Mathematical relation ships between alloying elements and technological deformability indexes

C. O. RUSĂNESCU[a] , M. RUSĂNESCU[b*], T. IORDĂNESCU[c], F. V. ANGHELINA[d]
[a] *University Polytechnic, Faculty of Biotechnical Systems Engineering Bucharest, Romania*
[b]*Valplast Industries Bucharest, Romania*
[c]*Metallurgical Research Institute Bucharest, Romania*
[d]*Faculty of Materials and Mechanical Engineering,18-24 Unirii Bld., 130082, Valahia University of Targoviste, Romania*

The aim of the paper is to assess mathematical relationship between alloying elements and technological deformability indexes. The subject proposed is settled through a laboratory experiment, where plasticity is appraised by pressing tests. Three steel grades are used. (OLT 35 K, 16 Mo 3, 14 CrMo 4) in order to determine their grain growth trend and their initial grain size at austenitization temperature. Structural analysis examined surfaces was performed for each steel grade for the following purposes: to determine the trend of increasing grain; determining initial grain austenitization temperature used in attempts (T_a = 1200^{0}C) determine the deformation temperature austenitic grain.

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1. Introduction

The technological deformability is the materials ability to be deformed without damaging their integrity. The technological deformability determination may be resumed by two aspects:

- Plastic property assessment under different stress condition and deformation rates; temperature ranges. Three which the material shows adequate plastic properties are pursued;
- Deformation resistance assessment for different condition and deformation rates; temperatures for which the deformation resistance shows the lowest values are emphasized.

The technological deformability testing aims, massing, identify the optimal plastic deformation condition (temperature, deformation rate) and by correlation, the evolution of microstructure during deformation.

2. Working method and materials used

Three experimental batches were realized in a CIA furnace consisting in 50 kg ingots. The complete chemical analyze of all experimental batches is presented in Table 1.

The ingots were forged with a ϕ 18 mm hammer and then cooled by air. In order to provide a homogeneous structure, every batch was normalized at characteristically temperatures A_{c3} + 30^{0}C. During 30 minutes and subsequently.

Table 1. Chemical composition of experimental steel batches for boilers.

Steel grade	Chemical composition %			
	C	Mn	Si	S
OLT 35 K	0,16	0,48	0,23	0,017
16 Mo 3	0,14	0,57	0,35	0,015
14 CrMo 4	0,15	0,50	0,28	0,017
Steel grade	P	Cr	Mo	
OLT 35 K	0,011	0,18	0,02	
16 Mo 3	0,007	0,12	0,38	
14 CrMo 4	0,020	1,02	0,40	

At the end of the test, the specimens were quenched (during 3-5 seconds) in order “to freeze” the austenitic grain size at the end of plastic deformation.

Also as concern the structural aspect of the samples using optical microscopy methods emphasizing the grain size according to STAS 4203 and 5490 were performed

3. Experimental results and their interpretation

Hot pressing tests were performed and the experimental data processed.

All the values obtained (unite reduction degree and the deformation resistance) are presented for each steel grade, the initial test temperature and the pressing force in Table 2.

Table 2. The experimental results obtained after performing pressing tests.

Steel grade	Temperature (^{0}C)	F_{min}	
		Reduction degree[%]	Deformation resistance [MPa]
14CrMo4	800	35	294
	850	39,8	246
	900	42,4	233
	1000	46,6	213
	1100	50	198
	1200	54,9	186
16Mo3	800	38,5	256
	850	40,4	234
	900	43,6	215
	1000	47,3	193
	1100	51,9	184
	1200	57,4	167
OLT 35 K	800	38,4	237
	850	40,1	205
	900	42,7	187
	1000	48,6	168
	1100	55,4	154
	1200	59,9	149
Steel grade	Temperature (^{0}C)	F_{med}	
		Reduction degree[%]	Deformation degree [MPa]
14CrMo4	800	39,7	290
	850	43	274
	900	48,1	206
	1000	51,4	218
	1100	54,4	203
	1200	60,9	175
16Mo3	800	41,5	278
	850	45,5	251
	900	49,1	241
	1000	51,8	216
	1100	55,6	198
	1200	60,7	176
OLT 35 K	800	42,7	270
	850	45,3	252
	900	48	220
	1000	52,8	201
	1100	57,6	180
	1200	62,5	169
Steel grade	Temperature (^{0}C)	F_{max}	
		Reduction degree[%]	Deformed resistance[MPa]
14CrMo4	800	45,1	299
	850	47,1	284
	900	50,8	267
	1000	54,3	228
	1100	57,9	210
	1200	64,1	183
16Mo3	800	47,7	266
	850	50,2	251
	900	53,3	234
	1000	55,8	220
	1100	59,9	201
	1200	64	183
OLT 35 K	800	46,6	273
	850	49,2	257
	900	52,2	240
	1000	57,3	213
	1100	63,3	186
	1200	66,2	174

