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Fatigue Strength of Flame Cut Plates

Résistance à la fatigue des tôles oxycoupées

Ermüdungsfestigkeit von mittels Sauerstoffbrenner geschnittener Bleche

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SUMMARY
When steel plate is flame cut the resulting edges exhibit different mechanical characteristics to those of the basic product. These changes are particularly significant in the case of AE 355 steel. Many fatigue tests have shown that grinding does not improve behaviour beyond that of the untreated edge. However, shot peening of the flame cut edge raises the allowable fatigue stress by 30 to 35 MPa which is better than that obtained by preheating before cutting. Thus, with regards to fatigue strength, shot peened, flame cut elements fall into the highest class of welded connections.

RESUME
Lorsque la mise à dimension des tôles se fait par oxycoupage, les bords de ces tôles présentent des caractéristiques mécaniques modifiées par rapport à celles du produit de base, particulièrement dans le cas de l'acier de qualité AE 355. Un grand nombre d'essais de traction dynamique ont montré que des éprouvettes meulées n'ont pas un comportement meilleur que celui des éprouvettes oxycoupées n'ayant subi aucun traitement. Par contre, le grenaillage de la face oxycoupée permet de relever leur résistance à la fatigue de 30 à 35 MPa; valeur qui est supérieure à celle obtenue en préchauffant la tôle avant le coupage. On obtient ainsi des valeurs qui sont comparables à celles des meilleures classes d'assemblages soudés.

ZUSAMMENFASSUNG
Beim Zuschneiden von Blechen mittels Sauerstoffbrenner verändern sich an den Rändern die mechanischen Eigenschaften gegenüber denjenigen des Basisproduktes. Dies trifft insbesondere für den Stahl der Qualität AE 355 zu. Zahlreiche dynamische Zugversuche haben gezeigt, dass Prüfkörper mit nachgeschliffenen Schnittstellen kein besseres Ermüdungsverhalten aufweisen als unbehandelte. Im Gegensatz dazu erhöht das „shot-peening" den Ermüdungswiderstand um 30 bis 35 MPa. Dieser Wert ist besser als derjenige, der mittels Vorerwärmung vor dem Schneiden erreicht werden kann. Man erhält so Ermüdungsfestigkeiten, die mit den besten Klassen von Schweissverbindungen verglichen werden können.

1. INTRODUCTION

Whenever the size dressing of steel plates is carried out by thermal cut, the edges present modified mechanical characteristics as compared with the basis product. These modifications are particularly perceptible in the case of AE 355.

These modifications are due to the particular thermal treatment endured by the cut edge which results in the creation of tempering structures with variable carbon contents. Additionaly, the non-homogeneous thermal distribution during the oxygen-cut operation entails the creation of residual stresses, the influence of which cannot be neglected as far as the fatigue strength or the stability are concerned.

Up to now, in Belgium, the treatment of such faces is quite expensive as most authorities required the grinding of the all oxygen-cut face on a deapth of 1 mm in order to remove all the matter which was structurally modified during the cutting. Therefore, a research was undertaken in order to investigate the influence of such modifications on the statical and dynamic behaviour of AE 355 steel plates and to try to discover some means of improving their mechanical characteristics.

2. CHARACTERISTICS OF OXYGEN-CUT EDGES

The priming of the cutting operation requires a heat quantity sufficient to bring a small portion of the piece to be cut to a high temperature, around 1350° C [1].

During the cooling, the cut edges undergo metallurgical transformations which induce hardening structures.

Generally that heat affected zone presents one of the two structures shown at fig. 1, depending on whether the cutting operation was performed with preheating or not [2].

