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TESTS RESULTS FOR 16Mo5.3b STEEL SUBMITTED TO THERMOMECHANICAL FATIGUE

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This paper presents thermomechanical fatigue tests of 16Mo5.3b steel test specimens, in temperature range 60ºC÷540ºC, with total strain control in which cycle of temperature variation, on ring surface test specimens. Thermal condition of test is with soaking, and without soaking period at maximum temperature 540ºC. Using a modern process of experimental data statistical analysis is tracing the material thermomechanical fatigue curve, and base on this is established the shell type structures durability.

1.THE EXPERIMENTAL MODEL

The installation scheme is shown in figure 1. The thermal-stressed element is the test specimen serially attached to a solicitation frame having a variable rigidity element. Model existence allows the test specimens thermo-cyclic solicitation systems development and, the testing rigidity variation of systems. These determine a temperature range (ΔT=const) and a constant total strain control ($\Delta\varepsilon$=const) for input data of the test specimen [3],[4],[5].

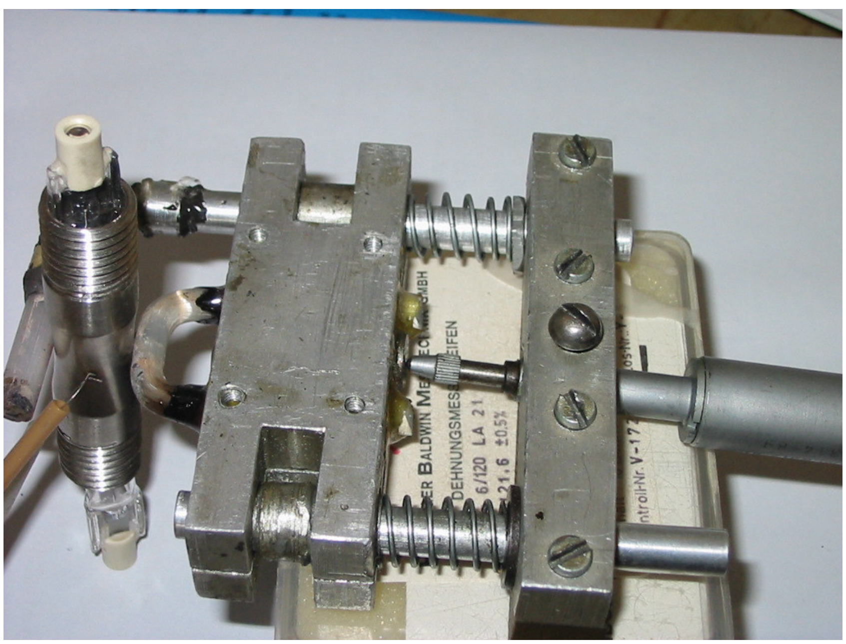

Fig. 1. Diametrical deformation transducer in contact with the test specimen

The installation shown in figure 1 is equipped with two changeable different rigidities springs. These springs allow total strain control different prescribed values for the same test specimen dimension. The installation realizes a cyclic solicitation of a cylindrical tubular test specimen, having a toroidal form on the calibrated zone (fig.2), with a compression stress during the heating half- cyclic and a stretching stress during the cooling one. Heating is made by a 1 kW power halogen lamp radiation. The control of temperatures is realized by a chromel-alumel thermo-couple, welded to the calibrated zone of the test specimen. They utilize diametrical tranducers to convert the diametrical deformation into axial deformation.

The installation is manufactured at ISIM Timisoara [3],[4],[5] It is under a computer control and all the records are realized using a specialized soft. This soft realizes a good management and control for the whole testing process and allows the following functions:

- Temperatures, diametrical deformations and stresses values acquisition;
- Real time temperature adjustment in accordancewith the imposed cyclic profile;
- Dialog with the operator for start or stop the testing parameters establishment ;
- Displaying of measures data during the test and their numerical and graphical calculus (the temperature variation diagram, the hysteresis loop, etc);
- Statistic calculus for experimental results, that means the graphical design of $\Delta\varepsilon$ – N (Coffin-Manson curve) [1],[2];
- Hysteresis loop for elastic- plastic deformation.