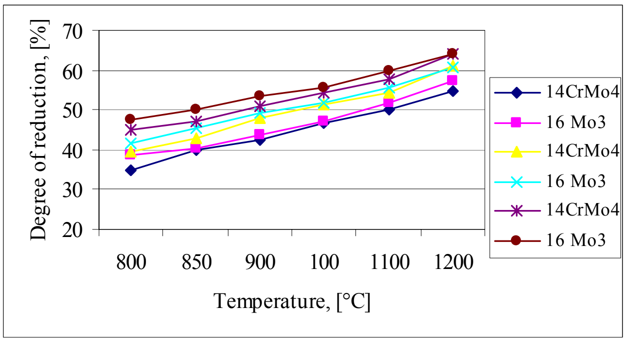


Fig. 1. Temperature dependence of the degree temperature variation for the three brands for three different forces at discharge.

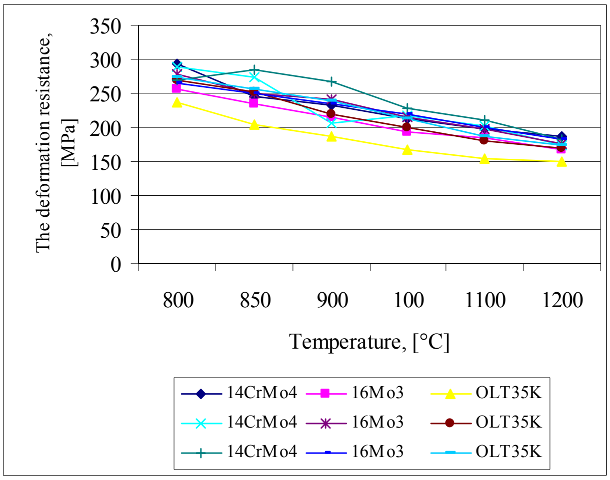


Fig. 2. Resistance to deformation of reduction for two grades of steel (0.2% Mo and 0.38% Mo) of pipes for boilers.

By help of the experimental values in Fig. 1-2 were drawn diagrams. In Fig. 1 are shown by comparison the influence of molibdene and chromium on the plasticity when pasing from residual values to minimum alloying percentage values. In the case of Mo, one can observe a similarly variation of quality independent of the deformation rate to shook (107-121 sec^{-1}). For values from 800 to approximately 950^{0}C. Mo allows a light increase of plasticity (1-3 %); over 1000^{0}C and 1200^{0}C. There results can be correlated with the deformation resistance variation for the three grades used (Fig. 2). There is an influence of temperature on the deformation resistance decrease under heat condition, the tested samples complying also with the order determined by the approximately 10 % increase of the deformation rate, resulting only a decrease of the difference of values at a given temperature there is a more significant difference between alloyed grades and carbon steel. In order to real the aim oh the subject, the purpose was to determine constitutive diagrams. Other authors have studied the mathematical model by which differential equations obtained [4,5,7]

By statistical processing following equation type was obtained:

$$Z = a + b \ln(X) + C(\ln y) \quad (1)$$

x – deformation y –deformation rate (sec.$^{-1}$)
z –deformation resistance

The values of parameters a, b, c are constant and are shown for each grade in the following table, together with the correlation coefficient, which have values above 0,93.

Table 3. Values of parameters a, b, c.

