EAN '97

35th International Conference on
Experimental Stress Analysis
June 4 - 6, 1997, Olomouc, Czech Republic

RESIDUAL STRESSES RELAXATION IN WELDED PIPES USING VARIABLE TORSION STRAINS
PART I.- THEORETICAL ANALYSIS AND EXPERIMENTAL EQUIPMENTS

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Abstract- Residual stresses induced in the pipes during welding process can change the geometric dimensions or can generate damages by initiate the cracks. Stress relief operations are an integral step in many production sequences and can be realise using thermal and mechanical methods as: schot peening, uniaxial tensions, vibrations. The paper presente some results of a theoretically analysis regardind stresses relief in the welded pipes both by cyclic torsional strains und uniaxial tensions. Experimental equipments and procedures has been presented too.

1.Introduction. Cold-drawn longitudinal welded pipes are widely used on account of their lower cost price. However, due to the non-uniform distibution of the stresses from the manufacturing process of the pipe, with direct implications on the strips and subsequently, ofthe pipe can,under certain conditions, be cracked along the welding seam. Specific thermal treatments are frequently used to decrease these residual stresses [2]. This paper presents some aspects concerning the possibility of decreasing the residual stresses by means of non-conventional loading methods by torsional vibrations.

2.Matrials, Physico-mechanical Characteristics, Samples. The ∅38×2 welded pipe which is the object of this study, is the result of cold plastic deformation ofthe rolled strip 119×2mm (OLT32-STAS 500-82) with chemical and mechanical characteristics presented in Tables 1nd 2.

Table 1 - OL 32 Chemical Characteristics

Material	Elements %								
	C	Mn	Si	P	S	Cr	Ni	Mo	Cu
OL 32	0,06	0,35	0,03	0,022	0,023	0,03	0,03	0,02	0,04

The used samples have been specially processed at ends with a view to clamping accordiond to Fig.1. For the correct driving in time ofthe samples, they have been drilled and fixed with screws as shown in Fig.2. On using the Murnagham relation [1] and on taking into account the effect of degree ofthe torsion (Poyting effect) by using the cylindrical coordinates **r, θ, z**.

Table 2 -Mechanical Characteristic of Steel OL 32

Material	Elastic limit R_{01} [MPa]	Yield limit R_{02} [MPa]	Elastic modulus E [MPa]	Poisson ratio γ	Ultimate stress R_m [MPa]	Breaking elongation [%]	Rupture construction z [%]
OL 32	217 - 231	232 - 235	1,51 - 1,84 x 10^5	0,285 - 0,288	318 - 320	26,2 - 27,16	70 - 72,85

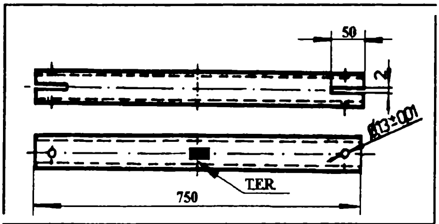

Fig.1. The dimensions of the pipe samples used for research

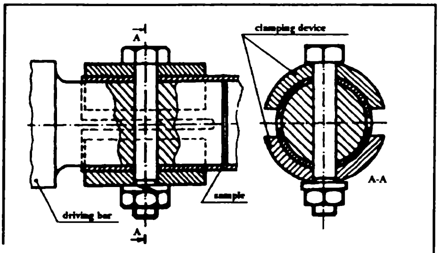

Fig.2. Clamping and driving system of the samples by torsion

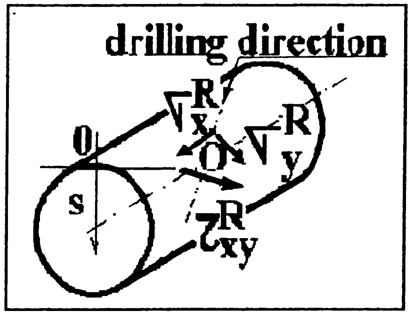

Fig.3. Distibution of stresses

$$r = r_0 + u \cdot (r_0, \theta^*)$$
$$\theta = \theta_0 + \theta^* \cdot Z_0$$
$$Z = Z_0 + K(\theta^*) \cdot Z_0$$

where:

r_0 , θ_0 , Z_0 = the inițial cilindrical coordonates;

r, θ, Z = the actuale cilindrice coordonates;