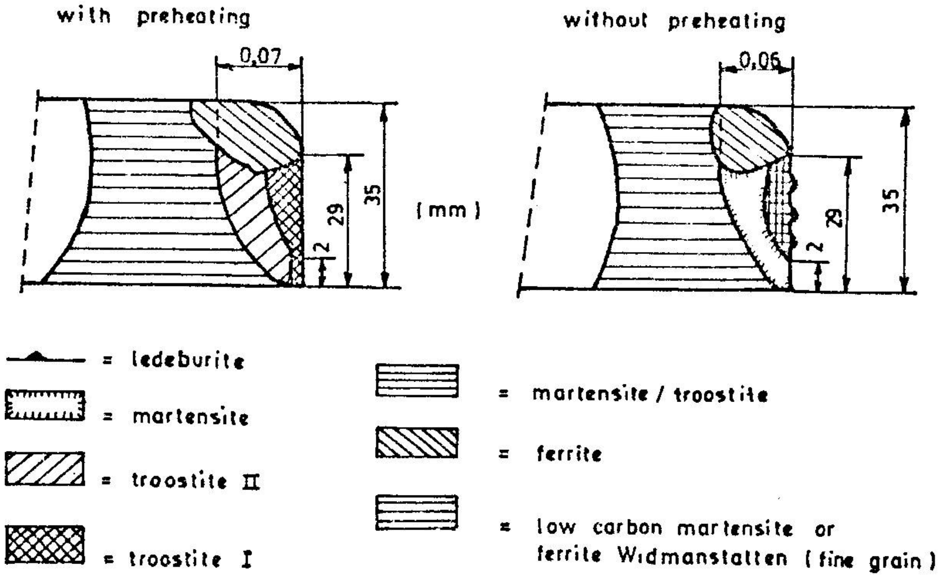

Figure 1. Structure of the heat affected zone after oxygen-cutting.

In addition to these metallurgical modifications several phenomena may be observed :

a) The carbon concentration is increased along the cut edge in a very thin layer about 0,1 mm deep.
As the hardness is a direct function of the carbon contents, one observes very high hardnesses in this thin layer and therefore along the cut edge. This increase of the carbon contents does not come from the cutting flame nor from the diffusion of carbon towards the cut edges, but from the material which was melt during the cutting. However, and this has not yet been explained, it is only beneath a depth of 1,5 mm (and not 0,1 mm) that the hardness begins to decrease to reach the value for the basic material about 3 mm from the surface (fig. 2).

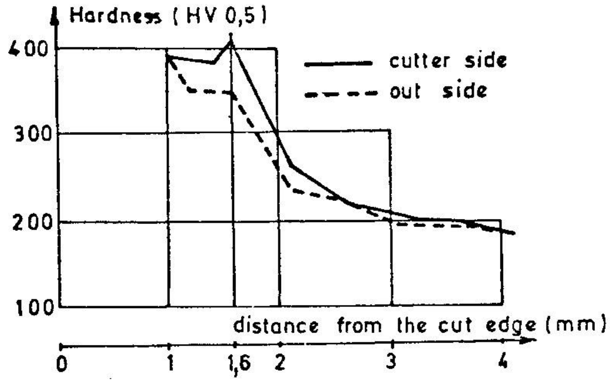

Figure 2. Measurement of the hardness near the cut edge.

b) The heat distribution due to the oxygen-cutting produces a field of residual stresses in the cut pieces. The distribution of these stresses along the edge has not yet been defined neither in sign nor in value. The tests made up to now are not significant as some authors speak of compression stresses [2,11] while others speak of traction stresses [6,10,11].

c) The cut surface presents grooves oriented in the direction of the cutting flame. In most cases these grooves happen to be perpendicular to the stress fields when the plate is put into service, which is very unfavorable as far as the fatigue resistance is concerned. Moreover the fatigue resistance may still be further hampered by additional imperfections. In addition such grooves also affect the resistance to brittle fracture which depends mostly on the depth and the sharpness of the grooves.

Generally, the defects are caused by a bad setting of the cutting torch or by a stop in the cutting operation. Some of these defects are always present particularly at the initial point of the cut. As a result of the thermal effect of the oxygen-cutting and of the geometrical characteristics of the cut edge, the following mechanical characteristics are modified :

a) The resistance to brittle fracture, related to the ductility of the material which is itself influenced by deformation of the hardening structures and by the increase of the carbon contents of the cut edge.
b) The fatigue resistance, influenced by the residual stresses, the presence of grooves and the metallurgical structures.
c) The bearing capacity, influenced by the residual stresses near the cut edge.

The nature of the resulting metallurgical structures depends on the heat treatment applied to the edge to be cut. This treatment is a function of the heat quantity introduced and of the cooling speed. These two main parameters depend on various factors :

- the practical conditions of the cutting operation,
- the thickness of the plate,
- the nature of the cutting gas,
- the type of nozzle used,
- the cutting speed,
- the oxygen pressure.

3. TESTING PROGRAM

In order to determine the importance of the previously described effects on the actual behaviour of oxygen-cut pieces in practical situations, the following tests have been undertaken :

- measurements of surface conditions,
- folding tests of residual stresses,
- traction tests,
- dynamical tests.

The tests were performed on specimen coming from various pieces of steel before and after the cutting operation.

4. SPECIFICATIONS OF THE SPECIMENS

A great many factors influence the quality of an oxygen-cut surface. In the frame of this research, it is obviously not possible to consider the whole set of parameters nor to realize all their possible combinations.

