BEHAVIOUR OF SHOT PEENED WELDED STEEL UNDER CYCLIC LOADING

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ABSTRACT

The CREUSABRO 32 steel [1] TIG-welded joints were investigated before and after shot peening by mean of X-ray analysis and micro-hardness measurements. Fatigue tests were carried out to study and to optimise the shot peening parameters to improve the fatigue resistance of the welded joints. Beneficial effects of shot peening has been observed and 54% increase was noted for the used Almen intensity of 16-20 A.

KEYWORDS

Abrasion steel, Shot peening, Residual stress, Welding, fatigue life, TIG-welded.

INTRODUCTION

Abrasion steels combine excellent high mechanical properties and good weldability. They are used extensively for fabrication of welded constructions, typical applications include chemical process equipment, petroleum plate forms, etc. One of the most using is train's bogies. However, fatigue lifetime of welded train's bogies, used by Société National des chemins de Fer Tunisiens (the Rail ways Tunisian Company) seems to be insufficient and under estimated.

Welding provokes a non uniform localised temperature field, which involves a speed heating of the basis metal to the melting temperature and a kinetic cooling depending on the welding parameters.

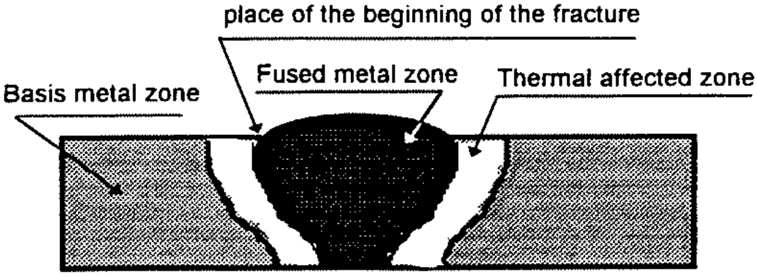

Figure 1 The different zones of the welding joints

As shown in the previous figure 1, three principals zones are created in the welding cord:

- the basis metal zone where the microstructure is slightly not affected (T < 600 °C),
- the thermal affected zone where the microstructure is small changed (600°C< T < 900°C)
- the fused metal zone where metallurgical modifications are produced (1200 °C< T < 1500°C).

Metallurgical, mechanical and geometrical modifications are created in the welding joints. They involve a brittleness, residual stresses and stress concentration, which decrease the fatigue performance of the welded parts.
Shot Peening [2] can be used to enhance the performance of welded parts [3]. Enhancement in fatigue strength stems from several effects, especially from the generation of compressive residual stresses and the increase of the surface hardening.

In this study, a welded steel CREUSABRO 32 joints, equivalent to 15 CrMo 15 05 M in the French norm (NF A 35-590) [1], obtained by TIG-dressing, and shot peened with various peening conditions were characterised and tested under cyclic loading. The aim of this paper was to study and to optimise shot peening parameters on the CREUSABRO 32 steel welding joints in order to improve fatigue lifetime of the train's bogies.

EXPERIMENTAL PROCEDURE

Material composition and Mechanical characteristics

The studied material was delivered annealed. The material composition and the mechanical properties of the investigated material are summarised in the following tables:

Table 1: Chemical Composition of the CREUSABRO 32

Element	Weight percent
Carbon	0.19
Silicon	0.35
Manganese	1.10
Chromium	1.30
Molybdenum	0.20
Sulphur	0.03
Phosphorus	0.03

Table 2: Mechanical Properties of the CREUSABRO 32

Mechanical characteristics	Values
Re limit of elasticity (MPa)	735
E Young Modules(MPa)	210 000
Rp0.2 0.2 % proof stress (MPa)	880
Rm Ultimate strength(MPa)	1030
A percentage elongation %	10
Kcv toughness (J/cm²)	65 à 70

The welding joints

The welding joints were obtained without post welding thermal treatment and by using the TIG-dressing. The figure 2 presents the details about the preparation of the welded specimens.