The test specimens are presented in figure 2.

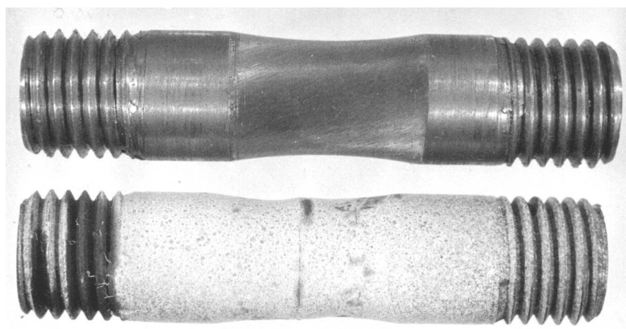

Fig.2. The initial and final form of the thermal fatigue test specimen

The interior of this test specimen is smooth cylindrical, with 12 mm diameter. In the central, built-up zone (hot-temperature zone ,zone of fracture), the exterior diameter is 13 mm. In the interior smooth cylindrical zone, the diameter is 14 mm. The thread fixing ends are M16.The execution precision was in perfect correspondance with the standards proceedings.

2. NUMERICAL EXAMPLE. DATA PROCESSING

2.1. 3600 second soaking period at maximum temperature of 540°C.

The thermomechanical fatigue tests from 16 Mo5.3b are conducted in temperature range 60°⇔540°C, with total strain control ($\Delta\varepsilon_{total}$=const), in wich cycle of temperature variation [3],[6],[7],[8].Thermal conditions of tests are with 3600 second soaking period at maximum temperature of 540°C.

The primarys test datas obtined to thermomechanical fatigue tests of 16Mo5.3b, saw-toothed conditions inter 60°⇔540°C, are shown on Table 1. Are presented pair of values from range (amplitude) of total strain dependent on the fatigue life N, number of cycles from crack, for 8 test specimen.

The primary test datas from 16Mo5.3b, inter 60°⇔540°C, with 3600 second soaking period at maximum temperature of 540°C *Table 1*

Number of test specimen	1	2	3	4	5	6	7	8
$\Delta\varepsilon_t$ [-]	0,0042	0,0042	0,006	0,006	0,0081	0,0081	0,0105	0,0105
$\Delta\varepsilon_t$ [%]	0,42	0,42	0,6	0,6	0,81	0,81	1,05	1,05
N[cycles]	664	591	158	165	150	134	60	51

The medium line regression and bands of dispersion are calculated in Table 2.

The medium line regression and bands of dispersion *Table 2*

Nr. crt	Δε [%]	Δε [-]	X	$\hat{Y} = \hat{A} + \hat{B}\cdot X$	N_{fmed} [cycles]	$\hat{Y}_{sup}$	N_{fsup} [cycles]	$\hat{Y}_{inf}$	N_{finf} [cycles]
1	1,05	0,0105	-1,9586	1,7157	52	1,9703	93	1,4611	29
2	0,81	0,0081	-2,0969	2,0574	114	2,231	170	1,8850	77
3	0,6	0,006	-2,2218	2,3660	232	2,5356	343	2,1964	157
4	0,42	0,0042	-2,3979	2,8011	633	3,0763	1.192	2,5259	336

The equation of line regression, Manson-Coffin Equation,[1],[2],[3],[4],[5], for probability P = 50% (e-med) is:

$y = 4.1487\cdot x^{-0.3126}$ or $\boldsymbol{\Delta\varepsilon_{tot}} = 4,1487\cdot \boldsymbol{N_f}^{-0,3126}$

where: $\boldsymbol{\Delta\varepsilon_{tot}}$ is the range (amplitude) of total strain [%];

$\mathbf{N_f}$ - number of cycles from crack.

In figure 3 is the thermomechanical fatigue curve, strain-life (ε-N), Manson-Coffin Equation,16Mo5.3b steel.