All parameters which are usually fixed by the cutting equipment manufacturer or for which the setting is easy and not prone to error have been fixed for the whole test program.

For the other parameters, the following values corresponding to general practice have been used :

- steel grade : AE 355 steel sheets with a carbon ratio around 0,18 %.The specimens were always cut in the direction of rolling.
- thickness of the sheets : most tests were made using two thicknesses : 20 and 35 mm. Complementary tests were made using 12 and 44 mm.
- initial steel temperature : two temperatures were considered : room temperature (20°C) and preheating to 100°C. The preheating was achieved with a flame torch in front of the cutter.
- post cutting treatment : several treatments were studied :
  - no treatment,
  - light grinding (whitened surfaces),
  - grinding up to the elimination of grooves (0,7 to 1 mm),
  - shot peening.

In the particular case of shot peening, the following parameters were used :

- shot material : steel shot of 1 mm diameter,
- shot peening duration : 1.5 minute,
- the shot peening machine had 6 turbines of 500 mm diameter rotating at a speed of 3.000 rev/min,
- distance between piece and turbine : 1 m.

In order to detect a possible influence of the nature of the shot material on the test results, some specimens were shot peened using cupper shot while others were treated in very unfavorable conditions for the final surface state :

- shot material : brand new corindon
- granulometry : 1190 to 1410 µm; type 16-80
- pressure : 60 to 70 MP_a.

5. TEST RESULTS

5.1. Surface Conditions

Surface condition measurements have been made on samples representing all the situations described above. Fig. 3 shows the resulting diagrams of some of these measurements. The general conclusion is that the overall aspect of the surface is not modified by the various treatments and that the grooves have still the same deapth.

The diagrams however do not show any evidence of a possible reducing of the sharpness at the grooves bottom , although this has been mentioned by several authors.

5.2. Residual Stresses

On the oxygen cut faces shot peening reduces the residual stresses (in traction) by about 100 MP_a (see Fig. 4).

On the other hand, the steel temperature before cutting has no significant influence on the value of these stresses.

5.3. Statical Tests

5.3.1. Folding tests

Several specimens have been folded around a mandrel having a diameter of 10 times the thickness of the steel sheet.

To achieve the most several situation, many specimens were folded in their plane with one cut edge in traction.

No cracking was ever observed after 90° folding even after a verification using a penetrating liquid.

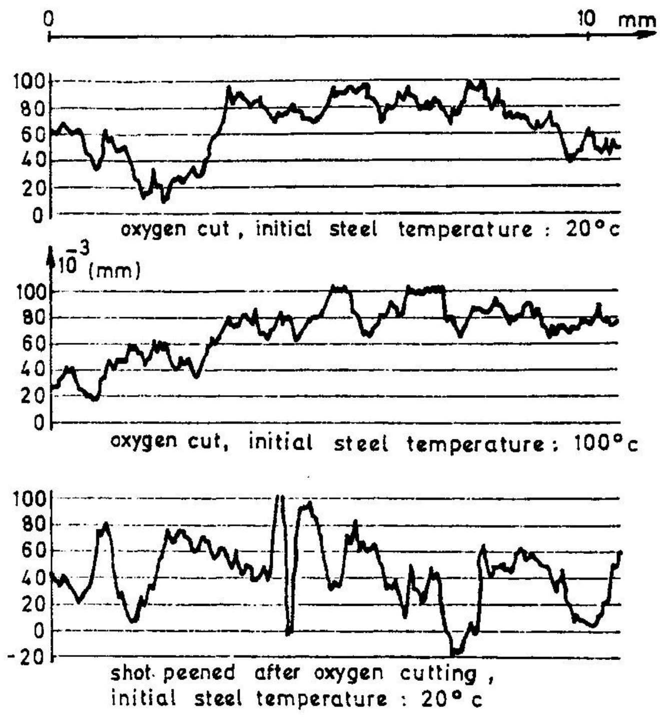

Figure 3. Measurements of surface conditions.

5.3.2. Traction tests

A typical stress-strain diagram for an oxygen-cut specimen is represented at Fig. 5 in comparison with the stress-strain diagram for the base metal.

It may be seen that the conventional 0,2 % elastic limit of the oxygen cut steel is equal or slightly higher than that of the base steel.

On the other hand, the apparent elastic limit cannot be pinpointed : during the loading of the specimen, the section yields progressively due to the traction residual stresses. It is however not possible to derive the level and distribution of the traction stresses on the only basis of these tests.

