THE ANNALS OF "DUNAREA DE JOS" UNIVERSITY OF GALATI
FASCICLE IX. METALLURGY AND MATERIALS SCIENCE
N^0. 1 – 2014, ISSN 1453 – 083X

EXPERIMENTAL RESEARCH ON HEATING BEHAVIOR OF SOME STEELS DURING HOT METALLURGICAL PROCESSING

Elisabeta VASILESCU
„Dunarea de Jos" University of Galati
e-mail: elisabeta.vasilescu@yahoo.com

ABSTRACT

The heating of steel semi-products in view of hot rolling process or heat treatments is achieved at the large scale in propulsion ovens for the increase of their deformability and to improving mechanical characteristics of finite products.

The main heating defects (oxidation and decarburation, overgrown grain size of steels) represent processes of alteration of the superficial layers or the decrease of the physical and mechanical characteristics of the finished products.

This paper presents the results of experimental researches on the oxidation susceptibility, variation of the depth of the decarburized layer and the susceptibility to overheat of two ship steel grades (A36 and E36 grade), during the heating for the hot metallurgical processing of the semi-products. It is the deepening of the researches about heating behavior of naval steels with different chemical compositions.

KEYWORDS: oxidation susceptibility, decarburized layer, susceptibility to overheat, main defects, ship steel grades, metallurgical processing

1. Introduction

The performance of obtaining products or providing services is ensured through a primordial factor called quality.

Maintaining performance requires continuous quality improvement and quality assurance includes all planned systematic actions necessary to provide adequate confidence that a product or service satisfies the quality requirements [15]. The quality of a steel product is determined primarily by the properties of the material which in turn depend on its nature, (type) characterized by chemical composition and by particular structure. The structure of a metal material can be modified by thermal treatment and / or thermomechanical, so product quality is directly influenced and in the greatest extent through the modification of its properties.

On steel products market quality of a product is defined by identifying the concept with one of the important features of the product, which is obviously superior in comparison to similar products. A rational use of a steel product for a given application is a complex and schematic matter that actually means providing steel grades that meet the maximum strength and durability characteristics under a minimum cost price. Capitalizing fully technological properties of steels contributes to process in optimal conditions the blank to obtain a finished product with optimum features. Defined as material sizes, heat treatment technological characteristics are expressed quantitatively by experimentally determined values, under conventional set, so those sizes to allow the comparison of different metallic materials or of the same metallic material with different structural states (ie values of critical points, critical transformation speed, susceptibility to overheating, susceptibility to deformation and rupture etc.).

Thus, susceptibility to overheating [3, 4] of steels characterizes kinetics of crystal growth of austenite formed by heating slowly to a temperature in the range of its stability. The size of the crystals formed in the austenite steels with different chemical compositions or with similar chemical composition but from different batches, depends in different ways on the temperature and duration of heating for the austenitising. Therefore, to characterize a steel overheating susceptibility we should determine the grain size of austenite formed, in heating conditions (temperature and holding time) set in a conventional manner, for different groups of steel.

Characterization of the behavior of a metallic material in the chemical interaction with the environment where the heating and cooling are made for a certain type of hot metallurgical processing (plastic deformation, heat treatment) is done using thermodynamic characteristics that define the chemical affinity of metallic material to the components of the environmental [3]. For this purpose, there are used the appropriate thermodynamic characteristics as the oxygen potential of the metal oxide, the activity of carbon, nitrogen activity, etc., whose values depend on the chemical composition and temperature of the metallic material. Using the values of the chemical characteristics of metallic materials can be selected, chemical compositions of the media heating / cooling, which at the temperature that the metallurgical process in being performed exerts on the superficial layers of metallic materials products, chemical actions corresponding prescriptions. Given these theoretical considerations, this paper aims to highlight the results of laboratory scale investigations on the susceptibility to oxidation and susceptibility to overheating of naval steels during heating of the products for to increase their deformability and the heat treatment applied.

2. Materials and experimental conditions

Heating steel semi-products to hot rolling furnaces powered (Specific conditions of the steel Plant in Galati) aims to reduce rolling resistance to deformation or heat treatment (normalization, improvement) requiredby the standard product.