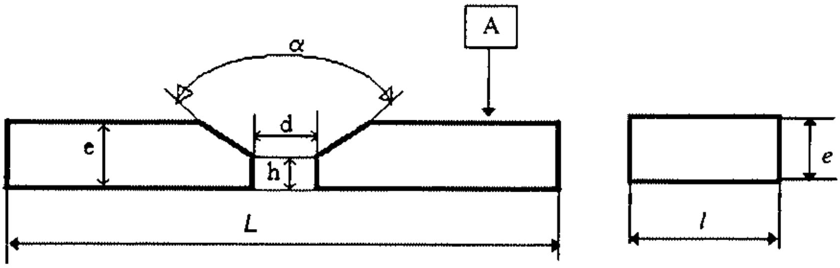

Figure 2 Geometry preparation of the welded specimens

To avoid the problem of deformation by welding, the test-pieces were constrained. The welding joints were checked up and selected by ultrasonic method. The welding conditions are summarised in the following tables:

Table 3 The welding conditions

Conditions	Values
size *L* x *l* x *e* (mm)	1 x 0,5 x 0,01
Welding method	semi-automatic with ATAL gaze
Number of passes	∅ fill 12/10
α (°)	35
h (mm)	2
d (mm)	2

Shot peening conditions

The test-pieces were shot peened on the upstream faces (A),as shown in the figure 2. Shot peening was performed with a steel shot S 230 R. The shot peening parameters, as follows the norm MIL S 13165 B, are given in the table 4.

Table 4 The shot peening conditions

Shot	Almen Intensity	Coverage percentage	Angle of impingement
MI 230 R	6-8 A	200%	90°
MI 230 R	12-14 A	200%	90°
MI 230 R	16-20 A	200%	90°

Laboratory investigations

The total investigation program consists of:
- analysing the residual stresses and FWHM in depth of the welding joints obtained with different surface finishing conditions,

- determination of the micro-hardness profile of the affected layer within the transverse direction (from the fused metal zone to the basis metal zone),
- determination of the S-N curves of the welding joints obtained with different surface finishing conditions.

X-ray diffraction analysis

Residual stresses (R.S.) and Full Width at Half Maximum peaks (FWHM) were analysed by means of a X-ray diffractometer D500. The R.S. and FWHM depth profiles were obtained, within the longitudinal (welding direction) and transverse directions as shown in figure 3, in the three zones of the welding joints (Fig. 1), by successive removal of material layers. Because of the specimen's thickness (10 mm), no correction of R.S. values has been performed due to the removal material.

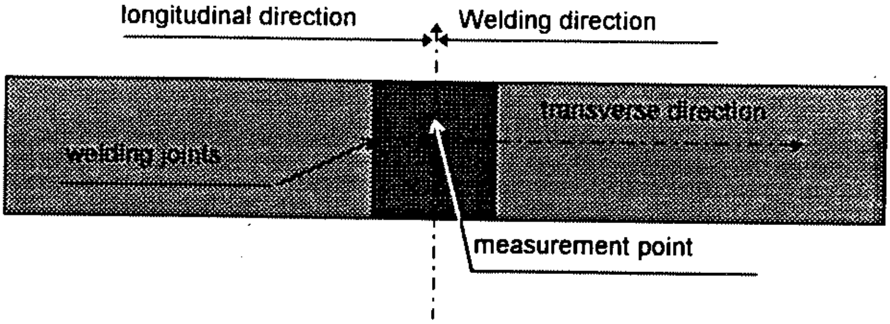

Figure 3 The measurement and welding directions

The appropriate diffraction parameters are detailed in the table 5.

Table 5 The X-ray diffraction parameters

Parameters	Values
Radiation	λ Cu $_{K\alpha}$ 30 kV- 30 mA
X-ray diffraction planes	{2 1 3} $2\theta \approx 141°$
Time of acquisition	180 s
ψ oscillation	± 3 °
ψ	-41.41 -33.99 -25.66 -14.48 0.00 20.70 30.00 37.76 45.00

Fatigue investigations

Determination of the coefficient of stress concentration

The Kt_{max} value due to the geometry of the welded joints was determined by using a Finite Element Modelling. The used meshing is presented on the figure 4. The maximal value of Kt_{max} was equal to 1.27.

