Study of the hot deformability of microalloyed steels using torsion tests

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The present paper emphasized the results of experimental researches concerning the influence of microalloying elements on the 31 VMn 12 steel characteristics for oil pipes manufacturing. In order to characterize the hot deformability 31 VMn 12 steels, the torsion test was used for three strain rates. (constant on testing) 0,01; 0.05; 0.1 sec^{-1} at temperatures of 800^0C, 900^0C, 1000^0C; 1100^0C, with strain directly on temperature, in an protective natrium atmosphere, until the failure point is reached. Structural aspects of the material used in the experiments are determined by optical microscopy. By using the interception method the mean value of the conventional diameter, for each heat under the initial deformation temperature condition, was determined.

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1. Introduction

The microalloyed steels are steels that contain besides C and Mn small quantities of elements such as Al, B, Nb, Ti, V. [2,3,4]

Because all these elements present an increased affinity to N, O, C, we can notice different precipitation reactions in steel.

Theoretically some of these precipitation reactions can precede or accompany solidification reaction, some others can arise during hot plastic shaping or during further cooling. The main effects of precipitation reactions are: a change in the ratio between the cold-hammering speeds and the recrystallization ones with effects upon hot deformability [1];

- inhibition or acceleration of transformation reactions into austenite phase during the cooling subsequent to hot plastic shaping.

- the steel we have used in our experiments is 31 VMn 12. It has reduced tendency in increasing granulation which, under the controlled temperature variation for rolling represents an advantage which must be exploited from the economical point of view.

Consequently we have to determinate the hot plastic shaping conditions which finally ensure to the material an as fine as possible ferrite grain, with positive effects upon the entire ensemble of properties (mechanical endurance, tenacity in exploitation, weldability), this thing being possible by a rationally conceived alloying system [5,6].

The study of the microalloyed steels by help of torsion testing takes place in general by heating to a sufficiently high temperature in order to allow the precipitation process and then a cooling to the initial temperature of the test. The cooling rate to the testing temperature as well as the deformation speed are chosen in such a way so that to simulate to the highest degree, industrial shaping conditions. This heating method used within the framework of the hot torsion testing allows us establishing the optimal composition as well as the deformability interval, in addition, being necessary the study of the hot deformability in the case of the direct heating of the material up to T_0.

The precipitate is in the most of the cases dynamically induced for the cases of microalloyed steels which have been treated by sinking them into solution, cooled up to T_0 and then tested. In spite of this the microalloyed steel heating directly to T_0 allows the precipitates existing before shaping the establishment of possible austenite for each mark. This charge is why by using this thermal regime for each charge composition we have studied its deformability in relation with recrystallization.

One of the main microalloying elements of steels used to obtain products having superior quality characteristics. Is vanadium. The main goals of vanadium microalloying are: grain finishing, hardening by precipitation and ductile – brittle transition temperature.

By performing tests on the SETARAM machine, for each pair of variables ε and T were determined the equivalent values σ_p , ε_p and ε_r corresponding to the four tested chemical composition.

The chemical composition of the steel used in experiments is presents in Table 1.

In our laboratory experiments we have used samples which have been extracted from for billets kept for 20 minutes under pressure and then cooled in plain air. From them we have obtained smaller torsion samples and have determined also their chemical composition.

2. Experimental materials

The steel we have used in our experiments – 31 VMn 12 STAS 8185-88 is an alloyed steel which hase been laminated in round or square billets and used for the fabrication of the tubular products for oil and natural gases equipment. We can also make bottling pipes for gases under pressure from this type of steel.

Table 1. The chemical composition of the steel 31VMn 12 used in experiments.