The main heating defects (oxidation and decarburization of steels) are processes that destroy superficial layers of heated material that leading to significant increases of the fuel consumption and lower of the furnace productivity (increased consumption of steel). Overcoming decarburized layer thickness over a certain value means discarding the material. The steel surface is oxidized more intense as the temperature and duration of heating are higher. Also if slabs have lower temperatures than those required by technological they return for a new heating. In this situation there is an increase in fuel consumption per ton of steel [14].

Using a suitable heating technologies of the slabs for rolling,, contributes substantially to the reducing of energy consumption.

The rolling can be achieved with higher values of passage reductions, the wear of subassemblies being entered in the normal range.

By maintaining a constant temperature during treatment are avoided rejects and technological limitations that arise from overheating or over maintaining, thus reducing losses by oxidation and respecting the scheduled quality of the treated product.

In shipbuilding, the highest amount of material is in the hull. The hull is made of sheets, strips, rods and profiles with thickness of maximum 50 mm, hot rolled weldable steels. In general, steel tables for constructions in transportation industry (marine, rail, land, etc.) can be obtained from the manufacturing flow of heavy plate mill No. 1 or No. 2 of the plant from Galati.

As mentioned, this paper is a development of previous experimental research [14] on the behavior at heating of the steel plate products for ships. It is planned to study the heating behavior of semi-finished steel, fine grained E36 in comparison with steel grade A36 (table 1). The author wished to study especially the heating behavior of flat steel products E36 given the results of the author's previous research, which demonstrated the possibility of performing the specific heat treatment (normalizing, annealing, etc.) with heating at lower temperatures (termical treatment with heating in the intercritical range of steel), with the important advantage of reducing susceptibility to oxidation and overheating.

Generally, constructions and naval parts are subject to the rules and specifications RNR or International Ship Register. The standard 8326-86 covers hot rolled steel sheets, with thickness between 4 mm and 60 mm used in welded naval constructions, primarily for bearing structure elements of river and sea vessels of different dimensions: small, medium and heavy sizes which are manufactured in accordance with the Romanian Naval Register. Under this standard, the tables for shipbuilding are classified into: normal strength steel sheets with minimum yield strength value of 235 N/mm^2 and high strength sheet steel with minimum yield strength value of 315 N/mm^2. The table below shows the chemical composition of steel samples under study.

***Table 1**. Chemical composition of the steels studied*

Steel Grade	Chemical composition (%)										
	C	Mn	Si	S	P	Cr	Ni	Mo	Al	Cu	Nb	V/Ti
E36	0.15	1.40	0.30	0.020	0.018	-	-	-	0.043	-	-	-
A36	0.17	1.45	0.27	0.017	0.029	-	-	-	0.033	-	0.031	0.021

Rectangular samples with dimensions of 10x10x50mm were machined and then metallographically prepared until mirror gloss. After degreasing in alcohol the samples were kept in desiccator for weighing.

Fig. 1. *Machined samples*

Experiments were performed in the laboratory in electric furnaces with forced bars.

The samples were heated at temperatures: 900°C, 1000° C, 1100° C, 1200° C with holding times of: 1 hour, 2 hours, 3 hours, 5 hours, 8 hours, in the oxidation atmosphere of the furnace.

Placing in the oven was made on a special holder that allowed exposure to the oxidant environment of all sample surfaces.

After oxidation the samples were subjected to mechanical removal of the corrosion products and were reweighted. Losses of weight were determined at oxidation temperatures and durations of maintenance experienced. The oxidation rate was also determined on each sample according to the experimental thermic regime (working temperature and holding time). In order to study the structural changes, the samples were cut. Sectional area of 10x10 mm size was metallographic prepared.

The microstructure was revealed by chemical attack: 2% nital and X100 magnification.

It has been measured the depth of the decarburized layer and it was determined the granulation score of the microstructure and Widmannstatten structure, by comparing with the standard images.

Next we proceeded to the processing of the experimental data. To facilitate interpretation and to elucidate the behavior at heating of the two brands of steel, graphs were plotted which easily illustrate the objective of the experiments.

