DETERMINING THE INPUT DATA FOR THE MECHANICAL CHARACTERISTICS OF THE COKING CHAMBER`S MATERIAL

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Abstract: The present paper propose to realize the calculus formulas for the mechanical and physical characteristics used as input data for continuous simulation of creep and thermal fatigue phenomena, applying the interpolation method with the third order Spline Functions.

1. INTRODUCTION

The material from which the coking battery's body is made is the composite steel, grade 16 Mo 5.3b, delivered in the form of sheet, obtained by hot rolling and usually used in the construction of boilers and pressure vessels. This material works at high temperatures and the technical conditions are set in the standard STAS 2883/3-88 (SR-EN 10028-2). It must be mentioned that this standard gives, in a tabular form, the mechanical and physical characteristics of this steel.

In order to realize the calculus for the continuous simulation of creep and thermal fatigue phenomena, some specific formulas are necessary. Since all mechanical and physical characteristics are given in a tabular form, mainly depending on temperature and, eventually, on sheet's thickness, these formulas must be found, because they are the input data for the simulation with finite element programs (thermal fatigue modulus).

2. THE CALCULUS FORMULAS FOR THE MECHANICAL AND PHYSICAL CHARACTERISTICS USED AS INPUT DATA FOR SIMULATION

In the present paper, it is proposed the solving of this problem by applying the interpolation method with Spline functions of order 3, using the experimental measurements. For this purpose, there were realized numerical calculus programs based on the programming modulus of the mathematical software Maple 11.

We specify that all programs presented here determine, by numerical calculus, the continuous analytical expression of the quantities of interest and realizes the graph of the quantity's variation versus the influence factor- the temperature.

2.1. CALCULUS FORMULAS FOR MECHANICAL CHARACTERISTICS

In STAS 2883/3-88, the yield strength Rp_{02} it is presented as a function of temperature, in a tabular form. In table 1, this dependence is showed for the sheet's thicknesses used in the coking battery's construction.

Table 1

Steel grade	Sheet's thickness, a [mm] $a \le 60$	Rp_{02} , [N/mm^2]						
	T, [°C]	200	250	300	350	400	450	500
16 Mo 5.3b		245	226	196	177	167	157	137

The interpolation method, based on Spline functions of order 3, used for $Rp_{02}(T)$, determines the analytical expression:

$$Rp_{02} = \begin{cases} 535{,}615 - 3{,}742 \cdot T + 0{,}0171 \cdot T^2 - 2{,}861 \cdot 10^{-5} \cdot T^3, & 200 \le T < 250 \\ -772{,}076 + 11{,}95 \cdot T - 0{,}0456 \cdot T^2 + 5{,}507 \cdot 10^{-5} \cdot T^3, & 250 \le T < 300 \\ 1138{,}692 - 7{,}157 \cdot T + 0{,}0180 \cdot T^2 - 1{,}569 \cdot 10^{-5} \cdot T^3, & 300 \le T < 350 \\ 822{,}076 - 4{,}443 \cdot T + 0{,}0103 \cdot T^2 - 0{,}830 \cdot 10^{-5} \cdot T^3, & 350 \le T < 400 \\ 1767{,}307 - 11{,}53 \cdot T + 0{,}0280 \cdot T^2 - 2{,}307 \cdot 10^{-5} \cdot T^3, & 400 \le T < 450 \\ -2214{,}153 + 15{,}01 \cdot T - 0{,}0309 \cdot T^2 + 2{,}061 \cdot 10^{-5} \cdot T^3, & 450 \le T < 500 \end{cases} \quad (1)$$

The interpolation was realized using the calculus program:

- restart:with(CurveFitting):with(plots):
- LT:=[200,250,300,350,400,450,500]:LRp:=[245,226,196,177,167,157,137]:
- Rp_02:=u-> Spline([seq([LT[k],LRp[k]],k=1..nops(LT))],u, degree=3):
- Rp_02'=evalf(Spline([seq([LT[k],LRp[k]],k=1..nops(LT))],T,degree=3)):
- plot(Rp_02(T),T=LT[1]..LT[nops(LT)]);