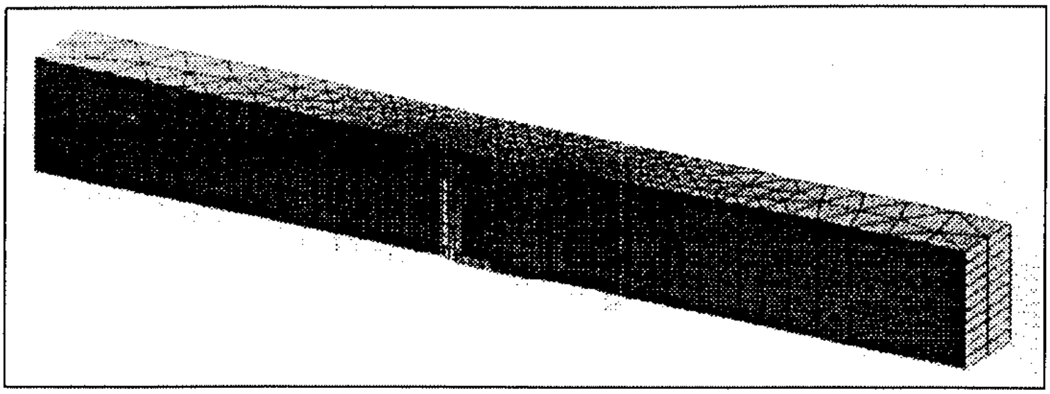

Figure 4 The used meshing for FEM calculations of the Kt_{max}.

The micro-hardness measurements

The mean values of the micro-hardness at 0.1 mm depth of the three affected zones, were conducted after polishing and chemical attack for the peened welding joints using the Almen intensity (12-14A). The used mass were 1.961 N.

The fatigue tests

For each shot peening conditions a set of samples were subjected to a repeated bending at load controlled $R\sigma = 0.1$ using different values of $\Delta\sigma$. The tests were carried until the beginning and the fracture of the samples. The Whöler curves were obtained and compared.

RESULTS

Residual stresses and FWHM analysis

The residual stress profiles obtained, within the longitudinal and transverse directions, in depth of the different welding joints are shown in figures 5, 6 and 7. The in-depth FWHM profiles are given in figures 8, 9 and 10. The tables 6,7 and 8 give the values of the surface residual stresses, the maximum absolute values of the compressive stresses, the shot peening affected depths and the surface FWHM values.

Table 6 Results of X-ray analysis in the basis metal zone

	Surface residual stress	Affected depth (mm)	Maximal R.S.	Depth of maximal R.S.	Surface FWHM (Maxi)
Welded	96	0.225	-124	0.065	0.043
6..8 A	-565	0.211	-565	0.078	0.042
12..14 A	-496	0.25	-603	0.085	0.044
16..20 A	-380	0.41	-576	0.145	0.043

Table 7 Results of X-ray analysis in the thermal affected zone

	Surface residual stress	Affected depth (mm)	Maximal R.S.	Depth of maximal R.S.	Surface FWHM (Maxi)
Welded	112	0.81	-451	0.022	0.046
6..8 A	-505	0.23	-636	0.045	0.042
12..14 A	-370	0.465	-599	0.065	0.047
16..20 A	-461	0.164	-677	0.168	0.045

Table 8 Results of X-ray analysis in the fused metal zone

	Surface residual stress	Affected depth (mm)	Maximal R.S.	Depth of maximal R.S.	Surface FWHM (Maxi)
Welded	-454	0.6	-471	0.097	0.040
6..8 A	-504	0.26	-504	0.005	0.041
12..14 A	-369	0.4	-508	0.06	0.043
16..20 A	-386	0.5	-484	0.15	0.041

