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STUDY OF THE THERMOMECHANICAL TREATMENT POST-DEFORMATION MAINTAINING TIME INFLUENCE ON THE MECHANICAL CHARACTERISTICS OF THE MICROALLOYED STEELS

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ABSTRACT

This paper-work shows the results of the laboratory researches of the post-deformation maintaining time influence on the physical-mechanical characteristics of the flat microalloyed steels, at high temperature thermomechanical treatments. The experiments have been made on the equipments of the Plastic Deformation and Thermal Treatments Laboratory from Faculty of Metallurgy and Materials Science using X60 steel – grade test specimen made at Mittal Steel Galati. The results of the laboratory experiments illustrated the importance of this technological parameter, which, together with temperature and deformation degree, decisively influences the structure and mechanical characteristics with a certain chemical composition of steel.

KEYWORDS: plastic deformation, thermomechanical treatment, post-deformation maintaining time.

1. Theoretical considerations

Combining the plastic deformation with thermal treatments is the most efficient way to put into operation all hardening mechanisms of steels (as hot or cold deformable ferro-alloys) this combination is the thermomechanical treatment essence.

The main part of the plastic deformation is due to the fact that, in this direct way, the crystallinity imperfections are created and, more than that, a certain oriented distribution of them is assured, which can be determinate by the used deformation diagram.

For a maximum hardening target, the light sliding plans of the structure are oriented to the external tangential tension direction, so that the metallic material plasticity is suddenly increased, even in hardened conditions.

To get to this basic target, the best way of the plastic deformation, the most efficient deformation degree, the best combination diagram of the thermal treatment with plastic deformation should be chosen and to correct, in an adequate way, the thermal treatment condition. When the deformation is made on the austenite at higher temperature than its simple recrystallization temperature, the thermo mechanical treatment is considered of high temperature (TTMTI) (HTTMT)

High temperature thermo mechanical treatment (TTMTI) consists in an initial hot plastic deformation of the stable austenite and finally, under cooling and processing of the deformated austenite into martensite, pearlite or bainite. HTTMT I) results depend mainly on austenite condition during hot plastic deformation. The process of the hot plastic deformation could be controlled and analyzed by strain-deformation curve on which could be seen those four stages characteristics of the workable hardening (fig.1). The first stage is corresponding to a week hardening by free and easy sliding of the grain dislocation and rotation. The second stage is characterized by an increased hardening, practically linear, determined by the multiple and broken dislocations, setting up obstacles in their movement (Cotrell-Lomer barriers, immobile steps in dislocations, dislocation agglomeration) the multiplication of the dislocation (the activation of the Frank-Read sources by the increase of the applied pressure). The dislocation density increases.

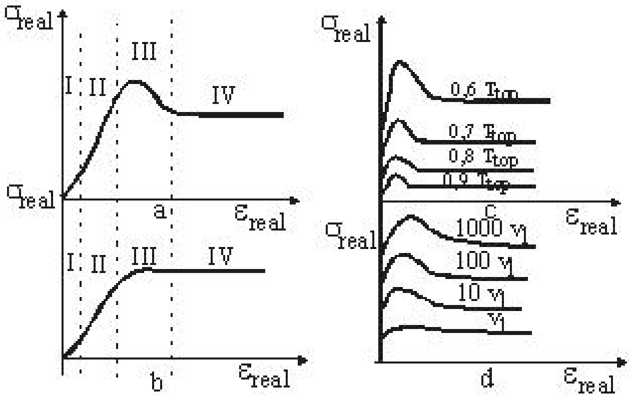

***Fig.1**. Deformation curve of the hot plastic deformation with hardening peak (point a) and without peak (b) and deformation temperature influence (c) and deformation speed (d) on the hardening curves.*