θ^* (t) = specific deformation (twisting angle / length unit) there have been determined the pipe stresses for a specific deformation θ under the assumptions "a","b" and "c", previously presented.

a- **a pipe embeled at one end and axially free at the end subjected to the torsion moment**

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$$\sigma_{rr} = \left[-\frac{1}{8} \cdot G \cdot \frac{2\cdot\lambda+3\cdot G}{\lambda+2\cdot G} \cdot \left(R_e^2 + R_i^2 - R_e^2 \cdot R_i^2 \cdot \frac{1}{r^2} - r^2 \right) \right] \cdot \theta^{*2} \tag{2}$$

$$\sigma_{\theta\theta} = \left[-\frac{1}{8} \cdot G \cdot \frac{2\cdot\lambda+3\cdot G}{\lambda+2\cdot G} \cdot \left(R_e^2 + R_i^2 - R_e^2 \cdot R_i^2 \cdot \frac{1}{r^2} - 3\, r^2 \right) \right] \cdot \theta^{*2} \tag{3}$$

$$\sigma_{zz} = \left[-\frac{1}{8} \cdot G \cdot \frac{\lambda\cdot(2\cdot\lambda+3\cdot G)}{(\lambda+G)\,(\lambda+2\cdot G)} \cdot \left(R_e^2 + R_i^2 \right) - \frac{1}{4} \cdot G \cdot \frac{\lambda+4\cdot G}{\lambda+2\cdot G} \cdot r^2 \right] \cdot \theta^{*2} \tag{4}$$

$$\tau = G \cdot r \cdot \theta^* \tag{5}$$

b - an end is embedded while the end subjected to a torsion moment is free in the axial direction;

$$\sigma_{rr} = \left[-\frac{1}{8} \cdot G \cdot \frac{2\cdot\lambda+3\cdot G}{\lambda+2\cdot G} \cdot \left(R_e^2 + R_i^2 - R_e^2 \cdot R_i^2 \cdot \frac{1}{r^2} - r^2 \right) \right] \cdot \theta^{*2} \tag{6}$$

$$\sigma_{\theta\theta} = \left[-\frac{1}{8} \cdot G \cdot \frac{2\cdot\lambda+3\cdot G}{\lambda+2\cdot G} \cdot \left(R_e^2 + R_i^2 - R_e^2 \cdot R_i^2 \cdot \frac{1}{r^2} - 3\, r^2 \right) \right] \cdot \theta^{*2} \tag{7}$$

$$\sigma_{zz} = \left[\frac{1}{8} \cdot G \cdot \frac{\lambda+4\cdot G}{\lambda+2\cdot G} \cdot \left(R_e^2 + R_i^2 - 2\, r^2 \right) \right] \cdot \theta^{*2} \tag{8}$$

$$\tau = G \cdot r \cdot \theta^* \tag{9}$$

where:

G = cross elastic modulus [MPa]

R_e, R_i, r = outer, inner and intermediary radius [mm]

λ = Lame[1] ratio

For the both loading variants, the equivalent stresses are given by the relation

$$\sigma_{ech} = \frac{1}{\sqrt{2}} \sqrt{\left(\sigma_{rr} - \sigma_{\theta\theta}\right)^2 + \left(\sigma_{\theta\theta} - \sigma_{zz}\right)^2 + \left(\sigma_{zz} - \sigma_{rr}\right)^2 + 6\tau^2} \tag{10}$$

c- a pipe embedded at on end and radyally blocked at the other end, loaded at torsion and thrust.