Heat No.	C %	Si %	Mn %	S %
1	0,27	0,24	1,22	0,014
2	0,29	0,28	1,20	0,011
3	0,28	0,24	1,16	0,005
4	0,28	0,28	1,24	0,007
Heat No.	P %	Cr%	Ni %	Cu %
1	0,013	0,14	0,08	0,12
2	0,014	0,09	0,05	0,09
3	0,010	0,15	0,07	0,09
4	0,015	0,14	0,12	0,14
Heat No.	Cu %	Mo %	V %	
1	0,12	0,010	0,12	
2	0,09	0,008	0,13	
3	0,09	0,007	0,12	
4	0,14	0,010	0,17	

The materials technological deformability represents an enhanced plastic deformation capacity without any damages upon material integrity, thus comprising both the plasticity notion and that of shaping resistance. Function of the plastic deformation procedure or of mechanical testing, the plasticity and the deformation resistance can be featured by specific indices.

Deformability determination by torsion method. Within the framework of this method the metallic materials hot deformabillity is measured by twisting a cylindrical small sample; the magnitude of the necessary moment for the twisting of the sample expresses the deformation resistance and the number of turns until rupture expresses the plasticity limit of the respective steel.

This method is the only one which allows us the obtention of large deformations along the whole length of the sample, being especially used for the determination of the metal characteristics at large deformations. Taking into account the fact that the tangential tensions play a major role in the process of rolling and forging, the deformability determined by torsion accurately reflects the steel behaviour to hot plastic deformation. Due to the fact that the sample is kept inside an inductor during the testing, the temperature constancy is satisfactorily assured.

During the testing the torsion sample is stressed in a way which is close to the stressed which appear in the real deformation processes, when the plastic flow is provoked by the tangential tensions components. During the testing the sample is changing its dimensions. In order to insure a constant deformation rate it is necessary to maintain a constant length of the sample, in this case, besides the shearing tensions, we have also stretching and compression tensions which modify the pure shearing state.

One of the disadvantages of this method it that in the sample section we encounter the whole deformation rates range from 0 in the center up to maximum at the sample surface. This is the reason for which, when determining the deformability we have to take into consideration only a thin layer from the sample surface where the deformation rate is maximal.

Supposing that along the axis of the circular sample undergoing a torsion no axial force arises, we can define the unitary effort state as shown in Fig. 1.

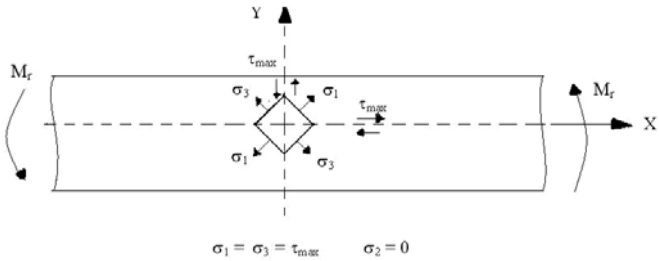


Fig. 1. Unitary stress state existing along the axis of the torsion cylindrical sample [1].

The hot torsion installation SETARAM enabled us to twist the samples from the for charges at three deformation rates within the interval 10^{-2}-$10^{-1}s^{-1}$ for inițial temperatures of 800, 900, 1000, 1200^0C.

The samples have been warmed up and twisted in argon protective atmosphere – in order to avoid oxidation – and rapidly hardness at the end of the tests. We have recorded for each sample the values of the moment, the number of turns until rupture and the temperature.

Another authors study hot deformability of low-alloyed steels using torsion tests [9].

3. Experimental results and discussions

The results of the experiments made by help of the hot torsion installation concerning the deformability characteristics of the steel 31 VMn 12 are given in table 2.

We present the values of the equivalent tension σ_M of the deformations ε_M and for rupture ε_r .

Due to the fat that tubes are deformed on the temperature range from 1150^0C to 850^0C and because this range vanadium particles. Are either dissolved in solution or precipitated (max. solubilisation temperature) of vanadium = 1100^0C), the austenite grain size in the initial deformation state of the three heats were deformed (deformation temperature during torsion 800-1000^0C).