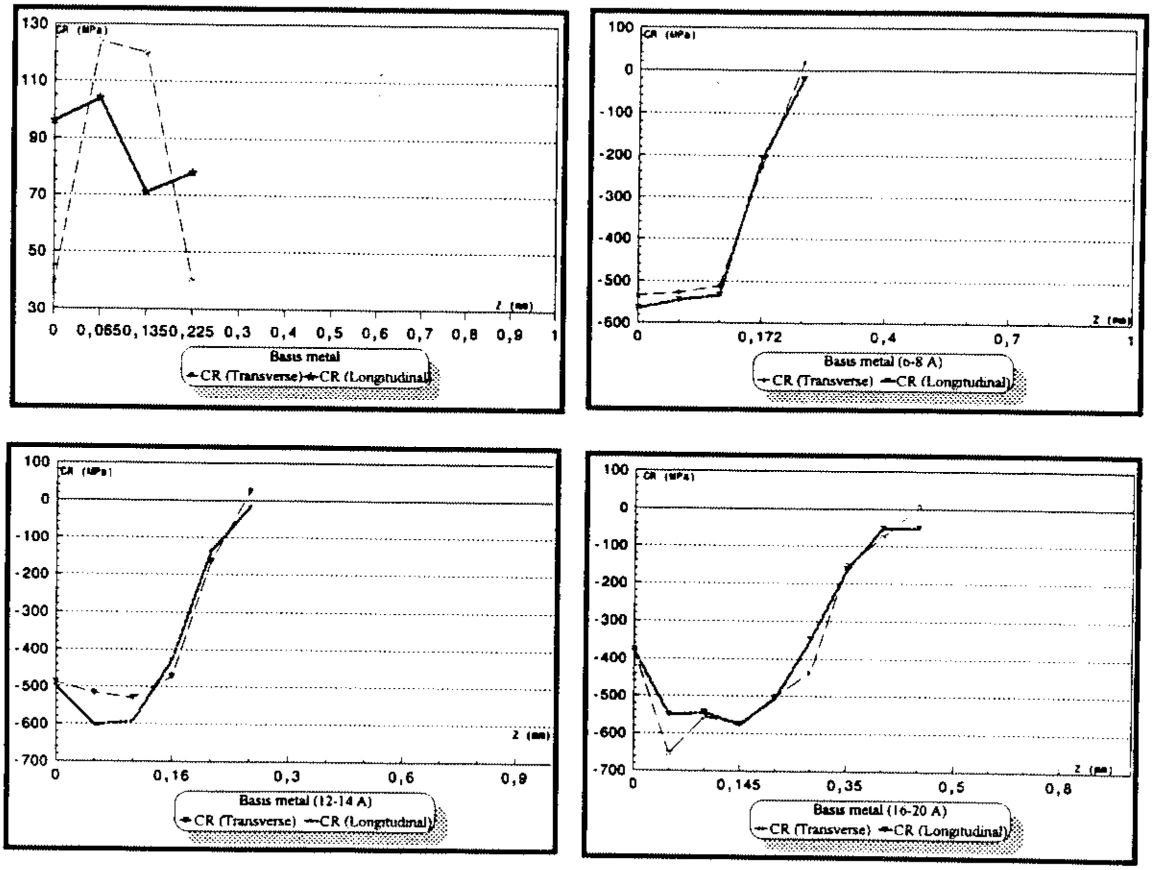

Figure 5 The in depth residual stresses obtained in the Basis metal zone for the different finishing conditions.