The stresses due the torsion moment, $\sigma_{rr}, \sigma_{\theta\theta}, \sigma_{zz}, \tau$, are identical whith tose mentioned at point "b" while the supplementary stress due to the thrust force F_t, is:

$$\sigma_T = \frac{F_t}{\pi \cdot \left(R_e^2 - R_i^2\right)} \tag{11}$$

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[1] $\lambda = \mu\tau/(1+\nu)(1-2\nu)$; for OL32 steel λ=0,858·10^5 [MPa]

In this case, the equivalent stress is given by the relation:

$$\sigma_{ech} = \frac{1}{\sqrt{2}}\sqrt{\left(\sigma_{rr} - \sigma_{\theta\theta}\right)^2 + \left[\sigma_{\theta\theta} - \left(\sigma_{zz} + \sigma_T\right)\right]^2 + \left[\left(\sigma_{zz} + \sigma_T\right) - \sigma_{rr}\right]^2 + 6\tau^2} \qquad (12)$$

Fig. 6 and 7 present the variations $\frac{\sigma_{rr}}{\theta^{*2}}, \frac{\sigma_{zz}}{\theta^{*2}}, \frac{\sigma_{\theta\theta}}{\theta^{*2}}$ and $\frac{\tau}{\theta^{*2}}$ function of the "r" radius for both pipe specifications under the "a" and "b" loading assumptions.

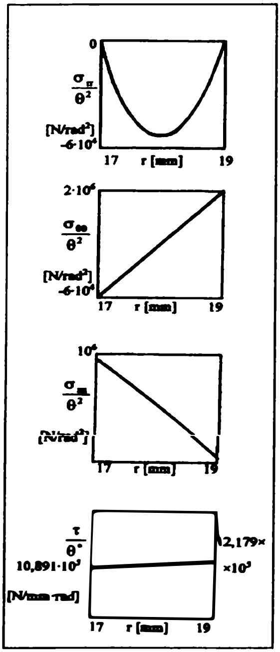

Fig.5.The distribution of the applied stresses for a Ø38×2 pipe loading during torsion under the assumtion one end embeded and ane axial free.

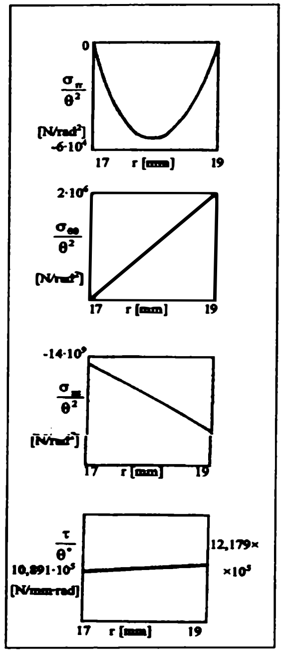

Fig.6. The distribution of the applied stresses for a Ø38×2 pipe loading during torsion under the assumtion one end embeded and one axially blocked

The distributions of stresses equivalent for one tip "c" situation are presented in Fig.7

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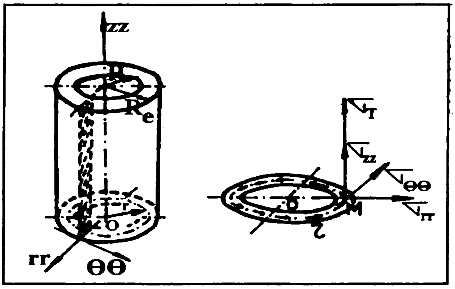

Fig.4. The orientation of the applied stresses

4.Stand Fot The Torsional Loading Of The Welded Pipes By Vibrations, At The Resonance Frequency

The need to study the influence of the torsional vibrations at the resonance frequency of the welded pipe samples upon the physico-mechanical parameters of the material and upon the remanent stresses (due to the manufacturing process), has imposed the designing and accomplishing of a stand to corespond to these requirements (Fig.8).

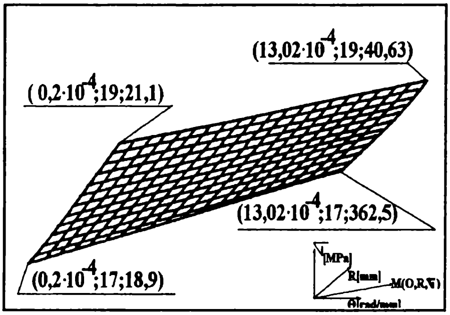

Fig.7-The distribution of the equivalent, maxim applied stresses function of the radius, specific torsional deformation and the axial thrust stress in $\varnothing$ 38×2 pipes under the following assuptions:-axial free end and the axial thrust stress-200MPa.