Steel grade	Constant values			Correlation coefficient
	a	b	c	
OLT 35 K	-3191,2	907,2	-230,4	0,9092
16Mo3	-2148,9	704,8	-248,8	0,9504
14 CrMo4	-3006,4	741,8	-5,7	0,9235

The content of chromium in the chemical composition of the three batches allowed the plotting in a deformability diagram (% Cr, T, R_d) of its influence on the resistance as well when the initial test temperature is decreasing as when the chromium content is increasing.

Structural aspects of steels

The analyze was performed for each steel grade having following ains:
- determination of the grain size increasing trend
- determination of the initial grain (size) at austenitization temperature as this is used in tests (T_a = 1200^{0}C)
- determination of the austenitic grain (size) at deformation temperature

In order to perform this analyze, the samples were heat treated under similar condition, according to STAS 590, by the cementation method. Recommended hereby for steels, which have a carbon content lower than 0,25 %.

Also many different type of researcher study the structural materials, have made metallographic test on samples was carried out by optical and electron microscopy [3,6,8,9].

The aim of the analyze trend in the case of the three grades, in order to estimate. The austenitisation condition for the tests performed [2].

The results obtained after treatment (Austenitisation) at 930 ± 10^{0}C, fuel medium are emphasized in Table 4.

Table 4. Austenised grain size Cementation method.

Steel grade	*Σ*	*Mean diameter conventional*
OLT 35	104	0,023
16 Mo 3	156	0,031
14 Mo Cr 4	106	0,022

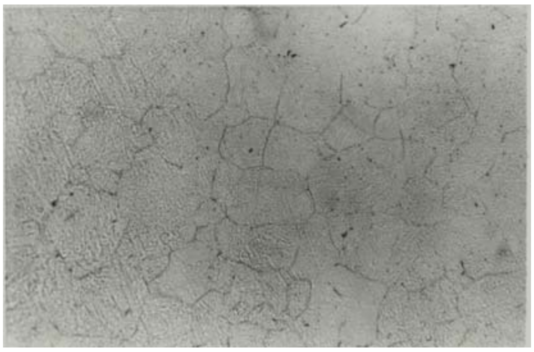
One can observe that the three steel grades show the same grain (size) growth trend.

The initial grain (size) during austenitisation. The water – cooled samples, were prepared by metallography according to STAS 5490, namely by the method of grain boundary attack.

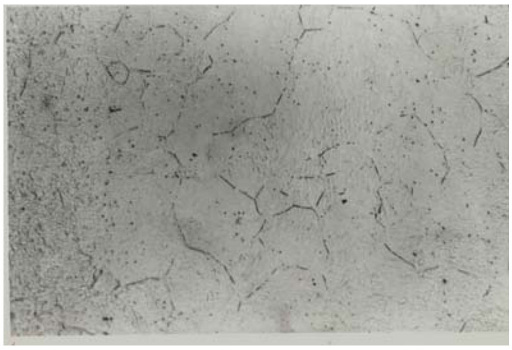
The results obtained are shown in Table 4.

One can observe that the grain size is the same during austenitisation at 1200^{0}C, there fore were obtained identical, initial condition for the three steel grades.

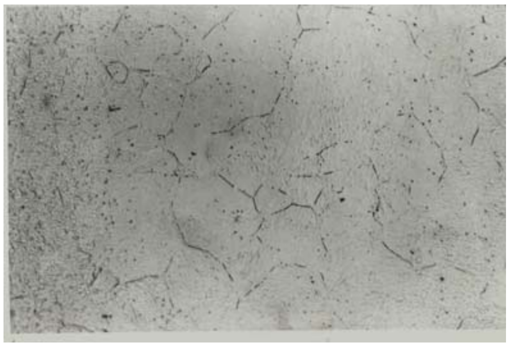
The structural aspects are emphasized in Fig. 3.



x 100 OLT 35K



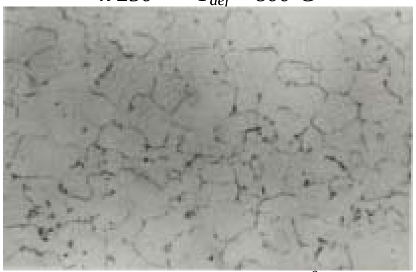
x 100 16Mo3



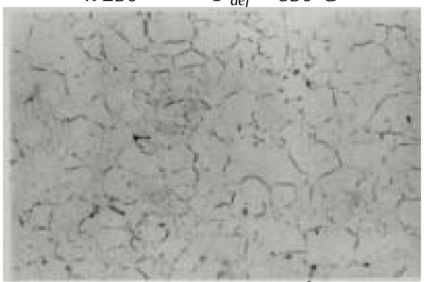
x 100 16MoCr4

Fig. 3. The aspect of the initial grain size at the heating austenitisation temperatureT = 1200^{0}C.