The graph is showed in figure 1:

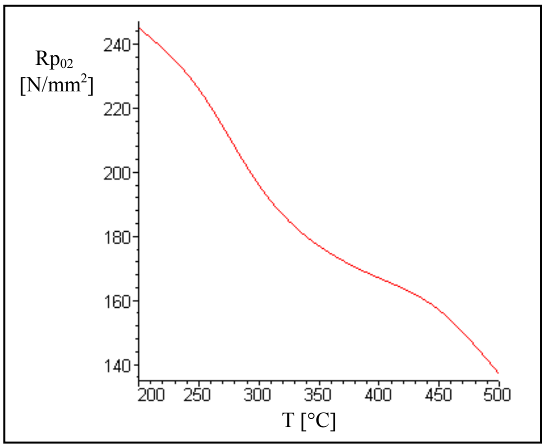

Figure 1: The graph of $Rp_{02}(T)$

For the long duration technical strengths Rr/10000 and Rr/100000, the mean calculus values depending on temperature (STAS 2883/-88) are presented in table 2. Applying the interpolation method with Spline functions of order 3, with the purpose of determining the calculus formulas for the long duration technical stress, leads to:

Table 2

Steel grade	T, [°C]	Rr/10000, [N/mm^2]	Rr/100000, [N/mm^2]
16 Mo 5.3b	450	298	245
	460	273	209
	470	247	174
	480	222	143
	490	196	117
	500	171	93
	510	147	74
	520	125	59
	530	102	47

Applying the interpolation method with Spline functions of order 3, with the purpose of determining the calculus formulas for the long duration technical stress, leads to:

$$Rr/10000 = \begin{cases} 34538{,}427 - 223{,}342 \cdot T + 0{,}4908 \cdot T^2 - 3{,}6358 \cdot 10^{-4} \cdot T^3, & 450 \le T < 460 \\ -80465{,}705 + 526{,}684 \cdot T - 1{,}13965 \cdot T^2 + 8{,}1793 \cdot 10^{-4} \cdot T^3, & 460 \le T < 470 \\ 98739{,}826 - 617{,}180 \cdot T + 1{,}29410 \cdot T^2 - 9{,}0813 \cdot 10^{-4} \cdot T^3, & 470 \le T < 480 \\ -\ 91782{,}989 + 573{,}587 \cdot T - 1{,}86662 \cdot T^2 + 8{,}1461 \cdot 10^{-4} \cdot T^3, & 480 \le T < 490 \\ 45272{,}030 - 265{,}525 \cdot T + 0{,}52581 \cdot T^2 - 3{,}5033 \cdot 10^{-4} \cdot T^3, & 490 \le T < 500 \\ -71857{,}939 + 437{,}254 \cdot T - 0{,}87974 \cdot T^2 + 5{,}8670 \cdot 10^{-4} \cdot T^3, & 500 \le T < 510 \\ 138156{,}53 - 798{,}124 \cdot T + 1{,}54256 \cdot T^2 - 9{,}9650 \cdot 10^{-4} \cdot T^3, & 510 \le T < 520 \\ -58104{,}488 + 334{,}150 \cdot T - 0{,}63488 \cdot T^2 + 3{,}9930 \cdot 10^{-4} \cdot T^3, & 520 \le T < 530 \end{cases} \quad (2)$$