This system allows the accoplishing of a high range of superimposing of static and dynamic loadings. The distinctive element of the equipment is the electrodynamic vibrator driving system B&K with a sinusoidal peak force (1780 N), maximum peak acceleration 1480 m/s^2, peak maximum displacement 19mm, resonance frequency 5,3 KHz. The vibrator is fixed on a metalic frame with screws and clamps to the driving mandrels, the driving being done by means of the lever 9. The lever 9 is provided with a system of compression helical springs 2 and 5 and force tensometer transducer, the entire ensemble making the connection between the frame and the vibrator. The stand allows the torsional loading of the symmetic alternating pipes ($\theta = 0$) and accordind to the "relaxation " cycles ($\theta \neq 0$), Fig.9.

The prestressing deformations θ , Fig.9., are accomplished by a screw-nut mechanism 6 as well as by a series of keyways shiftly (angular) disposed in the lever hub 9 by witch the mandrel is driven with a view to obtain the necessary torsional oscillations. The constant keeping of the amplitude during a loading process can be ensured (if we want to) by an angle tensometric transducer. The axial forces can be accomplished by turning the nuts 8.

5. Excitation And Measuring Block Diagram

Experimental researches aim to determine the response characteristic of the torsion moment function of amplitude, frequency, number of cycles, loading method.

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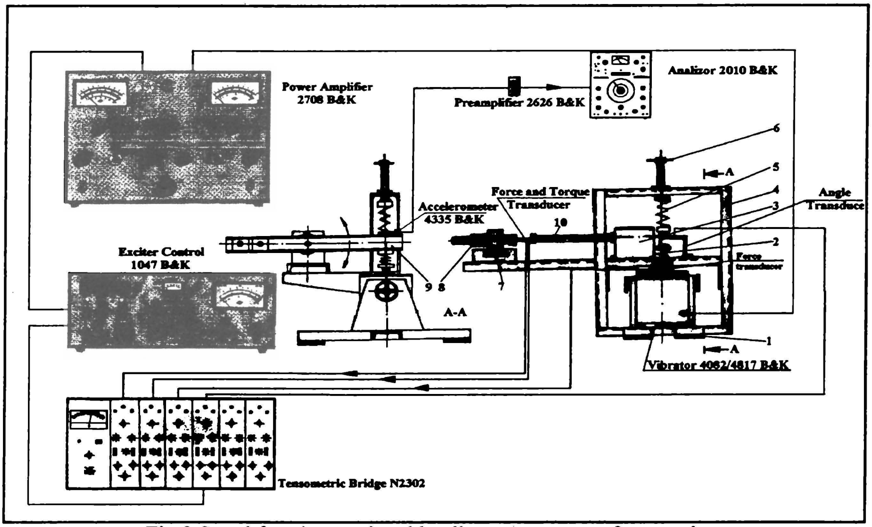

Fig.8 Stand for pipe torsional loading at resonance frequencies

The level of the residual stresses in the samples as well as the material hardness are studied separately after the loading stage.

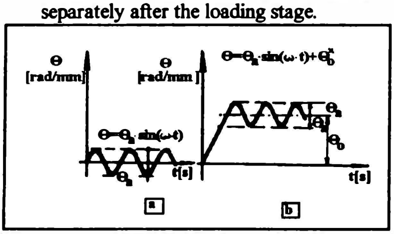

Fig.9 Methods for cyclic torsional loading

The excitation diagram includes the electrodynamic vibrator B&K fed the power amplifier 2708 B&K, contolled by the checking excitator 1047. A set of tensometric transducers in 2D connection with a view to determine the axial static prestressing force is amplified on the same torsion bar. All the tensometric transducers are connected to a tensometric bridge N2302.

6.Bibliography

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