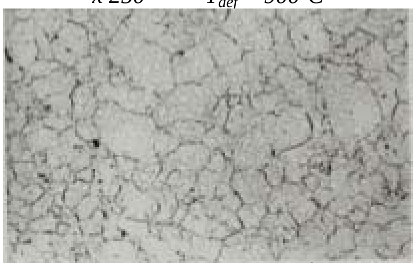
x 250 $T_{def} = 800^0C$



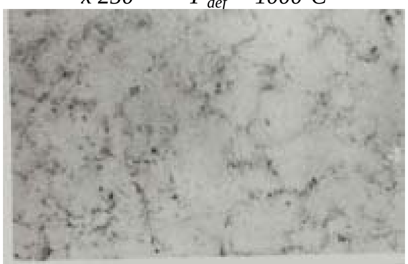
x 250 $T_{\ def} = 850^0C$



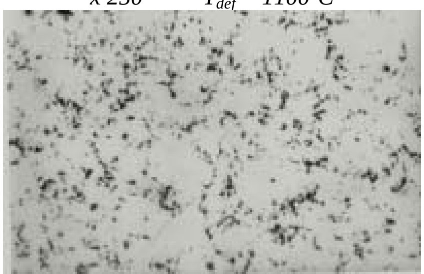
x 250 $T_{def} = 900^0C$



x 250 $T_{\ def} = 1000^0C$



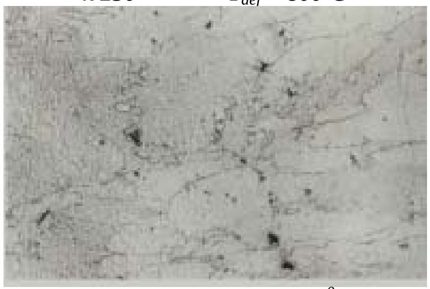
x 250 $T_{def} = 1100^0C$



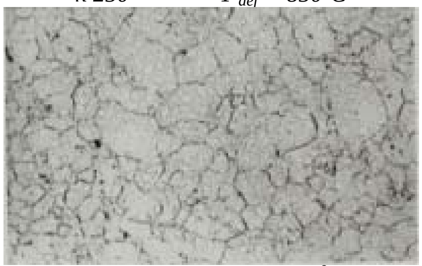
x 250 $T_{\ def} = 1200^0C$

Fig. 4. Aspects of evolution austenitic grain deformation at different temperatures ($T_a = 1200^0C$)- steel OLT 35.