Table 2. The equivalent values of tensions and deformations determine by hot torsion testing of for steel 31VMn 12 charge.

t[^{0}C]	$\dot{\varepsilon}$ [s^{-1}]	charge 1			charge 2		
		σ_{max} [MPa]	ε_{max}	ε_r	σ_{max} [MPa]	ε_{max}	ε_r
800	0.01	129	0.3	3.58	117	0.39	4.59
800	0.05	149	0.35	4.23	157	0.38	4.85
800	0.1	174	0.37	4.47	183	0.39	4.72
900	0.01	89	0.28	6.46	72	0.26	5.84
900	0.05	112	0.27	6.94	108	0.29	6.66
900	0.1	107	0.31	9.03	121	0.34	10.49
1000	0.01	62	0.26	7.06	51	0.32	7.94
1000	0.05	76	0.35	18.8	72	0.37	18.13
1000	0.1	67	0.4	16.64	78	0.45	19.38
1100	0.01	38	0.22	8.7	45	0.21	8.92
1100	0.05	53	0.27	23.61	58	0.28	23.95
1100	0.1	45	0.32	4.62	64	0.39	9.21
1200	0.01	27	0.53	29	53	0.58	37
t^{o}C	$\dot{\varepsilon}$ [s^{-1}]	charge 3			charge 4		
		σ_{max} [MPa]	ε_{max}	ε_r	σ_{max} [MPa]	ε_{max}	ε_r
800	0.01	131	0.34	5.52	114	0.3	5.76
800	0.05	161	0.37	5.45	165	0.47	4.65
800	0.1	182	0.41	5.35	176	0.66	4.32
900	0.01	89	0.27	10.89	84	0.24	6.25
900	0.05	128	0.33	13.65	110	0.35	15.16
900	0.1	137	0.41	7.09	136	0.39	18.29
1000	0.01	62	0.25	12.14	60	0.2	10.88
1000	0.05	65	0.38	21.8	70	0.44	21.47
1000	0.1	75	0.41	22.83	88	0.38	20.2
1100	0.01	47	0.21	10.82	58	0.22	12.18
1100	0.05	55	0.35	39	64	0.41	23.07
1100	0.1	58	0.43	38.56	68	0.78	28.53
1200	0.01	54	0.68	47	53	1.26	40.85

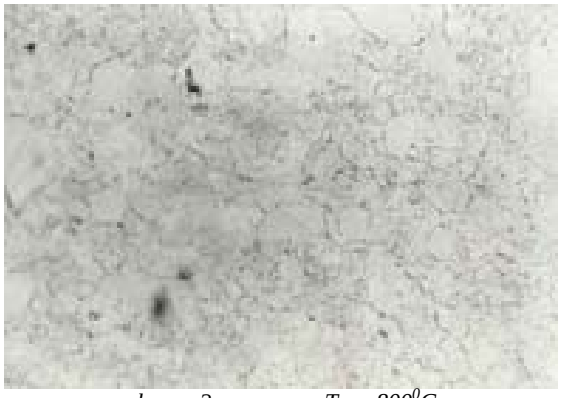
In Table 3 are emphasized the results obtained the aspect of the austenite grain size in the initial deformation state is presented in Fig. 2. One can observe that the austenite grain increases as heating temperature increase, within the temperature range from 800^{0}C to 1100^{0}C vanadium particles are partially solubilised. One can observe that, also for the same temperature, for all cases, the heat no. 4 showing a maximum vanadium level within the allowed range has always the lowest grain size compared with the other three heats showing a low vanadium content.

Also many different type of researcher study the structural materials, have made metallographic test on samples was carried out by optical and electron microscopy [7-15].

