are larger than those for low-carbon non-alloy steel. Since the coefficient of thermal expansion of aluminium is twice that of steel, in most cases, expansion must be restricted with mechanical resources during heating. Depending on the type of aluminium alloy, the straightening temperature is between 150 °C and 450 °C. In a range from 250 °C to 280 °C (light brown line), it is possible to monitor the temperature of the straightening flame quickly and easily with a wood chip or determine the temperature with selected thermochromic markers. Electronic contact thermometers are not recommended due to delayed indication. Also, pyrometers cannot be used due to emission regulations for practical operations. Temperatures above 1000 °C and prolonged maintenance of such temperatures may, under certain circumstances, as well as the use of a reducing flame, cause carburizing of the marginal area of the part. After the flame straightening operation, the oxides must be removed from the surface, or oxidation prevented in fact, by pickling or grinding during straightening to prevent further corrosion.

Table 1 shows the recommended temperature for flame straightening of various materials.

Table 1. Recommended temperature for flame straightening.

Materials	Specification	Alternative specification	Flame temp. [°C]
Mild steel	S235JT S355JO		600-800
Boiler steel	P265GH 16Mo3 13CrMo4-5		600-800
Fine-grain structural steel	S355N S890QL		550-700
TM steel	S355M S460M		550-700
Nickel alloys	2.4360 2.4602 2.4856	NiCu30Fe NiCr21Mo14W NiCr22Mo7Nb	650-800
Austenitic stainless steel	1.4404 1.4301 1.4541	X2CrNiMo17-12 X5CrNi18-10 X6CrNiTi18-10	650-800
Aluminium			150-450
Non-age-hardening Al wrought alloys	EN AW-3103 EN AW-5754 EN AW -5083	AlMn1 AlMg3 AlMg4.5Mn0.7	300-450 300-450 150-350
Age-harden ing wrought Al alloys	EN AW-6005A EN AW-6082 EN AW- 7072 EN AW- 7020	Al Si Mg(A) AlSi1MgMn AlZn1 AlZn4.5Mg1	150-200 150-200 150-350 600-800

The impact of $\Delta t_{8/5}$ cooling time on properties of heat-affected zones has been the subject of numerous investigations. Unfortunately, most of the time, a cooling time interval of 5 to 30 seconds is examined, which is in line with the usual range of the most widely used arc welding technologies /2–5/. Short (6-10 s) $\Delta t_{8/5}$ cooling time range is typically advised for high strength steels, particularly for the higher strength classes /6/. It is important to understand the behaviour, microstructure, and mechanical properties of the material under these cooling conditions because the cooling period during flame straightening can be significantly longer, sometimes exceeding 100 s.

PROCEDURE FOR BEAM STRAIGHTENING

The procedure will be explained on a large, welded steel bridge. At one of the webs of a bridge with large beams, a deformation of 26 mm occurred due to welding processes, and consequently it was necessary to repair it. The deformation occurred at the connection of two welded joints of the web. This weld was defined as X-joint with total penetration. The weld is positioned between two internal stiffeners of the steel box of vertical diaphragm-wall type. After the welding, the web moved to the inside of the cassette. The flame straightening procedure was used to straighten the web. The process began by setting some points in the material for applying heat with a burner/gun. The process consists of a circle with a diameter D_1 = 800 mm, drawn in the location of the maximum deformation on the web. This circle was then divided into 6 equal segments. At each point thus bonded, a circle of diameter D_2 = 150 mm is drawn, resulting in heating zones of the material, as shown in Fig. 3.

