Proceedings of the International Conference on Manufacturing Systems – ICMaS
Vol. 4, 2009, ISSN 1842-3183
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ADVANCED PROCESSING OF THE X60-X80 HEAVY PLATES FOR PIPELINES APPLICATIONS

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Abstract: *This paper presents only some partial results obtained when applying different regimes of thermo mechanical treatment on weldable steel thick plates of different thicknesses and qualities within experimental researches made at laboratory and industrial scale. The experiments have been made on the equipment of the Plastic Deformation and Thermal Treatments Laboratory from Faculty of Metallurgy and Materials Science using X60, X70, X80 steel – grade test specimen made at Mittal Steel Galati. The results of the laboratory experiments illustrated the importance of the technological parameters: the end deformation temperature, the deformation degree and post deformation maintaining time on the structure and mechanical characteristics. These results are confirmed at large scale by experimental researches in Mittal Steel conditions.*

Key words: *microalloyed steel, heavy plates, thermomechanical treatment, rolling, accelerated cooling.*

1. INTRODUCTION

High-strength heavy plates used in the production of pipes are generally produced by thermomechanical rolling followed by accelerated cooling (TMCP). Combining plastic deformation and thermic treatment- the essence of thermomechanical treatment - products with performant utilization properties are obtained. The following elements are decisive in approaching steel plates manufacturing using the thermomechanical control process: rational using of microalloying elements, high level of purity, diminishing segregation.

The development of high strength steels is show in Fig. 1. In the 70s, the hot rolling and normalizing was replaced by thermomechanical rolling by strict control of continuous casting parameters, control of thermo mechanical rolling parameters (heating temperature of the cast slab, multiple stage rolling, low finish rolling temperature, accelerated cooling).The latter process enables materials up to X70 to be produced from steels that are microalloyed with niobium and vanadium and have a reduced carbon content. An improved processing method, consisting of thermomechanical rolling plus subsequent accelerated cooling, emerged in the 80s.

By this method, it has become possible to produce higher strength materials like X80, having a futher reduced carbon content and thereby excellent field weld ability. Additions of molybdenum, copper and nickel enable the strength level to be raised to that of grade X100, when the steel is processed to plate by thermomechanical rolling plus modified accelerated cooling.

The main stages of the technological process are (Fig. 2): slabs heating (I); reversing mill stand rolling (II); fast cooling after rolling achieved by various procedures (III).

The reduction system/regime on passes is very well correlated with the initial and final rolling temperature and with the cooling regimen and the whole process is controlled on the computer on the basis of a mathematical pattern which follows the main parameters during the there main rolling stages.

Currently, there are several main direction for modernizing the structure of flat products rolling mills based on controlled rolling technology:

- updating and automatization of rolling mill stands;
- introducing the on-line heat treatment;
- ensuring hot rolling smoothness.

In order to attain this objectives, the manufacturing companies (such as: Davy Clecim) have designed new technologies and processing control systems.

In order to control the process, mathematical patterns for adjusting and controlling the technological parameters as well as for adjusting and balancing the mill stands have been used:

- the PLATE model: a self adaptable rolling model with optimizing algorithm; the PLATE model becomes the HYDROPLATE model if a hydraulic adjusting system is added;
- the CLECIM shape control model available for the Hydroplate model;
- the AWC plate shape control model;

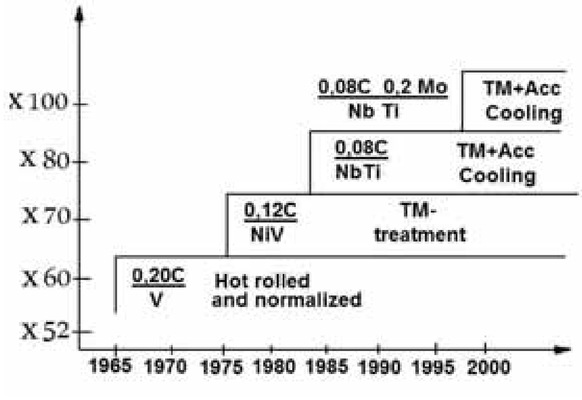


Fig. 1. History in Line Pipe Steels (Large Diameter Pipe).