$$Rr/100000 = \begin{cases} 4724{,}5508 + 40{,}3448 \cdot T - 0{,}0976 \cdot T^2 + 7{,}2349 \cdot 10^{-5} \cdot T^3, & 450 \le T < 460 \\ -59807{,}5522 + 399{,}581 \cdot T - 0{,}8786 \cdot T^2 + 6{,}3825 \cdot 10^{-4} \cdot T^3, & 460 \le T < 470 \\ -\ 32437{,}4241 + 224{,}878 \cdot T - 0{,}5069 \cdot T^2 + 3{,}7463 \cdot 10^{-4} \cdot T^3, & 470 \le T < 480 \\ 134712{,}855 - 819{,}810 \cdot T + 1{,}6695 \cdot T^2 - 11{,}3678 \cdot 10^{-4} \cdot T^3, & 480 \le T < 490 \\ -136971{,}433 + 843{,}562 \cdot T - 1{,}7251 \cdot T^2 + 11{,}7249 \cdot 10^{-4} \cdot T^3, & 490 \le T < 500 \\ 78741{,}0117 - 450{,}711 \cdot T + 0{,}8634 \cdot T^2 - 5{,}5320 \cdot 10^{-4} \cdot T^3, & 500 \le T < 510 \\ 10{,}0058910 + 12{,}4116 \cdot T - 0{,}0445 \cdot T^2 + 0{,}4031 \cdot 10^{-4} \cdot T^3, & 510 \le T < 520 \\ 91177{,}4167 - 513{,}554 \cdot T + 0{,}9668 \cdot T^2 - 6{,}0806 \cdot 10^{-4} \cdot T^3, & 520 \le T < 530 \end{cases} \quad (3)$$

The functions are generated by the following calculus program:

- restart:with(CurveFitting):with(plots):
- LT:=[450,460,470,480,490,500,510,520,530]:
- LRr_10000:=[298,273,247,222,196,171,147,125,102]:
- LRr_100000:=[245,209,174,143,117,93,74,59,47]:
- Rr_10000:=u-> Spline([seq([LT[k],LRr_10000[k]],k=1..nops(LT))],u, degree=3):
  Rr_100000:=u-> Spline([seq([LT[k],LRr_100000[k]], k=1..nops(LT))],u,degree=3):
  'Rr_10000'=evalf(Spline([seq([LT[k], LRr_10000[k]],k=1..nops(LT))],T,degree=3)):
  'Rr_100000'=evalf (Spline([seq([LT[k],LRr_100000[k]],
  k=1..nops(LT))],T,degree=3)):
- P1:=plot(Rr_10000(T),T=LT[1]..LT[nops(LT)]):
- P2:=plot(Rr_100000(T),T=LT[1]..LT[nops(LT)]): display(P1,P2);

The graph is showed in figure 2:

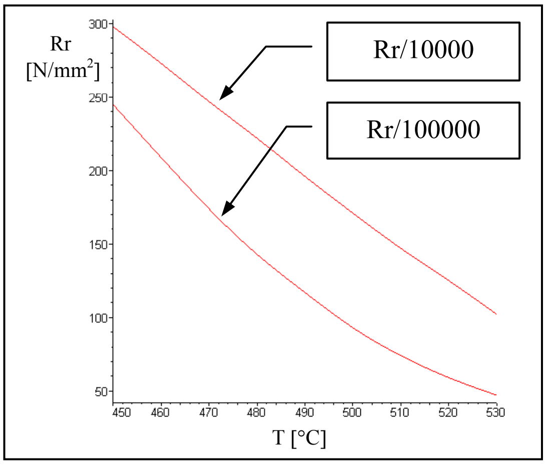

Figure 2: The graph of $R_r(T)$

2.2. CALCULUS FORMULAS FOR THE PHYSICAL CHARACTERISTICS

The physical characteristics used in calculus are: the Young's modulus E, the linear thermal expansion coefficient α and for the thermal conductivity λ. It is presented below, in table 3, the tabular dependence of these quantities in function of temperature.