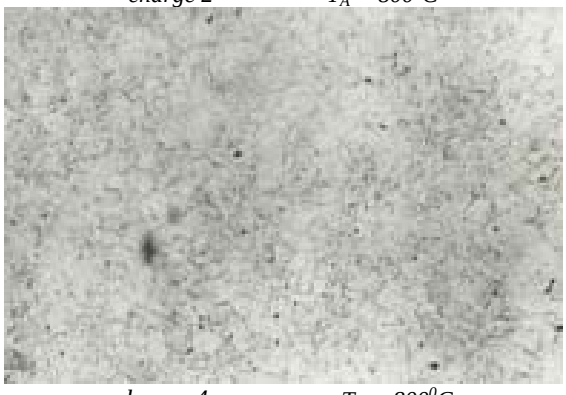
As resulting from these initial differences observed, the aim was to determine the manner in which the initial austenite grain size (at the begging of deformation) influences the deformability characteristics.

Table 3. Initial conventional mean diameter – D –.

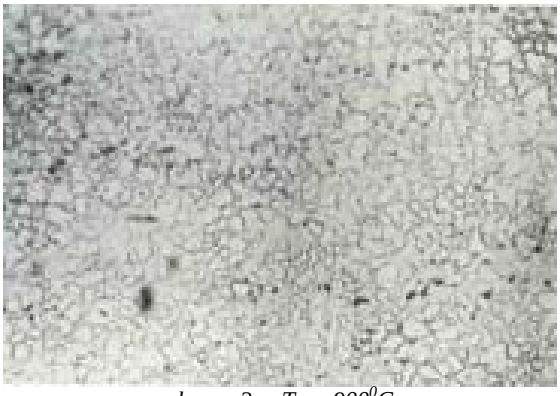
T_A ^{0}C	Heat no.	Grains number					Initial diameter [mm]
		η_1	η_2	η_3	η_4	Σn	
800	1	58	52	558	53	218	0,0044
	2	59	52	54	51	216	0,0044
	3	58	60	52	55	255	0,0043
	4	62	59	68	71	260	0,0037
900	1	19	16	13	17	65	0,0148
	2	17	21	15	16	69	0,0139
	3	16	17	22	12	67	0,0143
	4	19	22	17	20	78	0,0123
1000	1	11	14	13	19	57	0,0421
	2	15	14	12	17	58	0,0414
	3	10	13	18	12	53	0,0453
	4	15	18	19	13	65	0,0369
1100	1	10	7	9	12	38	0,0630
	2	9	11	10	9	39	0,0615
	3	10	9	10	9	38	0,0630
	4	11	9	12	9	41	0,0592