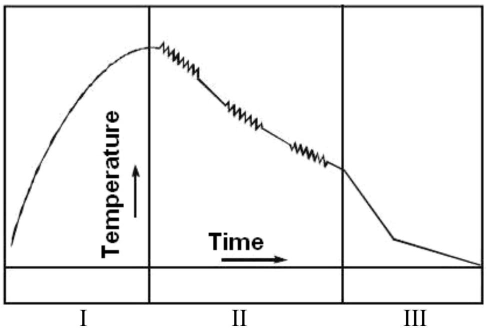


Fig. 2. Variation of slab temperature during thermomechanical treatment processing.

- the ADCO model for controlling the accelerated cooling and direct hardening equipment;
- the PLANE model for smoothness control.

The following were introduced as automation systems for rolling:

- MILL MASTER, which deals with data acquisition, thickness management, positioning, speed adjustment, etc. with the MAN MACHINE interface;
- MILL AUTOMATION COMPUTER including all software models facilities for data management.

Currently, rolling mills perform "compact" technologies (CSP Procedure/ Compact Strip Production) by renouncing a mill stand or a group of mill stands with more efficient equipment, maintaining in all cases the fast cooling installation.

This method is applied to hot strip rolling and consists in continually casting of some semi products 50–60 mm thick which are further rolled on the rolling train obtaining the final band 1−12 mm thick. The final rolling temperature is t_{sf} = 800–900°C. The final operation is cooling up to 450–600 °C. According to the intensity of cooling, a wide range of structures is obtained: ferrite, pearlite, bain.

Starting with 1988, a cooling installation has been working in the thick plate rolling mill Dillinger, which has a length of 30 m, named MULPIC, and disposed in the back of the quarto finishing mill. The system allows achieving high speeds of cooling the plates, from the rolling heat, speeds which can be compared with the ones obtained in a conventional installation for hardening. Due to the power of cooling of the high pressure part, with the Mulpic cooling machine there can be obtained maximum speeds similar to those of the conventional hardening machine.

HSLA plates used for pipes with big diameter, marine drilling platforms, and naval constructions, as well as for plate constructions which have very severe demands regarding the mechanical characteristics (especially the resistance and tenacity) are produced frequently through the process of thermomechanical rolling (TR) combined with *Accelerated Water Cooling* (ACC).

As a result of putting into practice the high pressure cooling, many other procedures of cooling have appeared, like Direct Quenching (DQ) and Quenching and Self tempering (QST), which can be applied for plates with a 12 mm thickness.

The water based cooling systems have been improved along the years by introducing supplementary devices which, beside water, also blow air. The system was named ADCO (Fig. 3) and uses the spraying of water and air which assures a greater flexibility and a larger range of speeds for cooling.

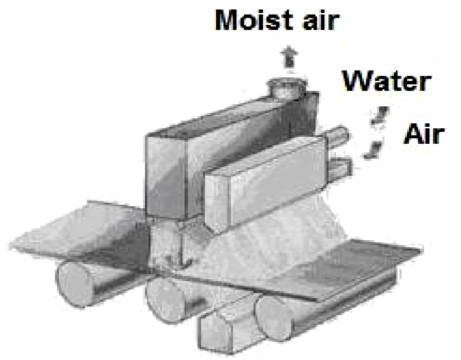


Fig.3. ADCO System.

Steckel Mill Rolling. These types of rolling mills with a greater flexibility use special mill constructions for TTM technology of the thick plates. They are used for rolling plates which have a higher resistance to deformation.

Rolling is reversible and after the last reductions, the strip is cooled in the installation placed behind the mill stand.

2. EXPERIMENTAL CONDITIONS

Plate temperature when entering ACC: 800–760°C ; transportation speed of plate in ACC 1 m/sec, maximum flow rate of the ACC cooling installation: 1250 m^3/h. Flow rate ratio Bot/Top: 1.54; Both at full and laboratory scale using X60 steel grade produced at Arcelor Mittal Steel Galati.

According to API5L/2000 norms, X42–X80 grade steels are used for heavy plates for pipes line with large diameter having the chemical composition and mechanical characteristics mentioned in Tables 1, 2, and 3.