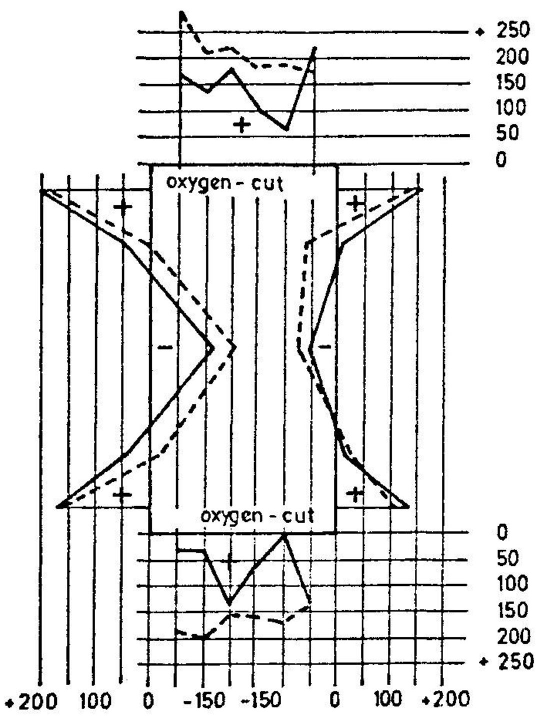

Figure 4. Residual stresses (MP_a).

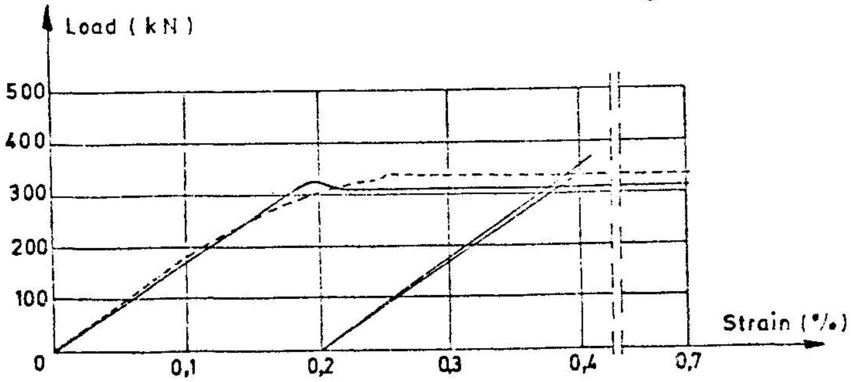

Figure 5. Diagram stress-strain.

5.4. Dynamic Tests

In reason of the severity of the grooves on the oxygen-cut edges and of the residual stress level measured on such edges, we have processed the dynamic test results using the method in application in the case of fatigue-loaded unrelaxed welded joints, for which the conditions are similar.

In this method, the fatigue cycles are only characterized by the stress range $\Delta\sigma = \sigma_{max} - \sigma_{min}$ without consideration for the stress ratio $R_s = \frac{\sigma_{min}}{\sigma_{max}}$.

Fig. 6 and 7 show some of the resulting WOHLER curves. Fig. 6 shows the effect of preheating on the fatigue resistance while Fig. 7 shows the effet of shot peening. In addition, Fig. 7 also shows the ultimate values for the 4 specimens shot-peened using corindon. If one considers that the two weakest results correspond to ruptures in sections where cutting defects had been ground and not in shot-peened regions,one may conclude that corindon gives as good results as other types of shot.

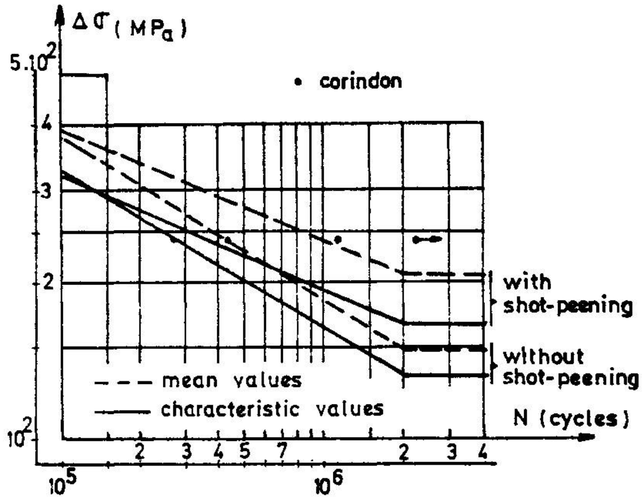

Figure 6. Fatigue tests results with and without shot-peening.

The tests have also shown that grinding the cut pieces only raises the characteristic value of the stress range from 132 to 150 MP_a and that all the corresponding endurance limits are valid whatever the thickness of the steel.