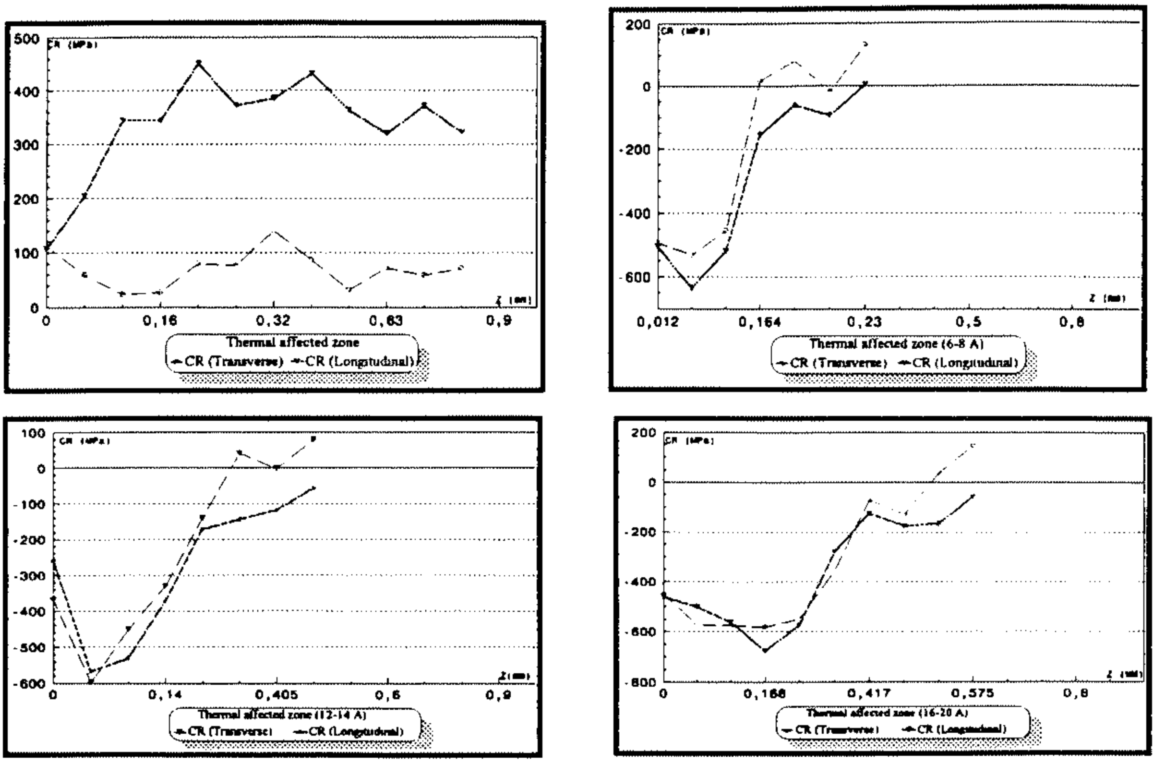

Figure 6 The in depth residual stresses obtained in the thermal affected zone for the different finishing conditions.

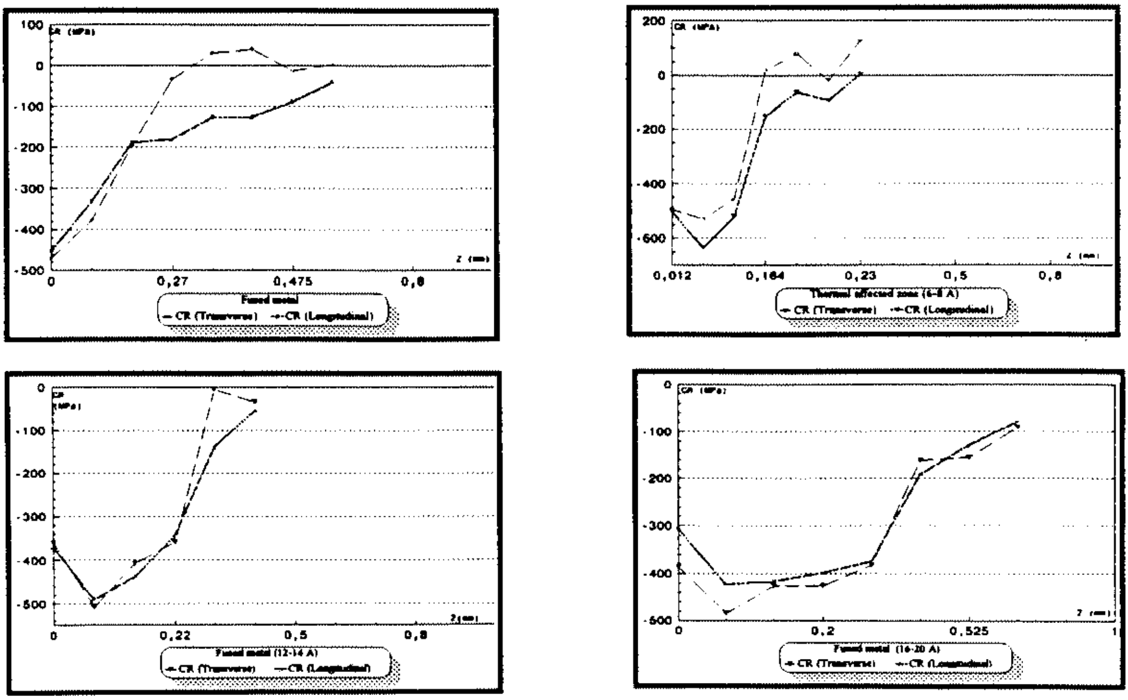

Figure 7 The in depth residual stresses obtained in the fused zone for the different finishing conditions.