Observation:

b) − niobium, vanadium, titanium or their combination is established according to an agreement between the producer and manufacturer;

c) − niobium, vanadium, titanium or their combination is established by the manufacturer;

d) − the total amount of niobium, vanadium, titanium should not exceed 0.15%.

Table 1

Chemical composition

No.	Grade steel	C max [%]	Mn max [%]	P max [%]	S max [%]	Other elements.
1	B	0.22	1.20	0.025	0.015	b, d
2	X42	0.22	1.30	0.025	0.015	c, d
3	X46, X52, X56	0.22	1.40	0.025	0.015	c, d
4	X60e	0.22	1.40	0.025	0.015	c, d
5	X65e	0.22	1.45	0.025	0.015	c, d
6	X70e	0.22	1.65	0.025	0.015	c, d
7	X80e	0.22	1.85	0.025	0.015	c, d

Table 2

Mechanical Characteristics

No.	Grade	Rm [MPa]		Rc max [MPa]		A5 min [%]
		min	max	min	max	
1	B	414	758	241	448	a
2	X42	414	758	290	496	a
3	X46	434	758	317	524	a
4	X52	455	758	359	531	a
5	X56	490	758	386	544	a
6	X60	517	758	414	565	a
7	X65	531	758	448	600	a
8	X70	565	758	483	621	a
9	X80	621	827	552	690	a

Table 3

Chemical composition [%]

C	Mn	Si	P	S	Al	V	Nb	Ti
0.09–0.12	1.30–1.60	0.17–0.30	max. 0.025	max. 0.007	0.015–0.050	0.030–0.080	0.030–0.050	max. 0.02

3. EXPERIMENTAL RESULTS

a) Full scale. The physical and mechanical characteristics and the microstructural aspects are presented in Tables 4 and 5

b) Laboratory scale. The paper presents the results of the researches at laboratory scale on the structural and mechanical characteristics modifications of microalloyed steel plates for special purposes by thermomechanical treatment. Structural changes as well as change of properties in the experimental variants of thermomechanical treatment have been compared to those revealed by classical treatments (e.g. normalization). Various types of thermomechanical treatment at high temperature were simulated using the following conditions: heating temperature: 800, 850, 900, 950, 1000, 1200 ^{o}C one or two rolling passes; deformation degree (ε): 30%, 50%; cooling in various agents (water, air); postdeformation maintenance (holding) time: 0, 20, 40, 50 seconds then water cooling.

Table 4

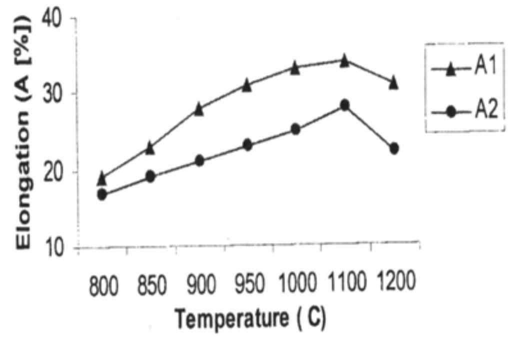
The influence of the end rolling temperature on the mechanical characteristics

No.	End rolling temperature°C (Te.r.)	Mechanical Characteristics		
		Rm [MPa]	Rc [MPa]	A5 [%]
1	770	605	569	41
	780	505	475	42
	800	560	480	44
	810	553	470	41
	820	558	476	45
	830	556	481	43
	840	553	470	40
	850	540	450	42
	860	535	445	42
2	810	571	510	36
	820	574	505	37
	840	560	480	41
	850	550	463	40
3	810	575	503	31
	830	580	505	32
	840	555	480	41
	850	550	465	42

Table 5

The influence of the end rolling temperature on the impact energy KV

Te.r. [°C]	KVmed [J]	
	–20 °C	–40°C
800	65.66	5.9.6
820	67	60
850	54	30.5



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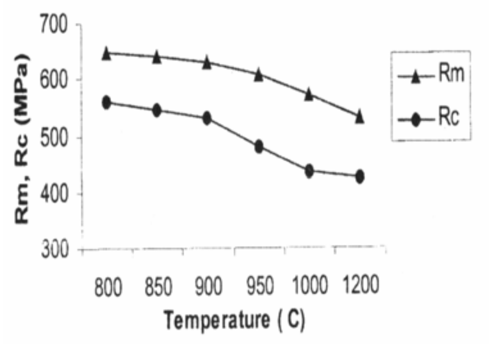