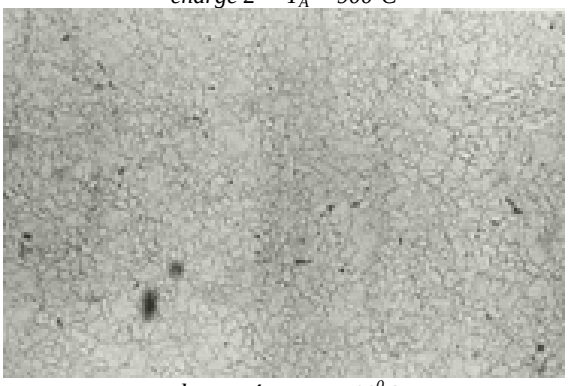
charge 2 $T_A = 800^0C$



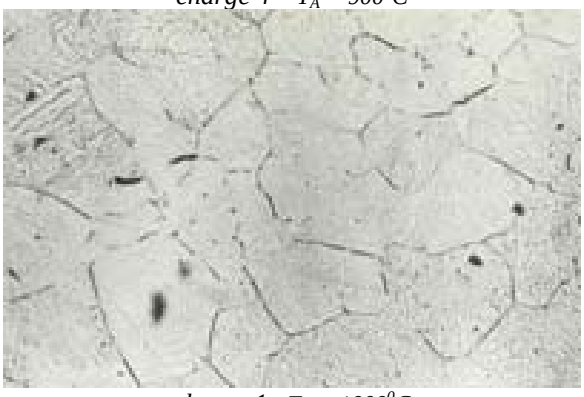
charge 4 $T_A = 800^0C$



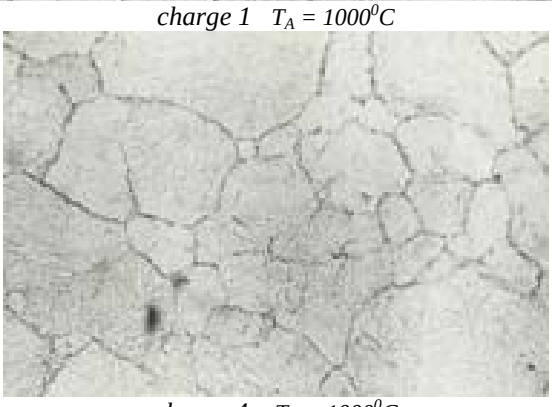
charge 2 $T_A = 900^0C$



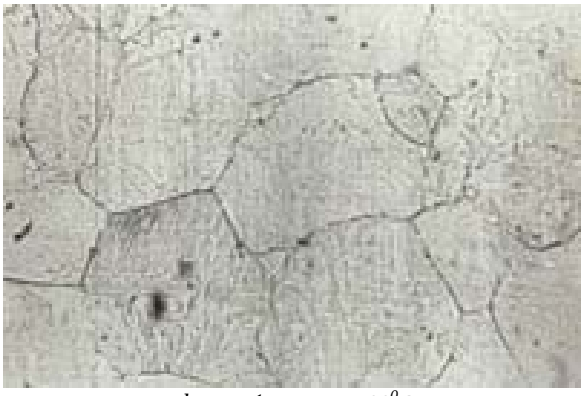
charge 4 $T_A = 900^0C$



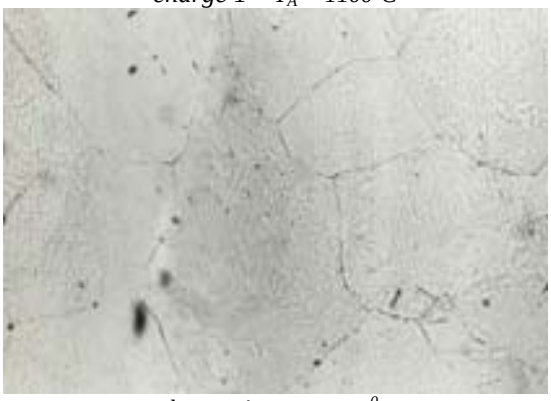
charge 1 $T_A = 1000^0C$



charge 4 $T_A = 1000^0C$



charge 1 $T_A = 1100^0C$



charge 4 $T_A = 1100^0C$

Fig. 2. Austenite grain aspect for different heating temperature a – vanadium 0.12 %, b – vanadium 0,17 %.

Taking into account that the dynamical recrystalization depends also on the existing components inside steel it can represent a mean of studying the kinetics of these products precipitation. That is ε_M is a characteristical parameter of the dynamical recrystalization which is the most easily to determinate. In Fig. 3 we present the ε_M dependence on temperature for four experimental charges coresponding to the rates interval we have studied. We can put into evidence the following main tendencies:

- in most of the cases the values of ε_M increases with the increase of the deformation rate in case of the same temperatures T_0. Charge 2 presents maximal differences between values on the same temperature in the interval 900...1000^{0}C in comparison with Charge 3 with minimal values and the same conditions, which corresponds to the procentual repartition of the sulphur from the composition. (0.011 charge 2 and 0.005 charge 3 respectively)
- the values ε_M decreases with the increase of the temperature at the same deformation rate, most obviously for all charge incase of a rate of 0.01 s^{-1}.