The third stage is characterized by a slow down parabolic hardening determined by a plastic deformation and softening by the restoring and dynamic polygonizing. In this stage, up to the hardening peak, a polygonizing substructure is formed, with elongated subgrains, where a great density of free dislocations exists, unfixed in sub limits. After outrunning of the hardening maximum to the end of the third stage, the substructure is stable, polygonizing (getting a dynamic equilibrium condition) and subgrains become equiaxis, with more reduced density of the free dislocations. The second stage appears up to ε = 7…10%, when the hardening is increased and the third stage covers the deformation field from ε = 7…10% up to ε_{max}. The fourth stage, established, is specific to hot plastic deformation. It is characterized by the deformation temperature and speed, i.e.: $T_{def} > 0,5\ T_{top}$ and $\varepsilon > 10^{-4}\ s^{-1}$. In this stage, those two processes are balanced, softening determined by the restoring or dynamic recrystalization and hardening due to plastic deformation.

The development way of each of the mentioned stages depending on the internal parameters, material (chemical composition, atoms movability, energy of the packing defects) and external, technological parameters (deformation and temperature degree, post-deformation maintaining time, deformation speed).

Thus, according to the manufacturing conditions where the hot deformation is made, the metallic material might be in many various structural conditions, which go from the (hot) hardening condition up to that of static recrystalization (refining). This could be then fixed by quick later-on cooling, influencing the development of the subsequent transformation, final structure and metallic material characteristics.

Post-deformation maintaining time is a parameter for thermo mechanical treatment. The higher its value, the more favored are its polygonization and static recrystalization in detriment to the hot hardening structure, particularly the ratio of polygonized volume and hardened volume increases, though the volume of the polygonized austenite might increase or decrease according to the recrystalization process. Simultaneously, the density of dislocation in hardened and polygonized volumes decreases, as well as the global density (volume) of dislocations (which reaches values of $1,2\ .10^9 – 2\ .10^9\ cm^{-2}$).

Experimental conditions

For experiments, test specimen of X60 steel grade has been used having chemical composition and mechanical characteristics mentioned in **Table no.1**, and size of 5x10x70 mm.

***Table 1** Chemical composition and mechanical characteristics of test specimen X60 steel grade*

C	**Mn**	**Si**	**V**	**Al**	**Nb**	**Ti**	**Rm**	**$Rp_{0,2}$**	**A**
[%]							[MPa]		**[%]**
0,09… 0,12	1,30… 1,60	0,17… 0,30	0,03… 0,08	0,015… 0,05	0,03… 0,05	max. 0,02	min 413	min 331	min. 22

Test specimen heating was made in the electrical furnace with sillite bars, at 900°C temperature of all experimented ranges. The maintaining time in the furnace, calculated according to the specimen thickness, was 15 minutes for all conditions.

The rolling was made in the laboratory rolling mill with rolls diameter D = 129mm.

More thermo mechanical treatment conditions have been experimented, such as:

- one pass rolling with deformation degree ε_1 = 15%; ε_2 = 30%

- air still maintaining time after deformation 5, 10, 20, 40 seconds, and then water cooling. The first test specimen has been cooled directly in water (maintaining time: 0 seconds) without air maintaining, and the last one was cooled in air only.

Experiments results

a) The first series of the test specimen has been rolled with ε_1=15%. After thermo mechanical treatment, the test specimen has been processed and then submitted to the mechanical tests. The results are mentioned in **Table 2** and diagrams fig.2.

Table 2. *Mechanical characteristics of the test specimen rolled with ε_1= 15%*

Test specimen number	**Post-deformation maintaining time**	**Mechanical characteristics**			
ε_1 = 15%	(seconds)	**Rm**	**Rc**	**A**	**Hardness**
		[MPa]		[%]	[HB]
1	0	775	630	19	286
2	5	760	622	20	268
3	10	703	590	21	255
4	20	678	599	22	252
5	40	671	555	23	250
6	60	576	432	33	190