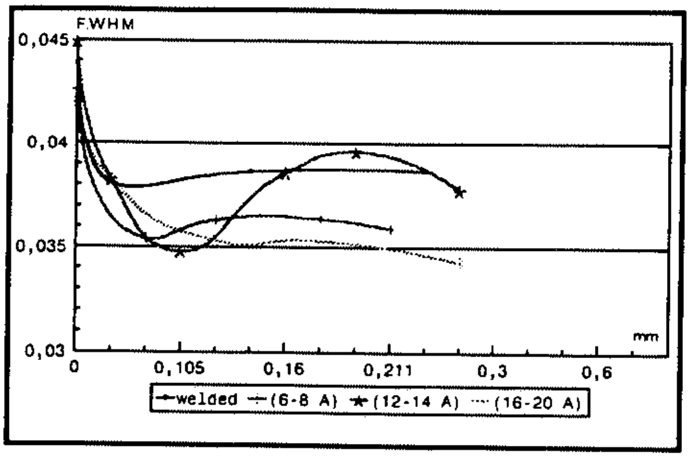

Figure 8 The in depth FWHM obtained in the Basis metal zone for the different finishing conditions.

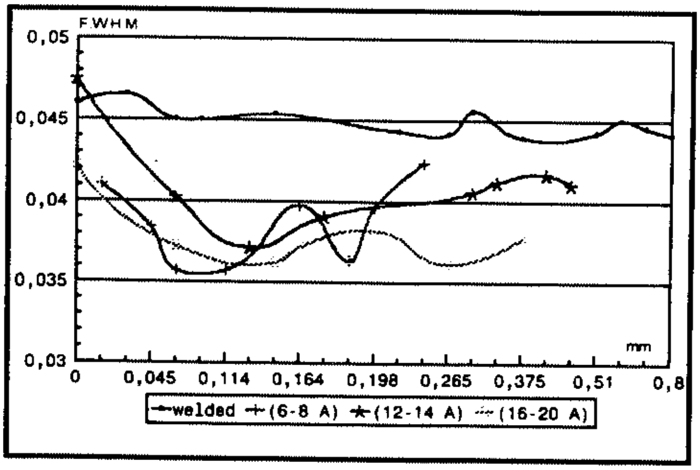

Figure 9 The in depth FWHM obtained in the thermal affected zone for the different finishing conditions.

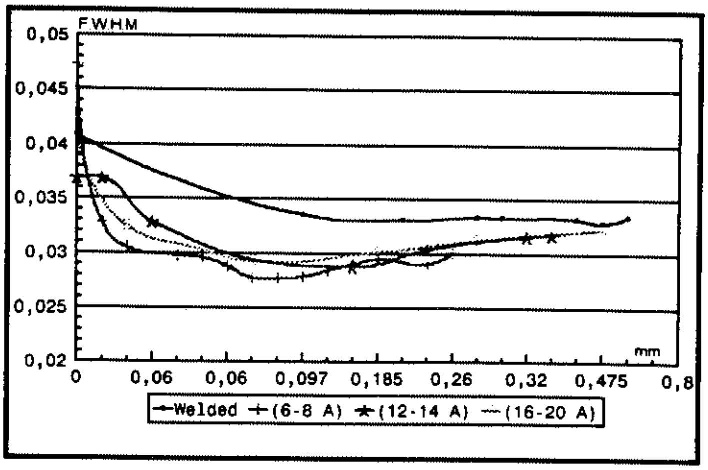

Figure 10 The in depth FWHM obtained in the fused zone for the different finishing conditions.

Micro-hardness measurements

Figure 11 shows the change of the micro-hardness within the transverse direction, from the fused metal zone to the basis metal zone.