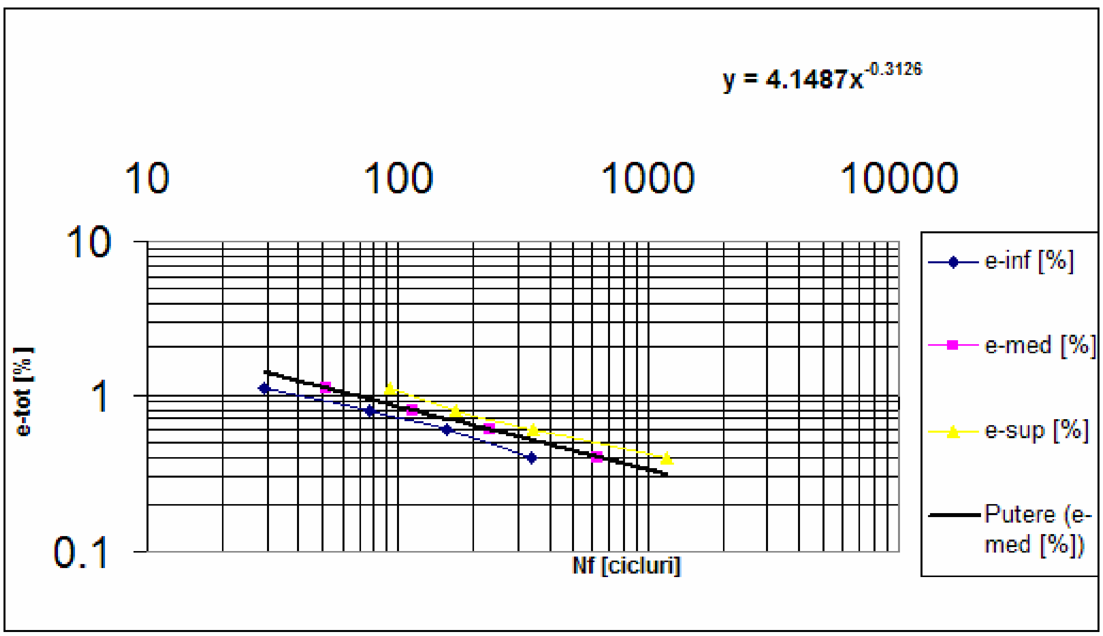

Fig.3. Manson-Coffin Equation from 16Mo5.3b steel, the thermomechanical fatigue tests are conducted in temperature range 60°⇔540°C, with 3600 second soaking period at maximum temperature of 540°C.

2.2. 600 second soaking period at maximum temperature of 540°C

The thermomechanical fatigue tests from 16 Mo 5.3b are conducted in temperature range 60°⇔540°C, with total strain control ($\Delta\varepsilon_{total}$=const), in wich cycle of temperature variation. Thermal conditions of tests are with 600 second soaking period at maximum temperature of 540°C.

The medium line regression and bands of dispersion are calculated in Table 3.

The medium line regression and bands of dispersion *Table3*

Nr. crt	Δε [%]	Δε [-]	X	$\hat{Y} = \hat{A} + \hat{B} \cdot X$	N_{fmed} [cycl]	$\hat{Y}_{sup}$	N_{fsup} [cycl]	$\hat{Y}_{inf}$	N_{finf} [cycl]
1	1,05	0,0105	-1,9586	1,8361	68	2,0794	120	1,5928	39
2	0,81	0,0081	-2,0969	2,1585	144	2,3272	212	1,9896	97
3	0,6	0,006	-2,2218	2,4500	282	2,6157	412	2,2843	192
4	0,42	0,0042	-2,3979	2,8604	725	3,1234	1.329	2,5974	396

The equation of line regression, Manson-Coffin Equation,[1],[2],[3],[4],[5], for probability P = 50% (e-med) is:

$y = 6{,}6893x^{-0.4275}$ or $\boldsymbol{\Delta\varepsilon_{tot}} = 6{,}6893\cdot \boldsymbol{N_f}^{-0{,}4275}$

In figure 4 is the thermomechanical fatigue curve, strain-life (ε-N), Manson-Coffin Equation,16Mo5.3b steel. The thermomechanical fatigue tests from 16 Mo5.3b are conducted in temperature range 60°⇔540°C, with total strain control ($\Delta\varepsilon_{total}$=const), in wich cycle of temperature variation .Thermal conditions of tests are with 600 second soaking period at maximum temperature of 540°C.

