DEFINING THE LARSON-MILER PARAMETER FOR A NEW ALLOY STEEL

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Abstract. This article shows how the Larson-Miler parameter could be defined through tests and then used to prognosticate the time to rupture for materials, working for a long time at a constant load and elevated temperatures. The necessary theoretical information, the methodology for carrying out the experiment and the approach to the experimental results processing are provided. The methodology exposed has been demonstrated with a practical study of a new alloy steel. Being relatively simple the proposed approach can be always used when such a prognosis is needed, provided that the Larson-Miler criterion is suitable for the studied material.

Keywords: creep, rupture, strength, steel, Larson-Miler parameter

1. Introduction

The strength of the materials, working for a long time at a constant load and elevated temperatures, is evaluated according to two criteria: the creep strength and the creep rupture strength. The creep strength is called the stress, at which the creep strains for a given time interval t at temperature T reaches the extent, defined by the technical conditions. The creep rupture strength $R_{u/t/T}$ is called the stress value σ, at which the material is destroyed for time t_R at a given temperature T. In order to define experimentally the creep strength, the changes in the creep strain should be observed, which complicates the experiment. The creep rupture strength is easier to determine, because only the time to rupture is measured.

In the engineering practice the following problems have to be solved:

- The working stress $R_{u/t/T}$ and the working temperature T are given. The problem is to find the time to rupture t_R;
- The time to rupture t_R and the working temperature T are given. The problem is to find the working stress $R_{u/t/T}$, at which the material will be destroyed for time t_R.

There are different dependences, giving relations between the values $R_{u/t/T}$, t_R and T, which enable the solving of the above two problems. These dependences are called parameters and are named after the researchers having proposed them - for example Larson-Miler parameter (table 1). These parameters have been determined experimentally and are valid for specific materials. For the different materials there are different parameters that are suitable.

The parameters, given in table 1, are determined at elevated temperatures and stress, when the time to rupture is short. After that they are used to prognosticate the time to rupture at lower temperatures, for which the same stress will give considerably higher values of t_R.

The prognosticating is done in three steps. For example, when t_R is to be fined:

Table 1. Dependences between the values $R_{u/t/T}$, t_R and T

Parameter of:	Dependence	Material constants to be determined	Bibliography
Larson-Miler	$P_{LM} = f(R_{u/t/T}) = T(C + \lg t_R)$	C	[1]
Manson-Haferd	$P_{MH} = f(R_{u/t/T}) = \dfrac{\lg t_R - \lg t_a}{T - T_a}$	T_a, t_a	[2]
Manson-Brown	$P_{MB} = f(R_{u/t/T}) = \dfrac{\lg t_R - \lg t_a}{(T - T_a)^n}$	T_a, t_a, n	[3]
Manson-Succop	$P_{MS} = f(R_{u/t/T}) = \lg t_R + C.T$	C	[4]
Orr-Sherby-Dorn	$P_{OSD} = f(R_{u/t/T}) = \lg t_R - \dfrac{B}{T}$	B	[5]

1) An experiment is carried out, in which the time to rupture is measured for different load and temperatures. The parameter, giving the best relation between the values $R_{u/t/T}$, t_R and T, is determined. A graph of the function $P = f(R_{u/t/T})$ is drawn.
2) The value of P is determined for the given value of $R_{u/t/T}$ from the graph, drawn in point 1.
3) t_R is expressed and calculated from the equation of the corresponding parameter.

The most precise and most frequently used dependences in practice are those, proposed by Larson-Miler and Manson-Haferd. The parameter P_{MH} is more precise than P_{LM}, but it contains two constants. P_{LM} contains only one constant, which makes it preferable and easier to put into practice.

2. Aim of the study

The problem is set to define the Larson-Miler parameter P_{LM} for alloy steel 1.4859 (G-X10NiCrNb3220), produced by “Centromet” JSC – Vratza, with chemical composition, given in table 2. The steel is designed for the production of pipes for reformer installations, working for a long time (10-30 years) at great load and temperatures of about 800 °C.

Table 2. Chemical composition of steel 1.4859 (in %)

C	0.05÷0.15
Ni	31.0÷33.0
Cr	19.0÷21.0
Si	0.50÷1.50
Mn	0.50÷1.50
Nb	0.5÷1.5
S	≤0.030
P	≤0.045

3. A methodology for defining the Larson-Miler parameter

It is recommended to determine experimenttally the time to rupture t_R for at least three values of the stress σ ($\sigma_1 > \sigma_2 > \sigma_3$), at a given temperature T. In the present study there will be tested three test pieces for three different values of σ, at two different temperatures T – a total number of 18 test pieces will be tested.