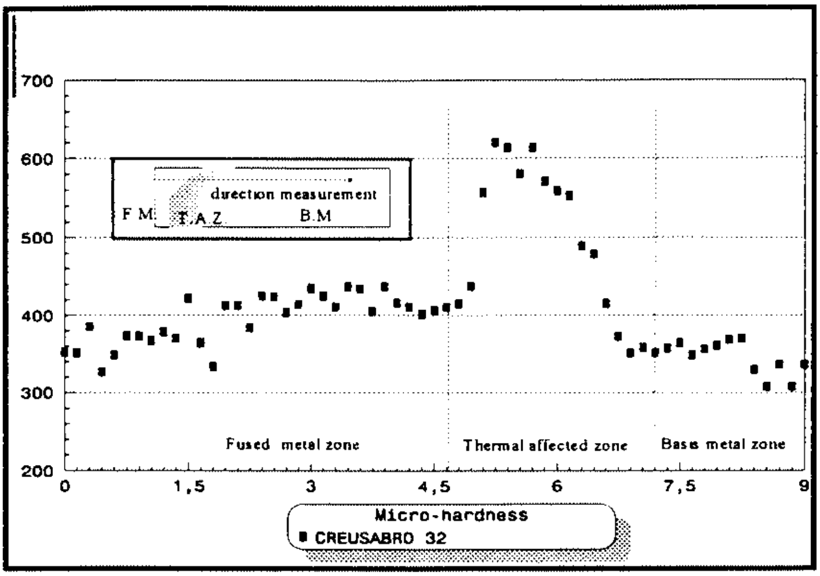

Figure 11 The change of the micro-hardness at 0.1 mm depth of the affected layers

Fatigue tests

Figures 12 and 13 show, respectively, the S-N curves until the beginning of the fracture and until the fracture (50% fracture probability) of the CREUSABRO 32 steel welded joints without and with different post-weld shot peening.

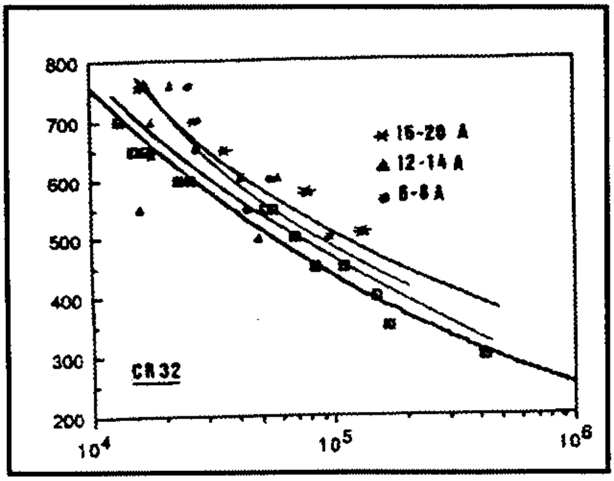

Figure 12 S-N curves (50% fracture probability, beginning of the fracture) of the CREUSABRO 32 steel welded joints without and with post-weld shot peening

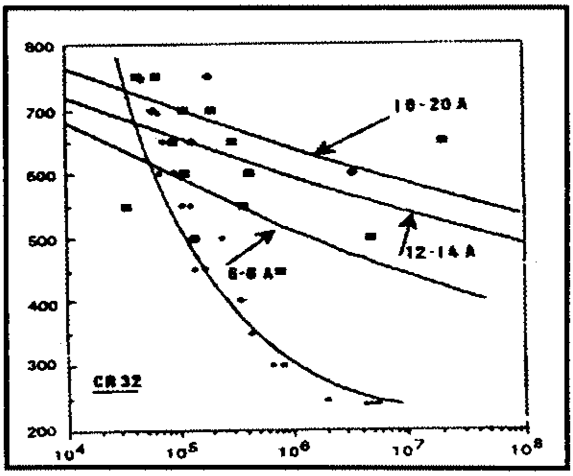

Figure 13 S-N curves (50% fracture probability, fracture) of the CREUSABRO 32 steel welded joints without and with post-weld shot peening

The table 9 presents the obtained fatigue limits of the welded joints obtained with different shot peening conditionns.