Table 3

Steel grade	T, [°C]	E, [N/mm^2]	α [m/°C]	λ, [kcal/mh°C]
16 Mo 5.3b	20	$21,3\cdot10^4$	$11,4\cdot10^{-6}$	42
	100	$21,0\cdot10^4$	$12,5\cdot10^{-6}$	41
	200	$20,0\cdot10^4$	$13,1\cdot10^{-6}$	40
	300	$19,3\cdot10^4$	$13,6\cdot10^{-6}$	38
	400	$18,5\cdot10^4$	$14,0\cdot10^{-6}$	36
	500	$17,6\cdot10^4$	$14,4\cdot10^{-6}$	33
	600	$16,6\cdot10^4$	$14,7\cdot10^{-6}$	30

The functions for the Young's modulus E are generated by the following calculus program:

- restart:with(CurveFitting):with(plots):
- LT:=[20,100,200,300,400,500,600]:
- LE:=[21.3e4,21e4,20e4,19.3e4,18.5e4,17.6e4,16.6e4]:
- E:=u-> Spline([seq([LT[k],LE[k]],k=1..nops(LT))],u,
- degree=3):
- 'E'=evalf(Spline([seq([LT[k],LE[k]],k=1..nops(LT))],T,degree=3)):
- plot(E(T),T=LT[1]..LT[nops(LT)]):

Applying the interpolation method with Spline functions of order 3, with the purpose of determining the calculus formulas for the Young's modulus E, leads to the analytical expression:

$$E = \begin{cases} 213408{,}5296 - 20{,}426 \cdot T - 0{,}2131 \cdot 10^{-14} \cdot (T-20)^2 - \\ \qquad - 2{,}6677 \cdot 10^{-3} \cdot (T-20)^3, \quad 20 \le T < 100 \\ 217164{,}7042 - 71{,}6470 \cdot T - 0{,}64025703 \cdot (T-100)^2 + \\ \qquad + 3{,}567 \cdot 10^{-3} \cdot (T-100)^3, \quad 100 \le T < 200 \\ 218536{,}0425 - 92{,}6802 \cdot T + 0{,}42992533 \cdot (T-200)^2 - \\ \qquad + 2{,}031 \cdot 10^{-3} \cdot (T-200)^3, \quad 200 \le T < 300 \\ 213289{,}6324 - 67{,}6321 \cdot T - 0{,}17944428 \cdot (T-300)^2 + \\ \qquad + 5{,}576 \cdot 10^{-4} \cdot (T-300)^3, \quad 300 \le T < 400 \\ 219716{,}5422 - 86{,}7913 \cdot T - 0{,}01214819 \cdot (T-400)^2 - \\ \qquad - 1{,}993 \cdot 10^{-4} \cdot (T-400)^3, \quad 400 \le T < 500 \\ 223601{,}2349 - 95{,}2024 \cdot T - 0{,}07196295 \cdot (T-500)^2 + \\ \qquad + 2{,}398 \cdot 10^{-4} \cdot (T-500)^3, \quad 500 \le T < 600 \end{cases} \tag{4}$$

The graph is showed in figure 3:

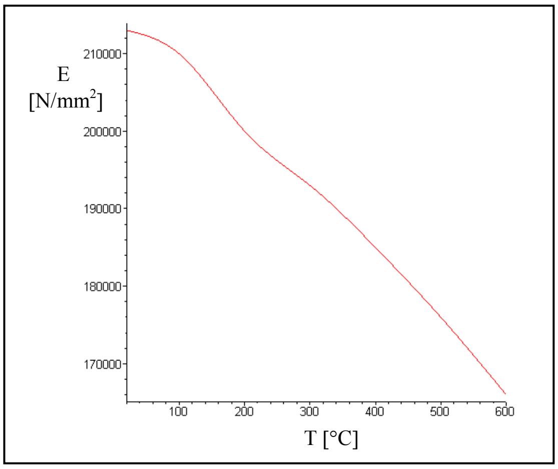

Figure 3: The graph of E(T)

The functions for the linear thermal expansion coefficient α, are generated by the following calculus program:

- restart:with(CurveFitting):with(plots):
- LT:=[20,100,200,300,400,500,600]:
- Lalpha:=[11.4e-6,12.5e-6,13.1e-6,13.6e-6,14e-6,14.4e-6,14.7e-7]:
- alpha:=u-> Spline([seq([LT[k],Lalpha[k]],k=1..nops(LT))],u,
- degree=3):
- 'alpha'=evalf(Spline([seq([LT[k],Lalpha[k]],k=1..nops(LT))],T ,degree=3)):
- plot(alpha(T),T=LT[1]..LT[nops(LT)]);