3. Experimental results

Table 2*. The loss of mass from the oxidation of steel samples depending on the heating regime*

Heating temperature	Holding time	Average mass loss A 36	Average mass loss E 36
[^{0}C]	[h]	[g/m^2]	
900	1	4.68	30.45
	3	22.08	34.46
	5	23.37	32.44
	8	-	29.50
	3	-	100.07
1000	1	25.45	32.99
	3	48.51	94.48
	5	69.93	80.35
1100	1	29.44	97.47
	3	69.31	94.16
	5	73.20	194.31
1200	1	-	61.70

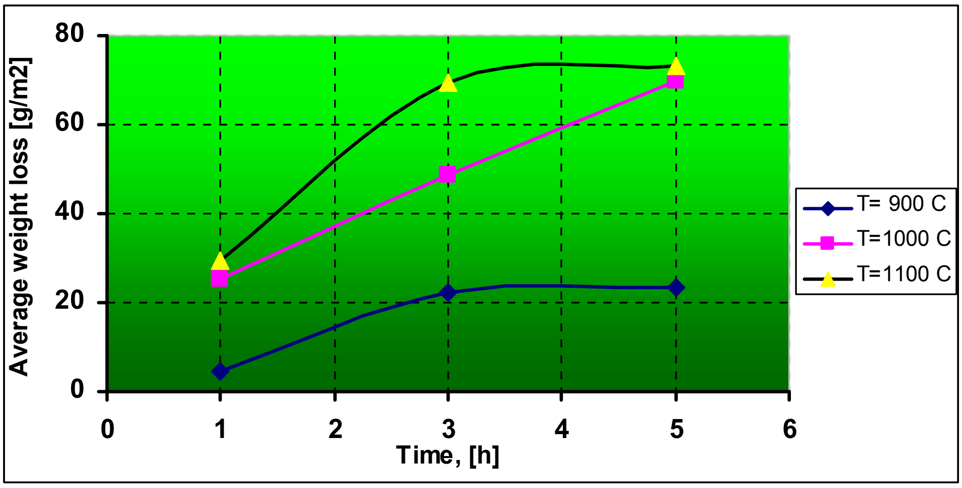

Fig. 2*. Mass losses at the oxidation of grade A36*

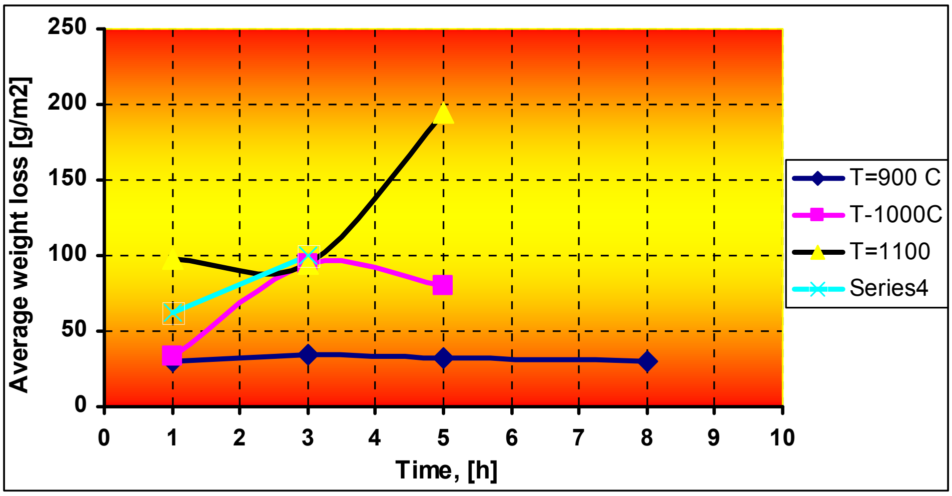