Table 9 Results of welded joints fatigue limits obtained with different shot peening

	Fatigue limit (begining)	Fatigue limit (fracture)	percentage increase (begining)	percentage increase (begining)
6..8 A	275	400	9%	35.5%
12..14 A	300	500	16%	50%
16..20 A	350	550	28%	54%

The fractures were observed in 75% of cases in the interface between the fused metal zone and the thermal affected zone, as shown in figure 1.

DISCUSSIONS

The results show that residual stresses due to welding are not significant in the basis metal zone. But important compressive residual stresses were observed in the depth of the thermal affected zone and in the fused metal zone. A directional effect exists, the R.S. are greater in the longitudinal direction than in the transverse direction. This prior residual stresses can affect the shot peening residual stresses, essentially in the deeper layers, as shown in figure 5, 6 and 7.

The figure 14 presents, qualitatively, the aspect of the residual stress profiles induced only by shot peening. Figures 5, 6 and 7 show that the pattern of residual stress profiles are quite similar in the three affected zones. However, the maximal absolute value of compressive residual stress, for the three affected zones, is greater in the thermal affected zone, intermediate in the basis metal zone and minimal in the fused metal zone. In opposite, the affected depth of compressive residual stresses is maximal in the fused metal zone, meddle in the basis metal zone and minimal in the thermal affected zone. Those results are in good agreement the previous theoretical works [4] [5],

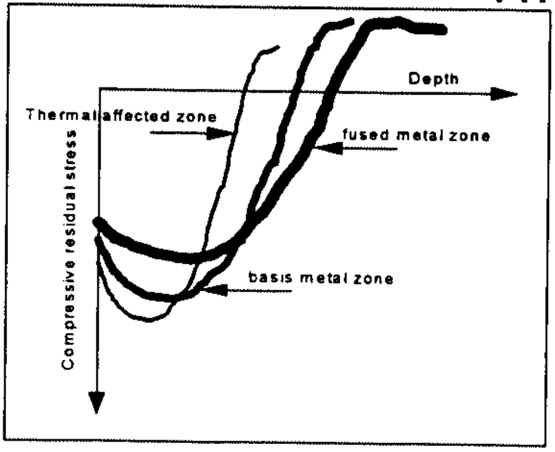

Figure 14 the qualitative aspect of the in-depth residual stress profiles due only to shot peening.

The fractures of test samples, after cyclic loading, were observed, for the majority of cases, in the interface of the thermal metal zone and the fused zone. This is can be interpreted by the following explanations:

- The applied tensile stress due to the cyclic bending and residual stress is maximal in the fused metal zone.
- The stress concentration is in the limit between the thermal affected zone and fused metal zone.
- The fused metal zone is the less harder of the affected zones.

It can be observed in tables 6, 7 and 8 for the different finishing surface conditions that the affected depth of the compressive residual stress increases with the Almen intensity. While maximum compressive stresses are independent upon the Almen intensity. Those results are in agreement with previous experimental and theoretical results [6] [7] and they are in concordance with the results of the S-N curves which show an improvement of the fatigue life with Almen intensities.

CONCLUSIONS

(i) The welding joints were characterised before and after shot peening. The residual stresses, the FWHM and the micro-hardness were determined and analysed in depth of the three different zones; the basis metal zone, the thermal affected zone and the fused metal zone. It was observed that the compressive residual stresses were minimal in the fused metal zone which is the less harder of the affected zones.

(ii) The fractures after fatigue tests were observed, in the majority of cases, in the interface between the fused metal zone and the thermal affected zone. This is can be interpreted by the following explanations:

- The applied tensile stress due to the cyclic bending and residual stress is maximal in the fused metal zone.
- The stress concentration is in the limit between the thermal affected zone and fused metal zone.
- The fused metal zone is the less harder of the affected zones.

(iii) The results of the fatigue tests show a pronounced improvement of the fatigue performance of CREUSABRO32 steel welded joints obtained by TIG-dressing. It was observed that the fatigue limit (10^6 cycles) increases with the Almen intensity. A 54% increase was reached for the shot peening using the Almen intensity of 16-20 A. It is worth noting, that using an excessive Almen intensity may provokes a local surface damage.

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