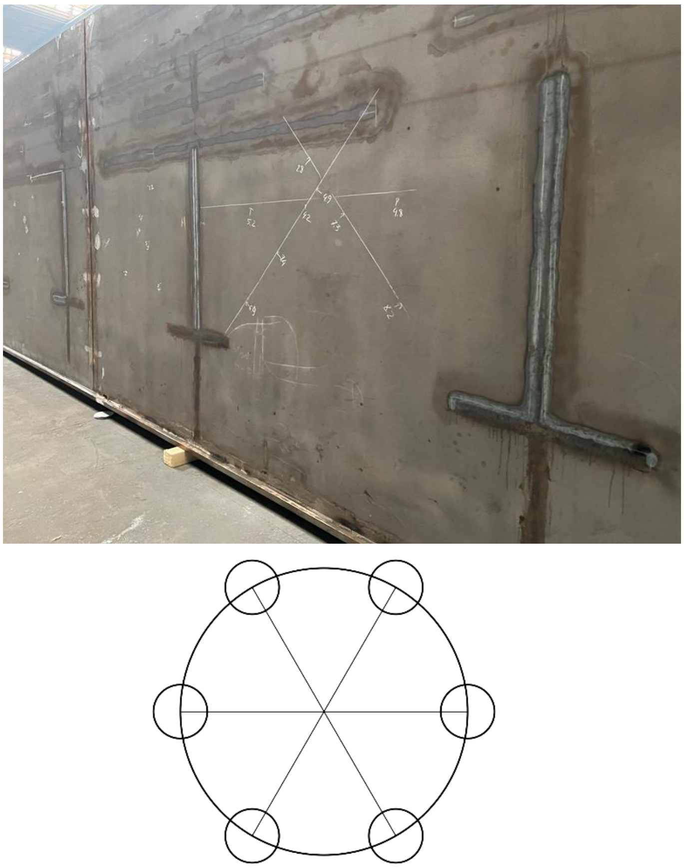

Figure 3. Heated areas, D_1 = 800 mm, D_2 = 150 mm.

The temperature to which the material (S355J2+N) has been heated for straightening purposes is 600-700 °C. For straightening, a simple burner with oxyacetylene flame was used. Figure 4 illustrates the web after completion of the straightening process. The deformation has been repaired, and the web of the box girder is within parameters. The procedure was followed starting from a case study used in France; the procedure is exposed in Fig. 5.

Figure 4. Large beam straightened.

Figure 5. Image of the process used in France to correct a web with large deformations.

Experimental studies and tests have shown that thermo-mechanical rolled S355M steels can be straightened without any problems. Applying the straightening process by heating in strips can be carried out up to 900 °C without affecting the mechanical properties, /1, 6/.

Applying heating, for example, at a temperature 700 °C for short operations and 600 °C for longer operations, is acceptable. When using higher temperatures, the material yield strength decreases. The whole procedure was carried out considering procedures described in technical literature and Linde's recommendations for flame straightening. Finally control procedures confirmed that there were no changes in beam structure; NDT tests validated the procedure.

CONCLUSIONS

The size of the heat-affected area, as well as the resulting effects during flame straightening are determined by several factors:

- heat source performance, including its size, kind, and industrial gas type;
- size and type of heated area (large area, line, spot, etc.);
- maximum temperature reached, considering both its temporal and spatial range;
- cooling environment, which comprises the size, shape, and thickness of materials as well as air or water cooling.

The geometrical approach served as the foundation for the proposed heat straightening methodology. The goal of the study was to offer a method for methodical identification of the sites and concentrations of heat.

The procedure applied in the investigation and thus repairing a high deformation in a welded steel bridge; was performed according to Linde's instructions, and according to technical literature. Future studies will be based on this type of structure to analyse in detail what is going on in the microstructure of the joints.

REFERENCES

1. Fundamentals of Flame Straightening, White Paper, BOC, Linde Group, 2009-2023, pp. 4-26.
2. Molnar, R., Feier, A., Chivu, O. et al. (2024), *An investigation of the effects of flame straightening heating on the high-strength structural steels microstructure*, Metallogr. Microstruct. Anal. 13: 1071-1081. doi: 10.1007/s13632-024-01141-7
3. Mičian, M., Harmaniak, D., Nový, F., et al. (2020), *Effect of the $t_{8/5}$ cooling time on the properties of S960MC steel in the HAZ of welded joints evaluated by thermal physical simulation*, Metals, 10(2): 229. doi: 10.3390/met10020229
4. Tervo, H., Mourujärvi, J., Kaijalainen, A., Kömi, J. (2018), *Mechanical properties in the physically simulated heat-affected zones of 500 MPa offshore steel for arctic conditions*, In: Jármai, K., Bolló B. (eds.), Vehicle and Automotive Engineering 2 (VAE 2018), Lecture Notes in Mech. Eng., Springer Cham.: 779-788. doi: 10.1007/978-3-319-75677-6_66
5. Maurer, W., Ernst, W., Rauch, R., et al. (2015), *Evaluation of the factors influencing the strength of HSLA steel weld joint with softened HAZ*, Weld. World, 59: 809-822. doi: 10.1007/s40194-015-0262-z
6. Gáspár, M. (2019), *Effect of welding heat input on simulated HAZ areas in S960QL high strength steel*, Metals, 9(11): 1226. doi: 10.3390/met9111226

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