Fig. 3*. Mass losses at the oxidation of grade E36*

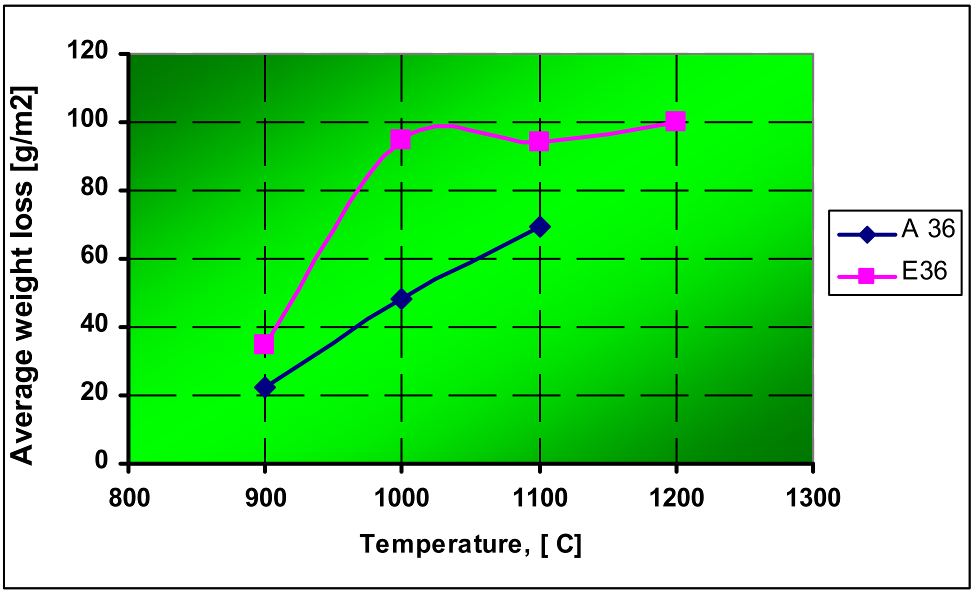

Fig. 4*. Variation of mass losses with the temperature, on 3 hour duration, at grades A36 and E36*

***Table 3**. The speed of oxidation of the steel samples according to the heating regime*

Heating temperature	Holding time	Average speed of oxidation A 36	Average speed of oxidation E 36
[^{0}C]	[h]	[g/m^{2}h]	
900	1	4.68	15.23
	3	7.36	11.55
	5	4.67	6.49
	8	-	3.69
1000	1	25.45	32.99
	3	16.17	31.49
	5	13.99	16.07
1100	1	29.44	97.47
	3	23.10	47.08
	5	-	38.86
1200	1		61.70
	3		33.36