Applying the interpolation method with Spline functions of order 3, with the purpose of determining the calculus formulas for the linear thermal expansion coefficient α, leads to the analytical expression:

$$\alpha = \begin{cases} 1{,}108566 \cdot 10^{-5} + 0{,}1571 \cdot 10^{-7} \cdot T - 0{,}19601 \cdot 10^{-22} \cdot (T-20)^2 - \\ \qquad - 0{,}30730 \cdot 10^{-13} \cdot (T-20)^3, \quad 20 \le T < 100 \\ 1{,}151834 \cdot 10^{-5} + 0{,}9816 \cdot 10^{-8} \cdot T - 0{,}7375 \cdot 10^{-10} \cdot (T-100)^2 - \\ \qquad - 0{,}3558 \cdot 10^{-12} \cdot (T-100)^3, \quad 100 \le T < 200 \\ 1{,}195154 \cdot 10^{-5} + 0{,}5742 \cdot 10^{-8} \cdot T + 0{,}3301 \cdot 10^{-10} \cdot (T-200)^2 - \\ \qquad - 0{,}4043 \cdot 10^{-12} \cdot (T-200)^3, \quad 200 \le T < 300 \\ 1{,}353566 \cdot 10^{-5} + 0{,}2144 \cdot 10^{-9} \cdot T - 0{,}8828 \cdot 10^{-10} \cdot (T-300)^2 - \\ \qquad - 0{,}1261 \cdot 10^{-11} \cdot (T-300)^3, \quad 300 \le T < 400 \\ 0{,}58400 \cdot 10^{-5} + 0{,}20399 \cdot 10^{-7} \cdot T + 0{,}2901 \cdot 10^{-9} \cdot (T-400)^2 - \\ \qquad - 0{,}4541 \cdot 10^{-11} \cdot (T-400)^3, \quad 400 \le T < 500 \\ 0{,}43307 \cdot 10^{-4} - 0{,}57814 \cdot 10^{-7} \cdot T - 0{,}1072 \cdot 10^{-8} \cdot (T-500)^2 + \\ \qquad + 0{,}3574 \cdot 10^{-11} \cdot (T-500)^3, \quad 500 \le T < 600 \end{cases} \tag{5}$$

The graph is showed in figure 4:

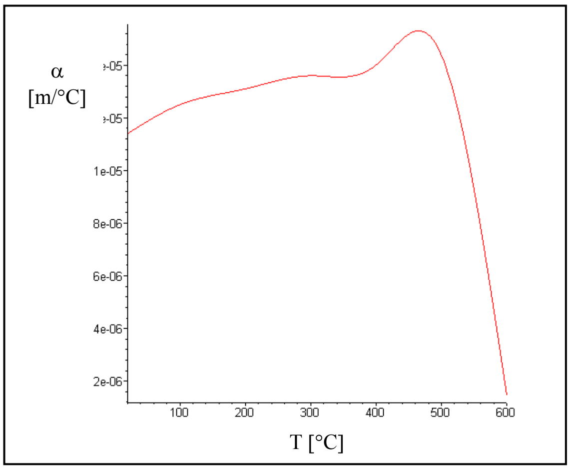

Figure 4: The graph of α (T)

The functions for the thermal conductivity λ, are generated by the following calculus program:

- restart:with(CurveFitting):with(plots):
- LT:=[20,100,200,300,400,500,600]:
- Llambda:=[42,41,40,38,36,33,30]:
- lambda:=u-> Spline([seq([LT[k],Llambda[k]],k=1..nops(LT))] ,u,degree=3):
- 'lambda'=evalf(Spline([seq([LT[k],Llambda[k]],k=1..nops(LT))],T,degree=3)):
- plot(lambda(T),T=LT[1]..LT[nops(LT)]):