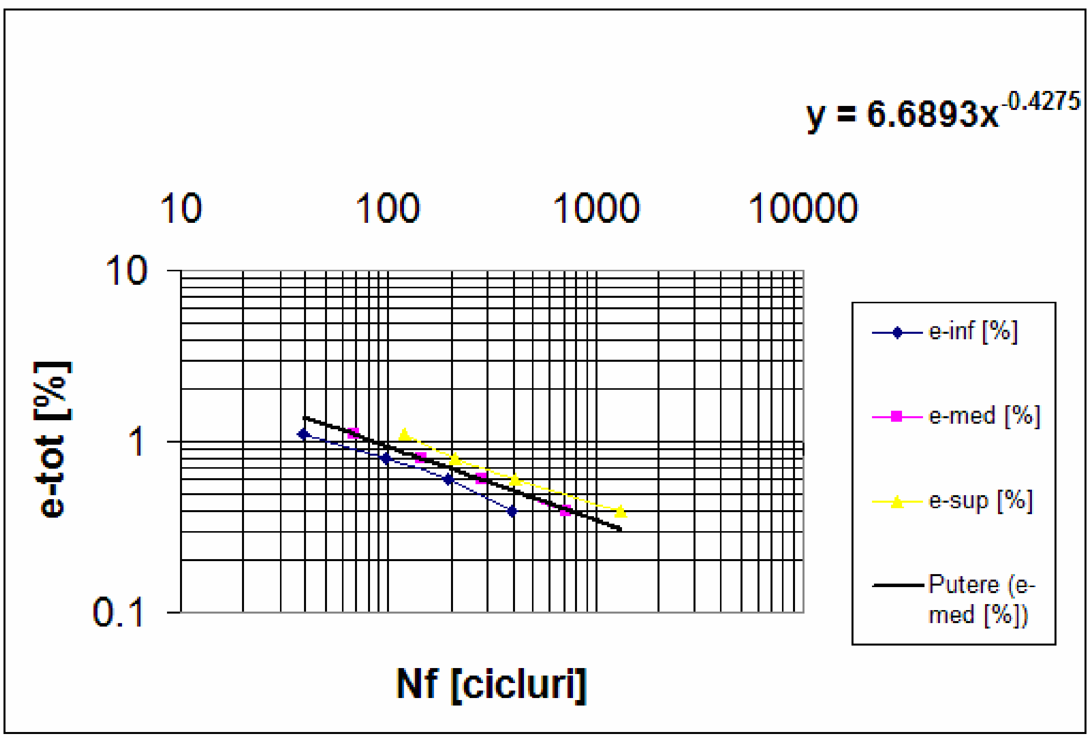

Fig.4. Manson-Coffin Equation from 16Mo5.3b steel, the thermomechanical fatigue tests are conducted in temperature range 60°⇔540°C, with 600 second soaking period at maximum temperature of 540°C.

2.3. Without soaking period at maximum temperature of 540°C

The thermomechanical fatigue tests from 16 Mo 5.3b are conducted in temperature range 60°⇔540°C, with total strain control ($\Delta\varepsilon_{total}$=const), in wich cycle of temperature variation .Thermal conditions of tests are without soaking period at maximum temperature of 540°C.

The medium line regression and bands of dispersion are calculated in Table 4.