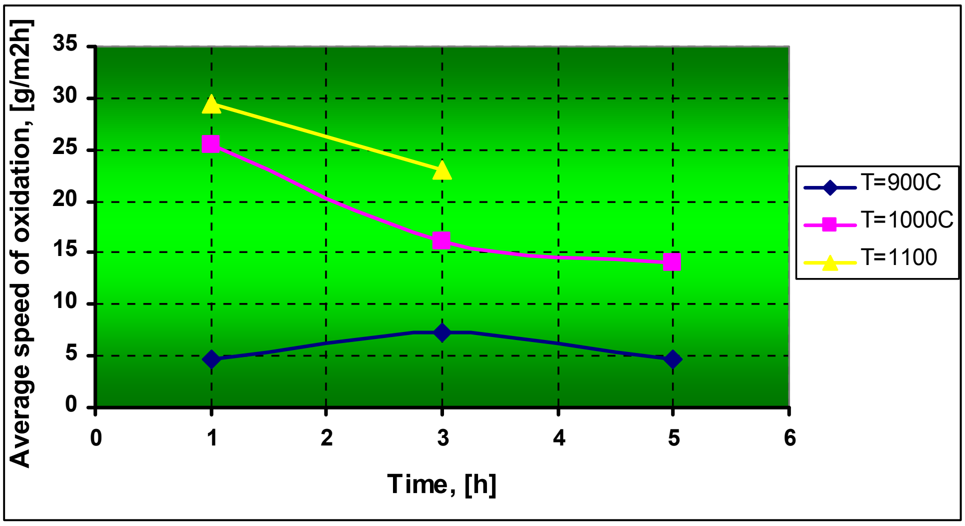

***Fig. 5.** Average speed of oxidation of the A36 steel samples according to the heating regime*

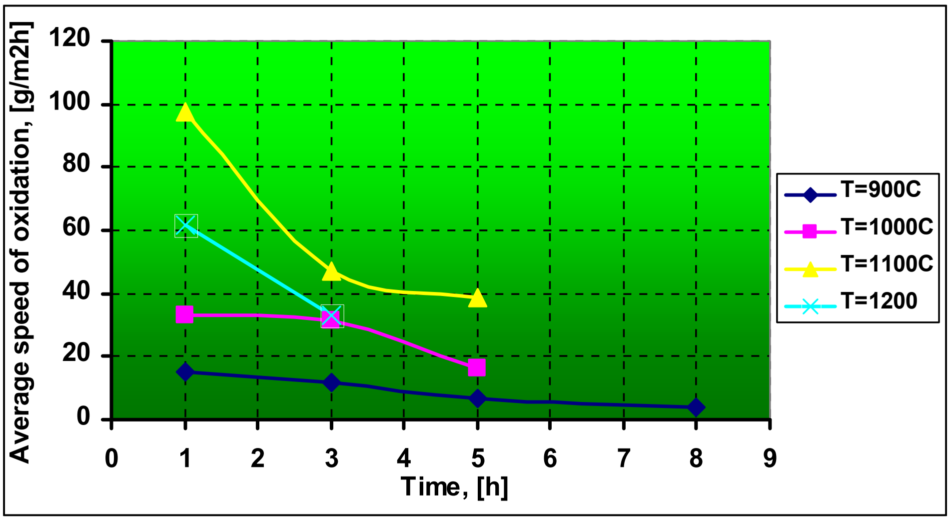

***Fig. 6.** Average speed of oxidation of the E36 steel samples* according to the heating regime

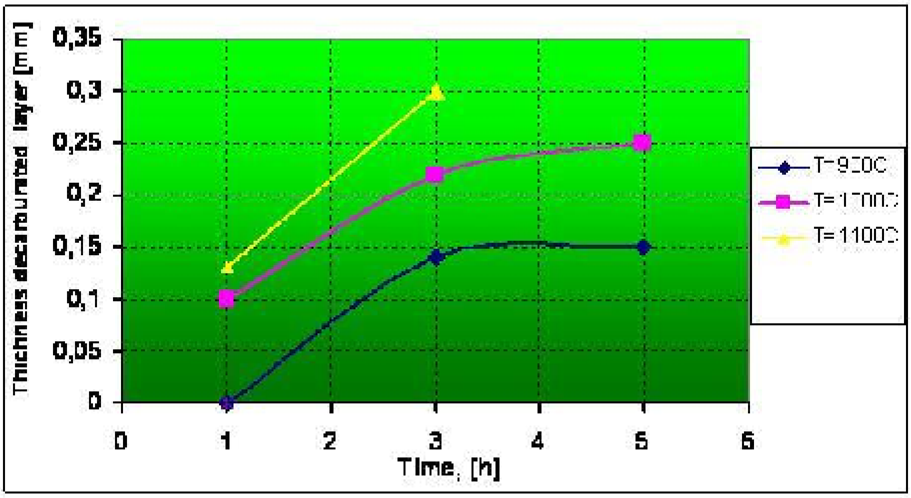

Fig. 7. *Variation of the depth of the decarburized layer with the maintenance duration and heating temperature for the grade A36*