At T_i = const (i = 1÷2) three test pieces are tested for each value of the stress – σ_j = *const* (j = 1÷3) and the times to rupture t_n (n = 1÷3) are defined. The mean values of the time to rupture t_{ij} are defined for the different combinations of T_i and σ_j:

$$t_{ij} = \frac{1}{n}\sum_n t_n = \frac{t_1 + t_2 + t_3}{3} \qquad (1)$$

For the stress σ_1 according to the relationship of Larson-Miler it could be written:

$$\begin{aligned} P_{\sigma 1} &= T_1(C_{\sigma 1} + \lg t_{11}) \\ P_{\sigma 1} &= T_2(C_{\sigma 1} + \lg t_{12}). \end{aligned} \qquad (2)$$

From (2) are obtained:

$$P_{\sigma 1} = \frac{T_1 T_2}{T_1 - T_2} \lg \frac{t_{12}}{t_{11}}; \qquad (3)$$

$$C_{\sigma 1} = \frac{1}{T_1 - T_2}\left(T_2 \lg t_{12} - T_1 \lg t_{11}\right). \qquad (4)$$

In much the same way as (3, 4) are determined $P_{\sigma 2}$, $C_{\sigma 2}$, $P_{\sigma 3}$, $C_{\sigma 3}$.

The mean value of the material constant C is determined as follows:

$$C = \frac{1}{j}\sum_j C_{\sigma j} = \frac{C_{\sigma 1} + C_{\sigma 2} + C_{\sigma 3}}{3}. \qquad (5)$$

Using the Larson-Miler dependence and the obtained value of C, P_{ji} is calculated:

$$P_{ji} = T_i\left(C + \lg t_{ji}\right). \qquad (6)$$

The mean values of P_j are determined:

$$P_j = \frac{1}{i}\sum_i P_{ji}, \qquad (7)$$

$$P_1 = \frac{P_{11} + P_{12}}{2}; \quad P_2 = \frac{P_{21} + P_{22}}{2}; \quad P_3 = \frac{P_{31} + P_{32}}{2}.$$

The errors between $P_{\sigma j}$ and P_j are calculated:

$$\Delta_j = \frac{P_{\sigma j} - P_j}{P_{\sigma j}} 100, \%. \qquad (8)$$

The errors calculated Δ_j are compared to a previously accepted admissible value Δ_{adm}. If the error is greater than the admissible value, additional experiments are carried for two more values of σ (σ_4 and σ_5) and the calculations are complemented. For this purpose the values $P_{\sigma 4}$, $C_{\sigma 4}$, $P_{\sigma 5}$, $C_{\sigma 5}$ are defined and C, P_{ji} and Δ_j are recalculated. If the result is again an inadmissible error value, another parameter should be applied (table 1).

If the resulting error value is less than the admissible one, then a function $\sigma_j(P_j)$ graph is drawn.

4. Carrying out the experiment

Figure 1 shows the testing stand, on which the experiments have been carried out. Figure 2 shows the test pieces made of steel 1.4859. The diameter of their testing section is 6 mm. They are made according to the requirements of the EN 10291:2000 standard.

Figure 1. A stand for testing materials at elevated temperatures

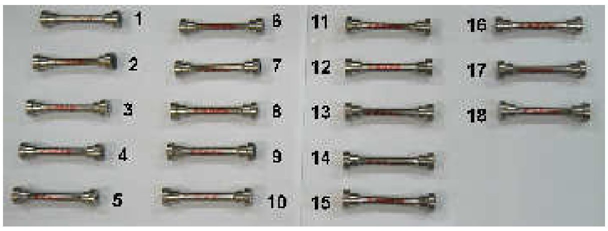

Figure 2. Test pieces

Table 3 shows the testing conditions and the measured times to rupture t_R for each test piece. The testing has been carried out at six different conditions, resulting as combinations of two temperatures (T_1 = 1000 °C and T_2 = 900 °C) and three loads (150 kg, 125 kg, 100 kg).

Table 3. Test piece testing conditions

T, °C	Load, kg	Test piece №	t_R, h
1000	150	1	0.41
		2	0.39
		3	0.42
	125	4	2.01
		5	2.16
		6	1.99
	100	7	11.97
		8	10.91
		9	12.06
900	150	10	6.42
		11	6.83
		12	6.71
	125	13	38.65
		14	39.20
		15	37.60
	100	16	240.21
		17	249.35
		18	247.19

5. Processing the results from the experiment

Table 4 shows the processing of the results from the experiment made. The stress on the test piece testing section is a leading value σ_j, which depends on the strength set during the experiment.