The medium line regression and bands of dispersion *Table 4*

Δε [%]	X	$\hat{Y} = \hat{A} + \hat{B} \cdot X$	N_{med}	$\hat{Y}_{sup}$	N_{sup}	$\hat{Y}_{inf}$	N_{inf}
1,05	-1,9586	1,80886	87,5	2,3514	225	1,2664	19
0,81	-2,0969	2,3280	182,5	2,7003	502	1,9557	91
0,6	-2,2218	2,7005	203,5	3,062	1.154	2,339	218
0,42	-2,3979	3,2260	1.083	3,8033	6.358	2,6847	446

The equation of line regression, Manson-Coffin Equation,[1],[2],[3],[4],[5], for probability P = 50% (e-med) is:

$y = 11{,}025 \cdot x^{-0{,}5543}$ or $\boldsymbol{\varepsilon_{tot}} = 11{,}025 \cdot \mathbf{N_f}^{-0{,}5543}$

where: $\boldsymbol{\varepsilon_{tot}}$ = range (amplitude) of total strain [%]; $\mathbf{N_f}$ = number of cycles from crack.

In figure 5 is the thermomechanical fatigue curve, strain-life (ε-N), Manson-Coffin Equation,16Mo5.3b steel.

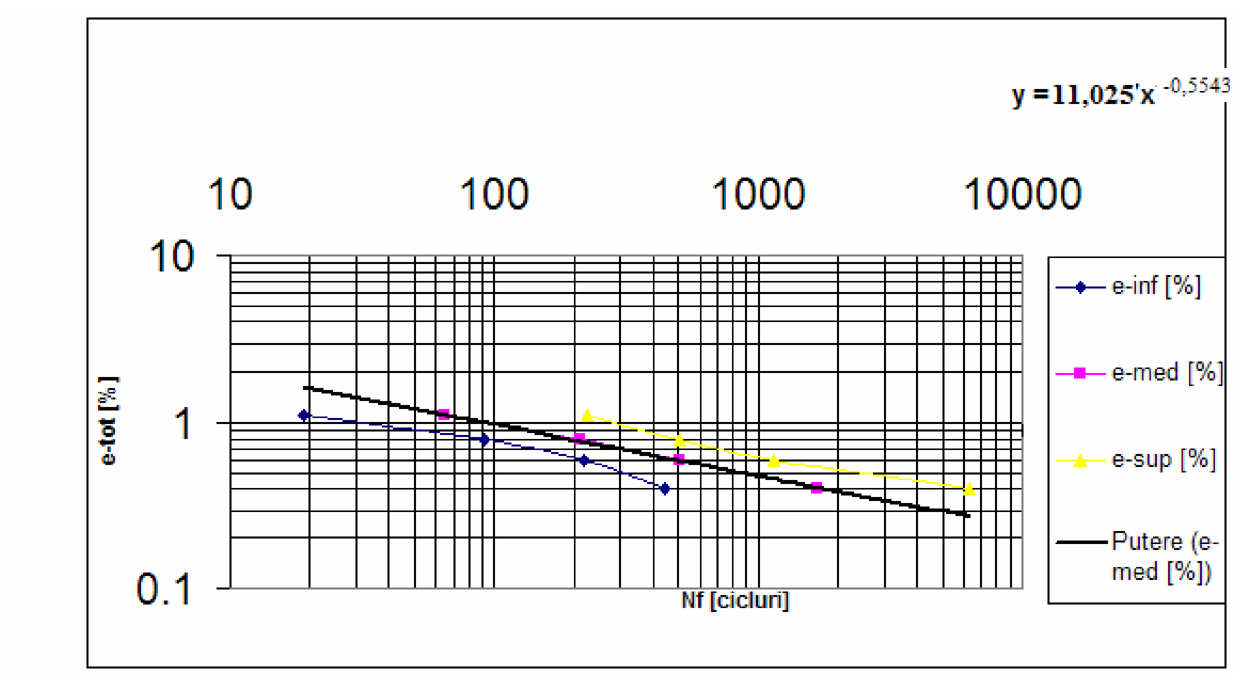

Fig.5. Manson-Coffin Equation from 16Mo5.3b steel, the thermomechanical fatigue tests are conducted in temperature range 60°⇔540°C, without soaking period at maximum temperature.

In figure 6 is the medium line regression in comparasion presentation for the third previous cases of thermomechanical fatigue tests.