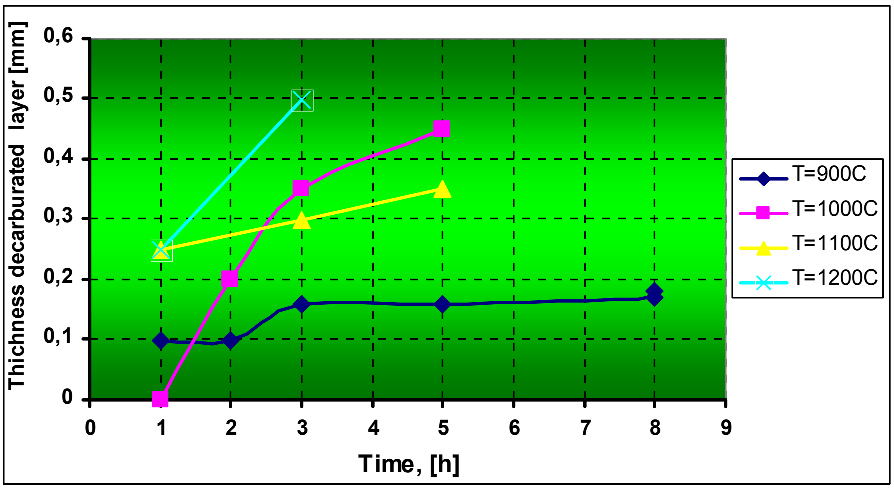

Fig. 8. *Variation of the depth of the decarburized layer with the maintenance duration and heating temperature for the grade E36*

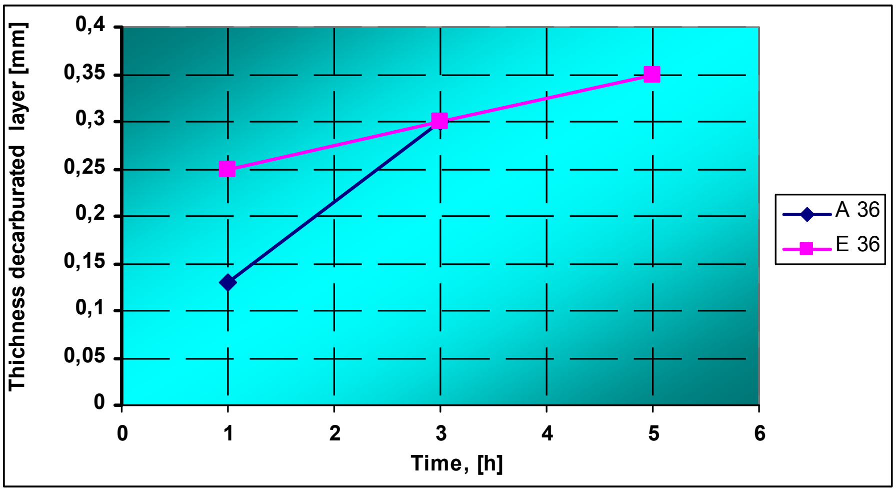

Fig. 9. *Variation of the depth of the decarburized layer with the maintenance duration at 1100°C for the grades A36 and E36*

Below there is presented the graphic variation of the depth of decarburization measured on the studied steel samples according to the experimental heating regime.

The microscopical aspects on the structural changes of the heated steel samples taken from shipbuilding plates

Steels analyzed and presented in Table 1 are additionally deoxidized with aluminum and present a medium to fine granulation.

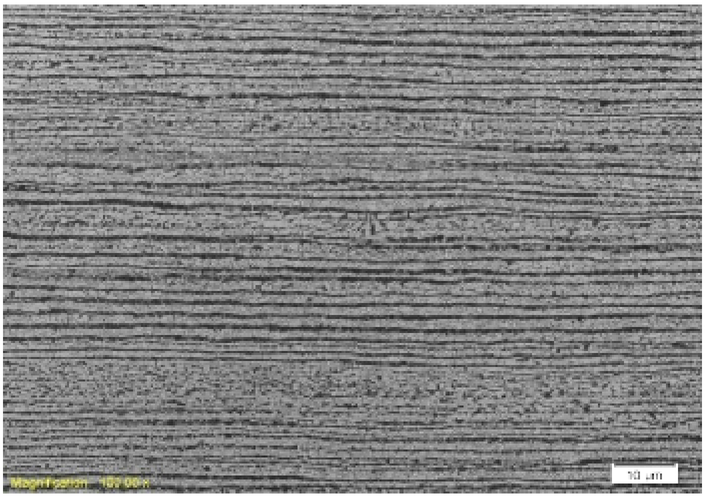

***Fig. 10**. Rolled State (X100, natal 3%), sample from shipbuilding steel A36, thickness 16 mm, ferrite and pearlite grains scoring 8-9, forming alternative rows score 4*

To observe the growing trend of austenitic grain together with increasing temperature and duration of maintenance, in the laboratory it was simulated the hot metallurgical processing through performing the heating of the samples at different temperatures and durations. The results for the A 36 steel highlight the growth of the austenitic grain for the next thermic regimes experimented: temperature of 880°C and 930°C and maintaing time of 2, 3, and 5min/mm.