As seen from the table 4 the scattering of the test results is small. The calculated error is within the range of ±2%. This precision is quite sufficient and gives grounds to accept the results as reliable. The mean value of the constant *C* for the studied material is 11.09.

6. Prognosticating the behaviour of material 1.4859 for time, exceeding the time of the experiments

There is a graph on figure 3 giving the variations of parameter P_{LM} depending on the creep rupture strength for material 1.4859. This graph is drawn taking the data from table 4, which are obtained at elevated temperatures. Figure 3 can be used to make a prognosis of t_R or $R_{u/t/T}$ at lower temperatures. This is demonstrated by the two examples given below.

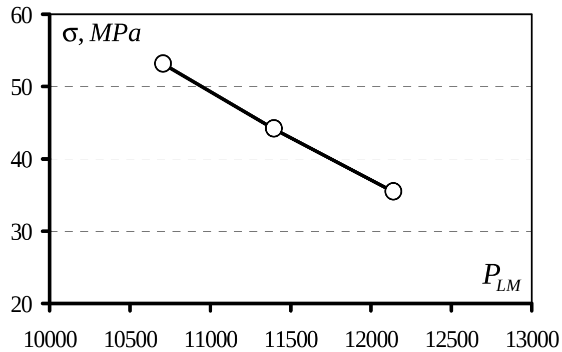

Figure 3. $P_{LM}(\sigma)$ graph for steel 1.4859

Example 1: Prognosticate the time to rupture of a construction element made of steel 1.4859, subjected to pure tension, if the working temperature is *T* = 700 °C, and the working stress is σ = 50 MPa.

Solution: From figure 3 it could be seen that for σ = 50 MPa the value of P_{LM} = 10900. Then

$$P_{LM} = T \cdot (C + \lg t_R);$$

$$10900 = 750 \cdot (11.09 + \lg t_R);$$

t_R = 2775.45 h = 115.64 days.

Example 2: We have a construction element made of steel 1.4859, subjected to pure tension, at working temperature of 750 °C. Prognosticate the stress, at which the time to rupture of the element will be t_R = 365 days.

Table 4. Experiment results processing

σ_j, MPa	T_i, °C	t_n, h	$t_{ji}=\frac{1}{3}\sum_{n=1}^{3}t_n$, h	$P_{\sigma j}$	$C_{\sigma j}$	$P_{ji}=T_i(C+\lg t_{ji})$	P_j	$\Delta=\frac{P_{\sigma j}-P_j}{P_{\sigma j}}100$, %
σ_1=53.08	T_1=1000	t_1=0.41	$t_{11}=0.41$	$P_{\sigma 1}=10890$	$C_{\sigma 1}=11.28$	$P_{11}=10703$	$P_1=10713$	$\Delta_1=1.63$
		t_2=0.39						
		t_3=0.42						
	T_2=900	t_1=6.42	$t_{12}=6.65$			$P_{12}=10722$		
		t_2=6.83						
		t_3=6.71						
σ_2=44.23	T_1=1000	t_1=2.01	$t_{21}=2.05$	$P_{\sigma 2}=11461$	$C_{\sigma 2}=11.15$	$P_{21}=11402$	$P_2=11405$	$\Delta_2=0.49$
		t_2=2.16						
		t_3=1.99						
	T_2=900	t_1=38.65	$t_{22}=38.48$			$P_{22}=11408$		
		t_2=39.20						
		t_3=37.60						
σ_3=35.39	T_1=1000	t_1=11.97	$t_{31}=11.65$	$P_{\sigma 3}=11915$	$C_{\sigma 3}=10.85$	$P_{31}=12156$	$P_3=12144$	$\Delta_3=-1.92$
		t_2=10.91						
		t_3=12.06						
	T_2=900	t_1=240.21	$t_{32}=245.58$			$P_{32}=12132$		
		t_2=249.35						
		t_3=247.19						
					$C=11.09$			

Solution: The Larson-Miler parameter is calculated:

$$P_{LM}=T\cdot(C+\lg t_R);$$

$$P_{LM}=750\cdot[11.09+\lg(365\cdot 24)]=11274.$$

From figure 3 it could be seen that for P_{LM} = 11274 the value of σ = $R_{u/t/T}$ = 44.5 MPa.

7. Conclusion

This article shows how the Larson-Miler parameter could be defined through experimental tests and then used to prognosticate the time to rupture and creep rupture strength for materials, working for long at a constant load and elevated temperatures. Here this is made for the new alloy steel 1.4859. The methodology demonstrated is relatively simple and does not require a huge experimental work or sophisticated calculations. It could be always used when such a prognosis is needed, as long as the Larson-Miler criterion is suitable for the studied material.

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