For the other two rates (0.05 and 0.10 s^{-1}) in case of the charge with high percentage of sulfur (0.014 charge 1 and 0.011 charge 2) we notice between 900-1000^{0}C a delay of the dynamical recrystalisation because of starting and ending of vanadium, nitrate, precipitation.

The samples which have been testing at 1200^0C present an enhanced increase of ε_M value, the last change putting into evidence by its value (1.26) an increase by about 50 % greater than in case of the first charge (0.53 – 0.58 and 0.68 respectively), the influence of the maximal vanadium percentage (0.17 – against 0.12 .... 0.13).

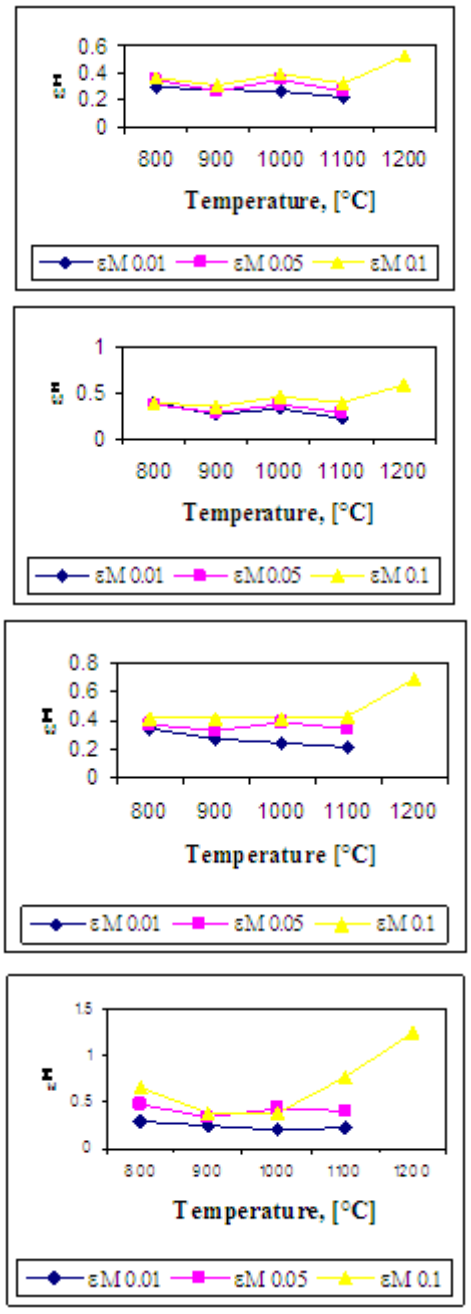


Fig. 3. Dependence ε_M-T obtained by hot torsion testing for four experimental charge (0.01 s^{-1}, 0.05s^{-1}, 0.10s^{-1}).

In Fig. 4 we express the plasticity in function of temperature for three deformation rates.