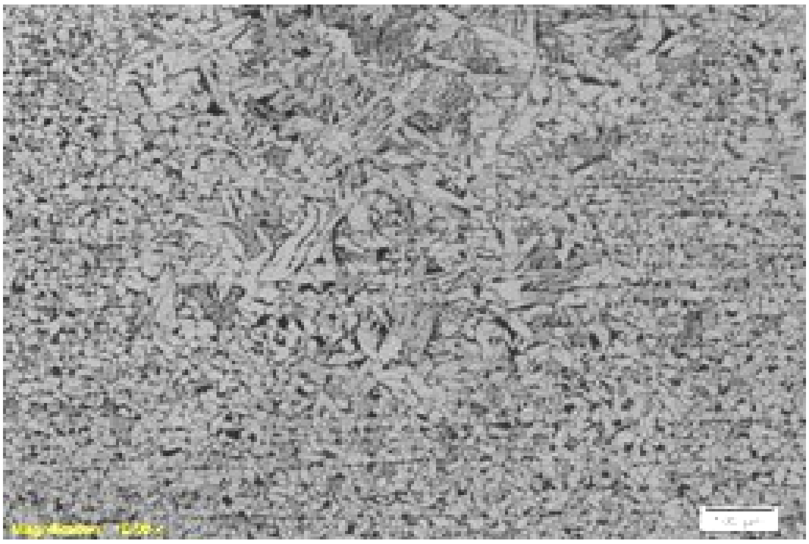

***Fig. 11.** Wd structure score 3-4, A36 samples subjected to heating regime: temperature 880°C / 3.0 min / mm holding time*

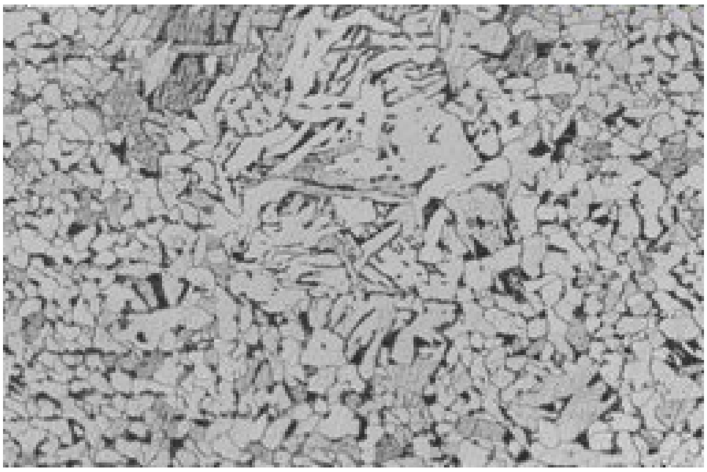

Fig. 12. *Wd structure score 3-4 A36 samples subjected to heating regime: temperature 930°C / 3.0 min / mm holding time*

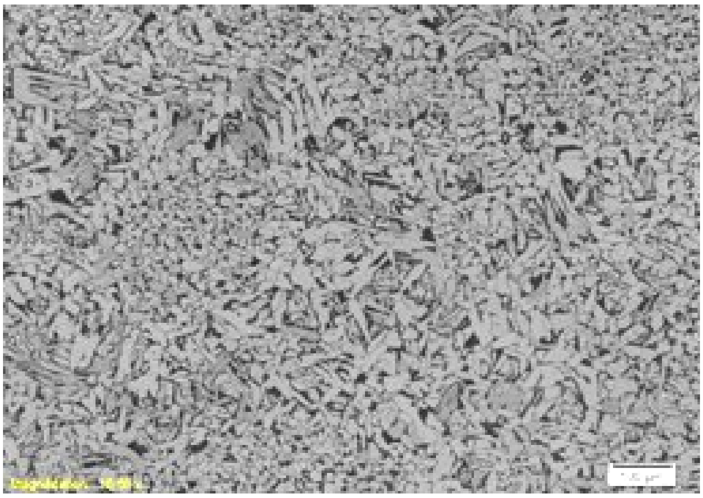

Fig. 13. *Wd structure score 4 A36 samples subjected to heating regime: temperature 880°C / 5.0 min / mm holding time*