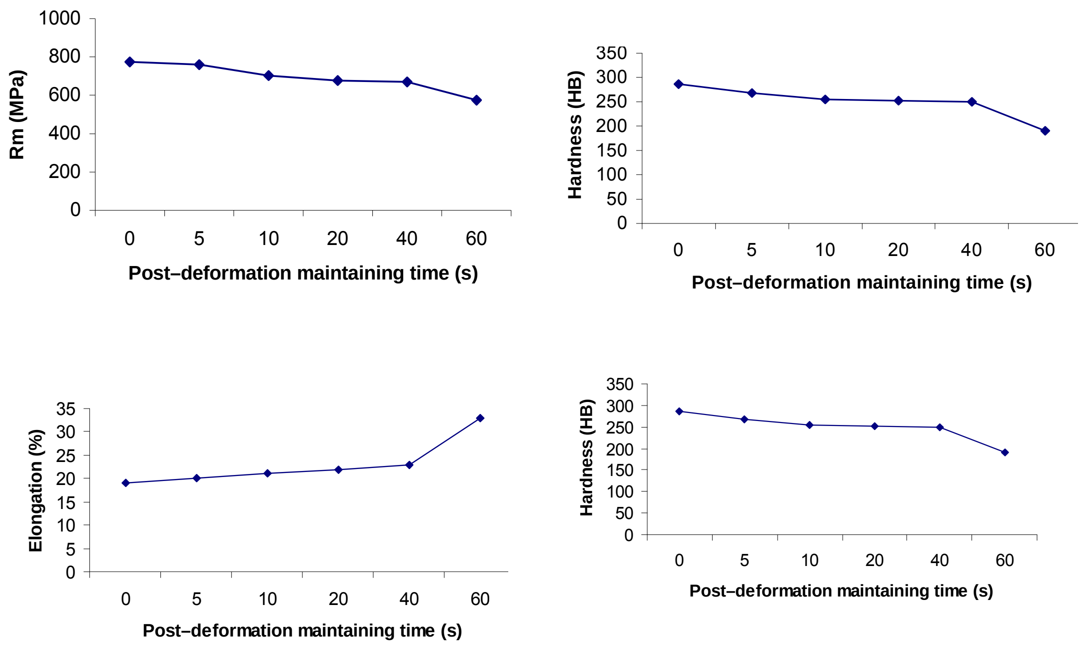

Fig.2 *The influence of the post-deformation maintaining on the test specimen mechanical characteristics rolled with ε_1= 15%.*

b) The second series of the test specimen has been rolled with ε_2= 30%. After thermo mechanical treatment conditions, the mechanical characteristics have been determined. The results are mentioned in Table 3, and diagrams fig.3

***Table 3**. Mechanical characteristics of the test specimen rolled with ε_2= 30%*

Test specimen number	**Post-deformation maintaining time**	**Mechanical characteristics**			
ε_1 = 30%	(seconds)	**Rm**	**Rc**	**A**	**Hardness**
		[MPa]		[%]	[HB]
7	10	726	619	23	261
8	20	686	514	27	230
9	40	637	487	29	225
10	60	580	423	30	193