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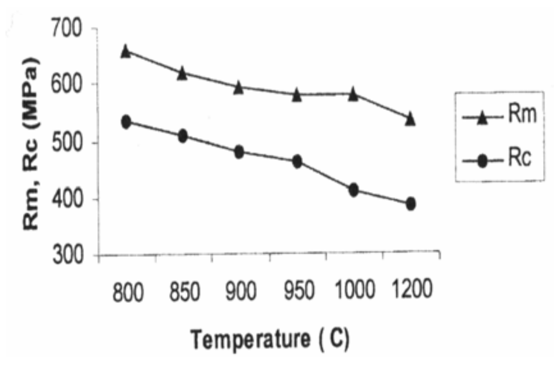

c

Fig.4. Mechanical caracteristics to the temperature and deformation degree:
a) ε=30%; b) ε=50%; c) elongation: A_1-ε=30%; A_2-ε=50%.

From Fig. 5 it can be noted that the structure is ferrite-perlitic, one for all testing temperatures but it has a different aspect. At 800 °C, the fine and slightly deformed grains appear after rolling direction. At 1200 °C, a coarsely structure with uneven grains appear.

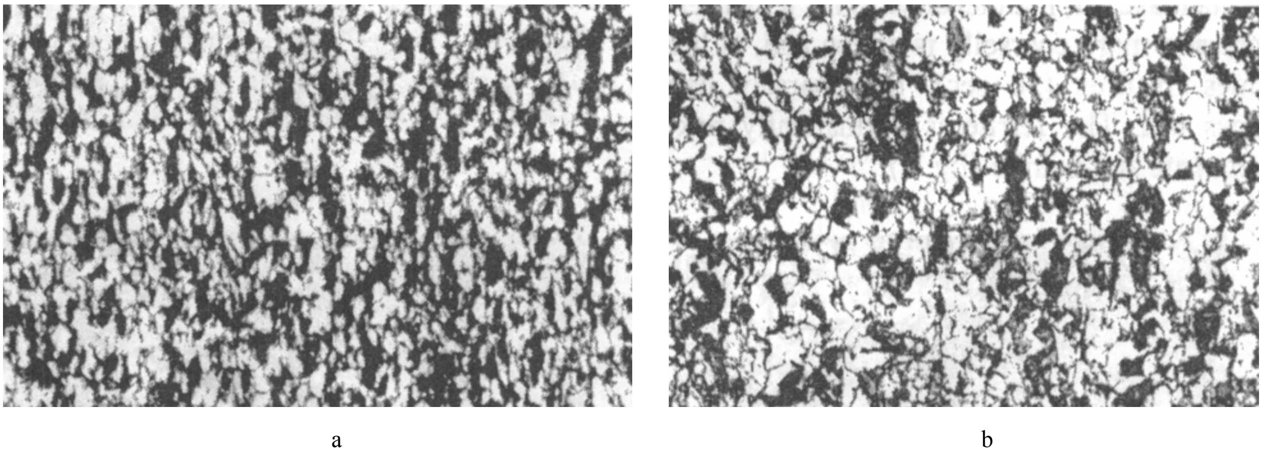

Fig.5. Structures to the rolling temperature:
a) 800°C; b) 1200°C (magnify x250).

The fine austenitic grain also promotes the development of the recrystallization, finally leading to a fine ferrite-perlitic grain and to high values of the mechanical characteristics.

4. CONCLUSIONS

In conclusion:

- The deformation degree influences the mechanical characteristics.
- Quick cooling after rolling highly influences the structure and the mechanical characteristics. If so, the ferrite, pearlite or martensite structure is finer than that in the case of normalizing or classical cooling, thus allowing a great range of proprieties to be obtained depending on cooling parameters and equipment construction on the rolling mill.
- Post-deformation maintenance influences the volume of the recrystallized austenite.
- It is able to mitigate thermomechanical treatment and cooling effects and to determine a very large range of structures and properties.

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