Applying the interpolation method with Spline functions of order 3, with the purpose of determining the calculus formulas for the thermal conductivity λ, leads to the analytical expression :

$$\lambda = \begin{cases} 42{,}2741 - 0{,}013547 \cdot T - 1{,}2088 \cdot 10^{-5} \cdot T^2 + 0{,}2014 \cdot 10^{-6} \cdot T^3, & 20 \le T < 100 \\ 42{,}9671 - 0{,}033358 \cdot T + 1{,}9579 \cdot 10^{-4} \cdot T^2 - 0{,}4914 \cdot 10^{-6} \cdot T^3, & 100 \le T < 200 \\ 35{,}1141 - 0{,}083458 \cdot T - 3{,}9317 \cdot 10^{-4} \cdot T^2 + 0{,}4901 \cdot 10^{-6} \cdot T^3, & 200 \le T < 300 \\ 61{,}0169 - 0{,}175569 \cdot T - 4{,}7024 \cdot 10^{-4} \cdot T^2 - 0{,}4691 \cdot 10^{-6} \cdot T^3, & 300 \le T < 400 \\ 6{,}24382 + 0{,}235229 \cdot T - 5{,}5674 \cdot 10^{-4} \cdot T^2 + 0{,}3866 \cdot 10^{-6} \cdot T^3, & 400 \le T < 500 \\ 64{,}2385 - 0{,}112739 \cdot T + 1{,}3918{,} \cdot 10^{-4} \cdot T^2 - 0{,}7732 \cdot 10^{-7} \cdot T^3, & 500 \le T < 600 \end{cases} \quad (6)$$

The graph is showed in figure 5:

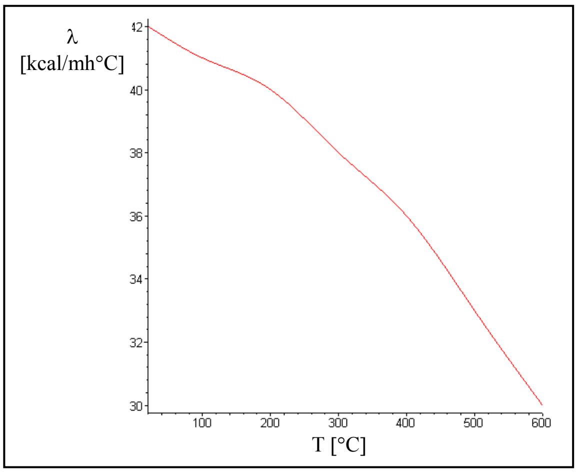

Figure 5: The graph of λ (T)

3. THE COFFIN-MANSON EQUATION

The relation between the strain and the number of cycles, ε-N, knew as the Coffin-Manson Equation, is obtained by modern experimental determinations. An experimental methodology is used in [1],[2],[3].

The Coffin-Manson diagrams are obtained and, also, the thermic fatigue curves, which are material's characteristics, and is showed in figure 6. The experimental techniques and the statistical processing for thermic fatigue tests results are very recent. This fact allowed the realization, for the first time in our country, of experimental researches on the third romanian steel, 16Mo5.3b. This one is used in coking chambers construction and the research is made with the aim of drawing the fatigues curves, which are material's characteristics, in three ways of solicitation (in the 60º-540ºC interval of temperature, specific to the thermic cycle of the coking chamber exploatation; pure thermic fatigue, without maintaining; thermic fatigue with 600 sec. maintaining at 540ºC; thermic fatigue with 36000 sec. maintaining at 540ºC) and three probabilities of realization (5%, 50%, 95%) .