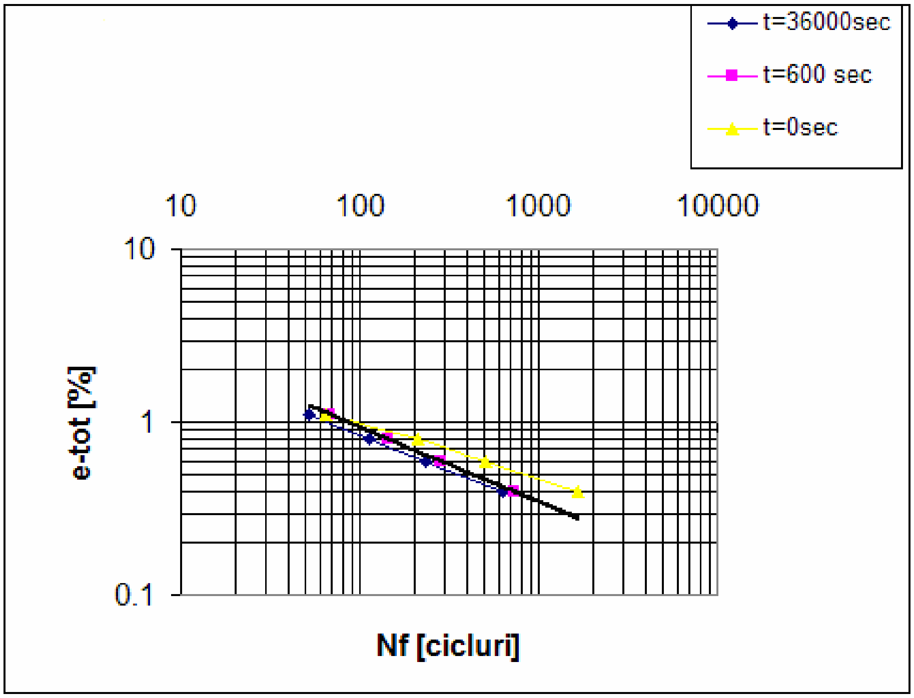

Fig.6.The comparasion for the medium line regresion, in the third previous cases of thermomechanical fatigue tests

This thing leads to the determination of the lifetime for the thermomechanical fatigue strained equipments. All the data regarding the thermal fatigue resistance for the thermal-resistant steels are very important for different components lifetime estimation, in the case of thermal fatigue exploitation conditions for industrial installation. This paper presents a method for thermomecanical state analysis the elements material volume that is submitted to heating and cooling process. They are exposed also the experimental model.

REFERENCES

1. Coffin, L.F., “*Predictive parameters and their application to high temperature low cycle fatigue*” in Fracture mechanics, 1969.
2. Manson, S.S., “*Thermal stress and low-cycle fatigue*” 1974, McGraw-Hill.
3. Mateiu, H, *„Experimentări privind oboseala termică pe diverse oțeluri. Cercetări privind comportarea la oboseală termică a oțelurilor pentru conducte din termoenergetică”* – Contract ISIM 636/C/A14/1995.
4. Mateiu, H., ş.a.,: *“Influence of holding time at maximum temperature on thermal fatigue of 14CrMo44 steel”* Proceed.Internat.Sympos. Welding 96, Beograd,1996, p 284.
5. Mateiu, H, *„Fenomenul de degradare la solicitari termomecanice”* Teza de doctorat, ISIM Timisoara,2002
6. Rie, K.T., a.o., *“Effect of temperature and hold time on low-cycle fatigue of steel 13CrMo44”* – in Proceed. Internat. Confer. on Fracture, Cannes, 1981, vol. 5, p 2371.
7. Pavel, Al. *”Oboseala termooligociclica”,*Editura Tehnica, Bucuresti, 1996
8. Rizea, N. “*Analiza fenomenelor de fluaj si oboseala ale invelisurilor subtiri cu aplicatie la aparatura statica petrochimica*” referatul I al pregatirii doctoratului, 2004.