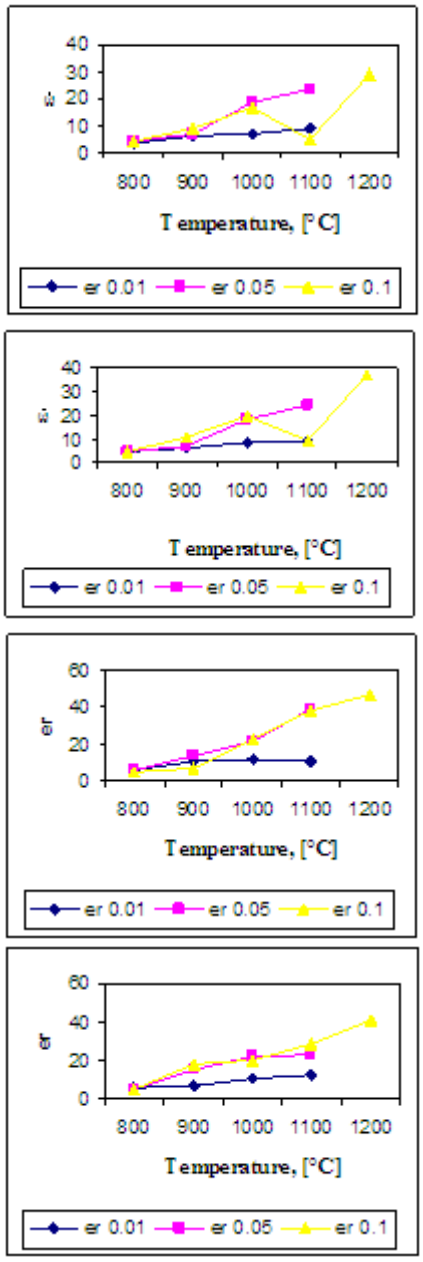


Fig. 4. Dependence the plasticity in function of temperature for three deformation rates.

4. Conclusions

The austenite grain size for the heat distorsion point when the vanadium content increases, is always smaller under the same heat temperature conditions up to 1100^0C; vanadium is a grain finisher for the ratio, which remained undissolved under theat temperature conditions.

The deformability of some steel 31 VMn 12 charge has been studied by direct warning at the initial temperature of the testing lying in the interval 800...1200^0C, these charge being twisted at deformation rates between 10^{-2} and 10^{-1} s^{-1}.

For all the samples we have processed the recorded quantities and we equated them to values of tension and deformation specific to the hot torsion testing:
- dynamic characteristic parameter recrystalisation ε_M has a tendency of increasing with the increase of ε and a decreasing tendency with the increase of T_0
- plasticity expressed by ε_r has a tendency of increasing with an increase of ε; as concerning the T_0 dependence, it is an increasing one in the interval 800-1000^{0}C, followed then by a decrease between 1000-1100^{0}C.

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References

[1] S. Badea, S. Draghici, Deformability of metallic materials, 1994.
[2] D. N. Crowther, B. Mintz, Material Science and Technology, **7**, 671 (1986).
[3] D. N. Crowther, Z. Mohamed, Transactions ISIJ, **5**, 366 (1987).
[4] C. Ouchi, T. Okita, Transactions ISIJ **10**, 906 (1986).
[5] H. Yada, N. Matsuzu, Transactions ISIJ **10**, 100 (1986).
[6] J. Adamczyk, R. Wusatowski, Steel Research, **7**, 305 (1995).
[7] Elena Valentina Stoian, Revista Metalurgia Internațional, **XV**(8), 54 (2010).
[8] I. N. Popescu, V. Bratu, M. C. Enescu, Statistica AEE '10 Proceedings of the 9th WSEAS, International Conference on Applications of Electrical Engineering, Recent Advances in Electrical Engineering, 225 (2010).
[9] Marijan Golja, Franc Vodopivec, Ilija Mamuzić, Materiali in Tehnologije **38**(3–4), 131 (2004).
[10] V. Tsakiris, W. Kappel, G. Alecu, J. Optoelectron. Adv. Mater. **13**(9) 1176 (2011).
[11] Ghita Constantin; Pop Nicolae; Popescu Ileana Nicoleta - Existence result of an effective stress for an isotropic visco-plastic composite; 21st International Workshop on Computational Mechanics of Materials (IWCMM); Aug 22-24,2011;Volume: 64, Pages: 52-56 DOI: 10.1016/j.commatsci.2012.03.058 Published: Nov 2012
[12] A. Veteleanu, Metalurgia International, **XVII**(4), 115 (2012).
[13] I. N. Popescu, S. Zamfir, F. V. Anghelina Advanced Manufacturing Engineering, Quality and Production Systems, Electrical and Computer Engineering Series, (2010), 230-234.
[14] D. Stoica, G. Stanciu - Digest Journal of Nanomaterials and Biostructures **8**(2), 513 (2013).
[15] Constantin Ghita, Ileana Nicoleta Popescu, Computational Material Science, **64**, 136 (2012).

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