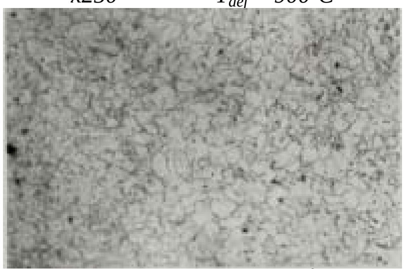
x 250 $T_{def} = 800^0C$



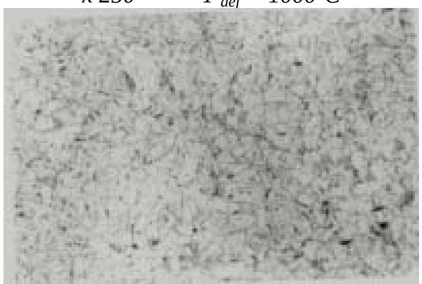
x 250 $T_{\ def} = 850^0C$



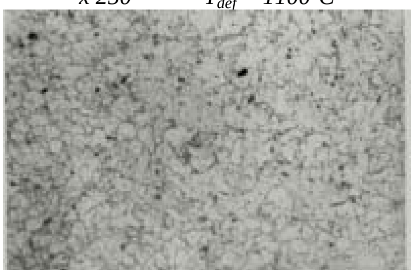
x250 $T_{def} = 900^0C$



x 250 $T_{\ def} = 1000^0C$

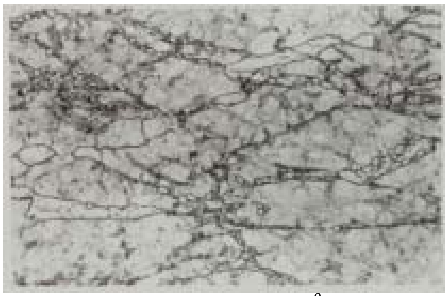


x 250 $T_{def} = 1100^0C$

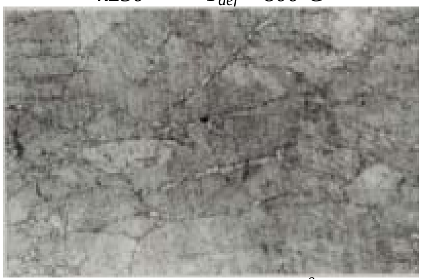


x 250 $T_{\ def} = 1200^0C$

Fig. 5. Aspects of evolution austenitic grain deformation at different temperatures ($T_a = 1200^0C$)- steel 16Mo3.

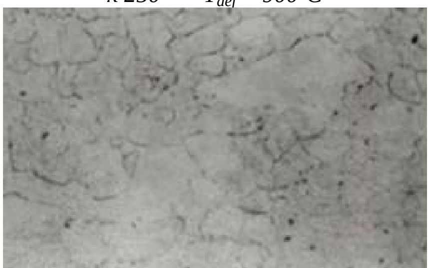


x250 $T_{def} = 800^0C$

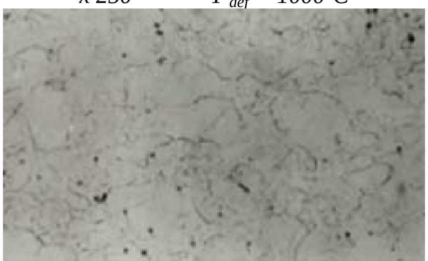


x 250 $T_{def} = 850^0C$

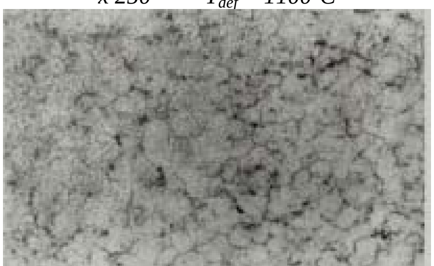
x 250 $T_{def} = 900^0C$



x 250 $T_{def} = 1000^0C$



x 250 $T_{def} = 1100^0C$



x 250 $T_{def} = 1200^0C$

Fig. 6. Aspects of evolution austenitic grain deformation at different temperatures ($T_a = 1200^0C$)- steel16MoCr4.

4. Conclusions

The laboratory experiments consisted in heat pressing tests on samples from the three steel grades: OLT 35 K, 16 Mo 3 and 14 CrMo 4. The tests were performed with mean deformation rates, which varied by ~ 15 % for a range of (107 .. 121 sec^{-1}).

The grade OLT 35 K emphasized a superior plasticity.

The increase of the deformation rate by approximately 15 % determined a classification of values for each temperature, in the case of the alloyed steels the differences decreasing step by step from 800 ^oC up to 1200 ^oC.

The performing of mathematical regressions with two independent variables allowed to determine the following equation: $Z = a + b \ln x + c \ln y$ with accurate correlation coefficients for the three studies steel grades, from 0,93 to 0,99.

The experimental work was finalized by plotting a deformability diagram R_d-T for the chromium content variation.

The microstructural analyze emphasized that the carbon steel OLT 35 (Reference steel grade). And the other two steel grades are dynamically recrystallising at a her temperature, therefore the end deformation limit has to upraised compared with the carbon steels; it is also necessary to comply strictly with it.

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*Corresponding author: rusanescum@yahoo.com