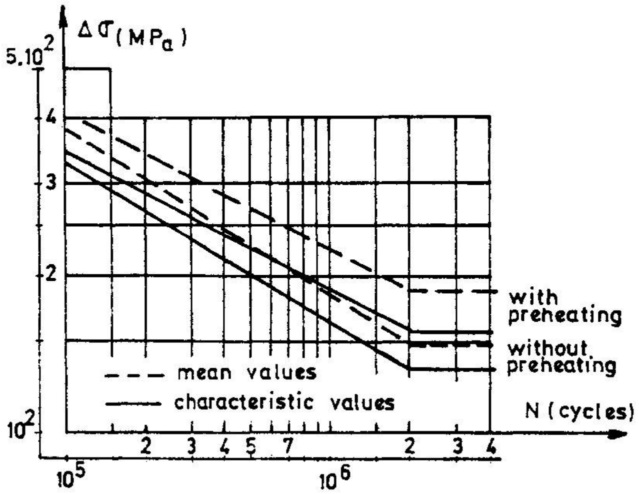

Figure 7. Fatigue tests results with and without preheating.

6. CONCLUSIONS

The shot-peening after oxygen cutting increases the fatigue resistance by 30 to 35 MP_a and the preheating by about 25 MP_a. Both effects may be cumulated.

The following table gives the 90 % characteristic values of the stress range for life duration longer than 2.10^6 cycles obtained for the various combinations of preheating and shot peening.

Characteristics values (90 %) of the stress range

Peening / Preheating	Without	With
Without	132	164
With	158	201

If these values are compared with those given for welded joints in function of their fatigue resistance, one can see that shot-peening, preheating and,better, combination of these treatments lead to oxygen-cut pieces with a resistance equivalent to that of the best joints. Now, constructions without any welding are very scarce. We are therefore of the opinion that in most cases the use of oxygen-cut steel sheets does not require any particular treatment, as most often the sheets are cleaned by shot-peening after shaping, before being prepainted.

On the other hand, if the construction must offer a high fatigue resistance, oxygen-cut edges must be milled out as simple grinding is not efficient enough.

REFERENCES

1 R. BAUS, W. CHAPEAU : Application du soudage aux constructions. Sciences et Lettres, Liège.
2 Netherlands Institute of Welding-Working Group 1913 : The Properties of Flame Cut Edges. Final Report, May 1973.
3 A. LEROY, M. EVRARD, G. D'HERBEMONT : La pratique du soudage oxyacétylénique et des techniques connexes. Publications de la soudure autogène, 1963.
4 SELLIER : Cours de soudage et de découpage au chalumeau.
5 Institut International de la Soudure : Projet de classification des surfaces obtenues par coupage thermique-soudage et tehcniques connexes. Vol. 25, mai-juin 1971.
6 JURGEN RUGE und Alfred KRAHL : Etude de la capacité au formage à froid des zones thermiquement influencées des tôles oxycoupées. Schweissen und Schneiden, n° 19, 1967.
7 A. ARCOUTEIL et J. MONNET : Conditions de mise en oeuvre des tôles en aciers résistant à la corrosion.
8 F. GOLDBERG : Origine de l'accroissement de la teneur en carbone à la surface des coupes dans l'oxycoupage des aciers. Soudage et techniques connexes, vol. 26, n° 12, 1972.
9. GOLDBERG, FREDRIKSSON, NOREN-BRANDEL : Coupage aux gaz des aciers de construction à basses températures. Le soudage dans le monde, vol. 11, 1973.
10 B.W. YOUNG and J.B. DWIGHT : Residual stresses due to longitudinal welds and flame cutting. University of Cambridge, Department of Engineering.
11 Von KURLAGUNDA N. RAO, JURGEN RUGE und HEINZ SCHIMMOLLER : Détermination des contraintes résiduelles dues à l'oxycoupage des tôles. Forschung n° 36, 1970.
12 Recommandations de l'I.B.S. (Institut Belge de Soudure)-Commission 15 B : Le calcul à la fatigue des assemblages soudés des constructions métalliques en acier.
13 H. THOMAS and F. GOLDBERG : Quality Recommendations for Thermal Cut Surfaces in Steel Structures subjected to Fatigue Loading. Document IIS n° XIII-902-78.
14 NBN 11702. Essai de pliage (2ème édition), 1961.
15 A. PLUMIER : Relation entre les paramètres de soudage d'une colonne et sa charge de flambement. Thèse de doctorat, Université de Liège, 1979.