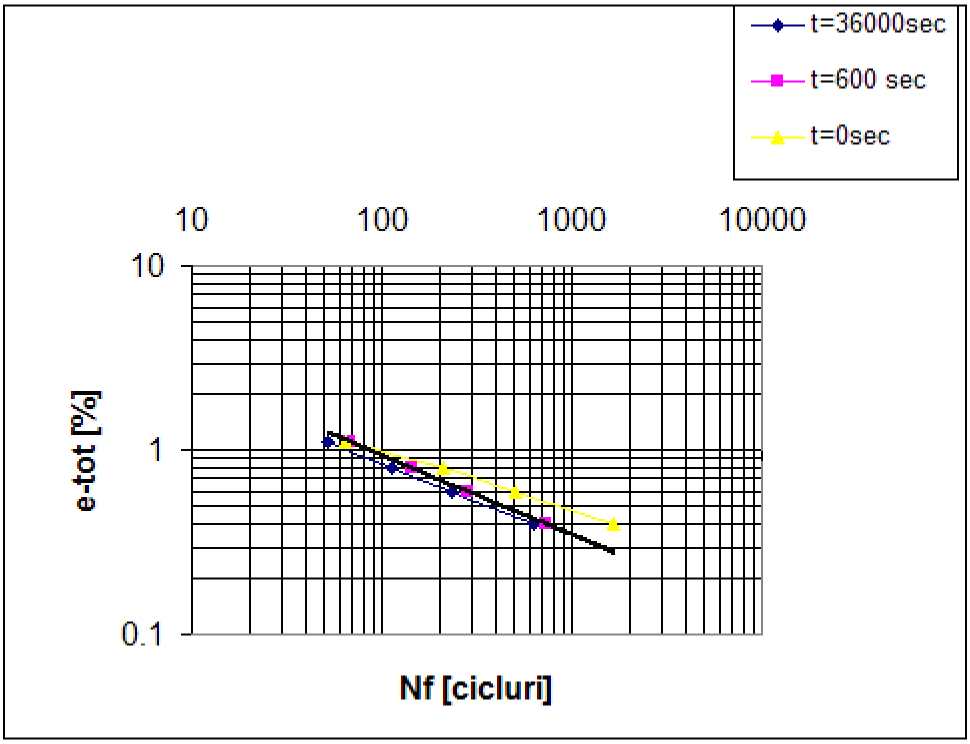

Figure 6: The Coffin-Manson diagrams for 16Mo5.3b steel.

4. CONCLUSIONS

The coking chamber has been considerated the best example for the creep phenomenon's study, associated with the thermic-oligo-cyclic fatigue.The Coffin-Manson diagrams are obtained and, also, the thermic fatigue curves, which are material's characteristics. All the mechanical and physical characteristics of steel depend on the temperature. All the programs presented in this paper determine, by a numerical calculus, their analytical expression. The Coffin-Manson Equation, experimentally determined, also, is imputed into the program as a material data and it is recognized by the program in she's mathematical form.

BIBLIOGRAPHY

1. Nicoleta Rizea „Contributii la calculul de fluaj si oboseala al invelisurilor subtiri cu aplicatie la aparatura petrochimica" teza de doctorat, 18 aprilie 2008
2. Nicoleta Rizea, Lavinia Stanciu "Standard practice for statistical analysis of linearized strain-life (ε-N) fatigue data, for 16Mo5.3b steel submitted to thermomechanical fatigue" Sesiunea anuala de comunicari stiintifice I.M.T. Oradea 2007, vol. VI, pag 83, CD ROM edition
3. Nicoleta Rizea, Ioan Popa "Tests results for 16Mo5.3b steel submitted to thermomechanical fatigue" Sesiunea anuala de comunicari stiintifice I.M.T. Oradea 2007, vol. VI, pag 84 CD ROM edition
4. * * * Maple 11, Maplesoft a Division of Waterloo Maple Inc 2007
5. * * * STAS 2883/1-88 Table de otel pentru cazane si recipiente sub presiune – Conditii tehnice de calitate
6. * * * STAS 2883/3-88 Oteluri destinate tablelor de cazane si recipiente sub presiune pentru temperaturi ambianta si ridicata– Marci si conditii tehnice de calitate
7. CosmosM 2007, Structural Research and Analysis Corporation 2007 (SRAC)