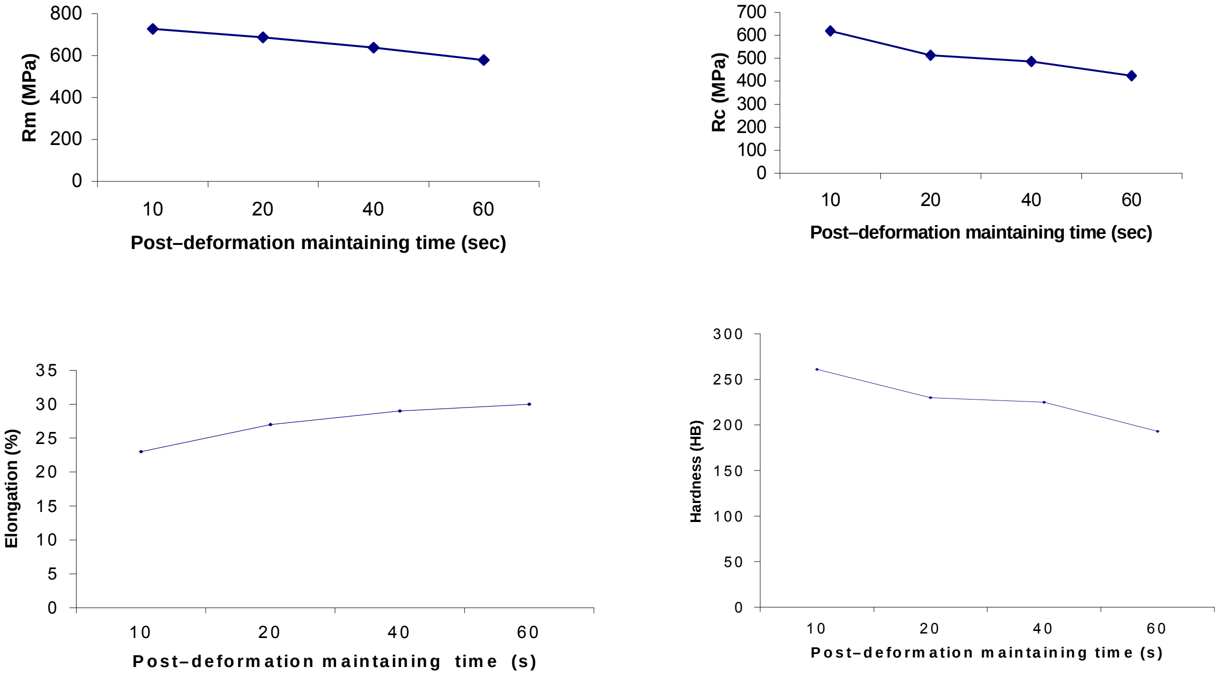

***Fig.3** The influence of the post-deformation maintaining time on the test specimen mechanical characteristics rolled with **ε_2**= 30%.*

Table 4 show the mechanical characteristics values comparatively, R_m and R_c, to the post-deformation maintaining time for the two test specimen groups (rolled with ε_1 = 15% and ε_2 = 30%).

***Table 4** .Mechanical characteristics of the test specimen rolled with ε_1= 15% and ε_2= 30%*

Post-deformation maintaining time	**ε_1 = 15%**		**ε_2 =30%**	
	Rm	**Rc**	**Rm**	**Rc**
	[MPa]			
0	775	630		
5	760	622		
10	703	590	726	619
20	678	599	686	514
40	671	555	637	487
air	576	432	580	423

As it could be seen from these experiments, the post-deformation maintaining time influences appreciably the mechanical characteristics of both deformation degrees. Generally, strength characteristics decrease with post-deformation maintaining time increase and elongation increases.

The low values of the maintaining time (0-10 seconds) approach the cooling to the hardening of the plastic deformated austenite. The maintaining time increase determines an increase of the recrystalized austenite volume, even a slight increase of the grains, determining a decrease of the strength characteristics, R_m and R_c, and elongation increase, too (**Tables 2 and 3**). The mechanical characteristics values (R_m and R_c) are comparable for the two deformation degrees, as it can be seen in fig.3, for the same post-deformation maintaining time. As regarding the deformation degree, it is ascertained that for ε_2 = 30%, the elongation values begin to exceed the minimum limit specified by standards, the strength characteristics being kept at high enough values. As usually, for TTMTI it is recommended a deformation degree of 25-30% according to the real possibilities of the equipment used.

Conclusions

In case of thermo mechanical treatments, the post-deformation maintaining time is an important technological parameter because it influences, together with the deformation degree and final rolling temperature, the processing way of the austenite static recrystalization, which, finally, leads to achieving certain mechanical characteristics. This is the reason why, in the rolling mills where these technologies can be applied, the distance between the finishing stand of the mill and the accelerated cooling installation of the heavy plates is extremely important.

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