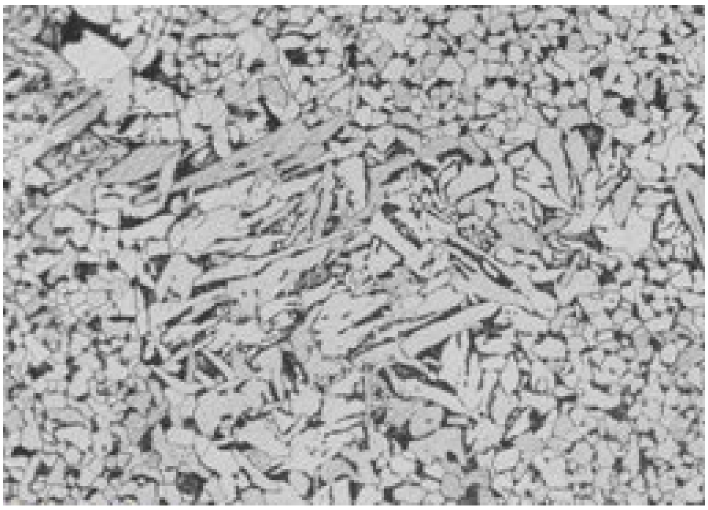

Fig. 14. *Wd structure score 4 A36 samples subjected to heating regime: temperature 930°C / 5.0 min / mm holding time*

4. Conclusions

The analysis of the oxidized samples revealed the presence of a porous oxide layer that detaches easily from the surface by rubbing, and a bright appearance coating, adhering to the surface, which is removed only by hot etching. The weight loss by oxidation / unit area, due to the formation of porous oxide, non-stick, it is negligible at 900˚C and increases with the temperature in the range of 900-1100˚C, for both steel grades studied. At a temperature of 1200˚C, the weight loss recorded for quality E36 is lower than at the temperature of 1100˚C, fact explained by the formation of adhesive oxide in larger quantities.

Of the two steel grades considered, at least in the temperature range 900-1100˚C, the oxidation process was more intense at E36 brand. The speed of oxidation increases with increasing temperature, higher in the first stage of oxidation, for 1 hour, and then decreases with the lasting period, being maximum at temperature of 1100˚C. Oxidation rate is also higher for steel E36. The depth of the decarburized layer increases with higher temperature (as a result of increased diffusion processes) and is less influenced by the duration of maintaining the temperature at 900°C. The influence of the maintenance period on the decarburization process is accentuated when the temperature rises.

Quality steel E36 exhibited higher decarburization tendency compared with to that of A36 steel, a conclusion that allows the adoption of appropriate technological solutions to hot metallurgical processing of products belonging to this quality of steel.

References

[1]. Adrian M. - *Tehnologia laminării*, Editura Didactică şi pedagogică, Bucureşti 1977.

[2]. Cheşa, I., Laşcu, N.S., Nedelcu, C., Rizescu, C., Teodorescu, M. - *Alegerea şi utilizarea oţelurilor*, Editura Tehnică Bucureşti 1984.

[3]. Dulămiţă T., Florian E. - *Tratamente termice si termochimice*, EDP Bucureşti 1982.

[4]. Gadea S., Petrescu M. - *Metalurgie fizica şi studiul metalelor, vol I; II; III*, Editura Didactică şi pedagogică, Bucureşti, 1979; 1981; 1983.

[5]. Geru, N. - *Metalurgie fizică*, Editura Didactică şi Pedagogică, Bucureşti, 1982.

[6]. Gheorghiu-Dobre, A., Nocivin, A - *Introducere in Stiinta Materialelor*, Editura Matrix, 1998.

[7]. Mantea St., Dulamita T. - *Teoria şi practica tratamentelor termice*, Editura Tehnica, Bucureşti, 1966.

[8]. * * * - *Manualul inginerului metalurg,* Editura Tehnică, Bucureşti, 1978.

[9]. Popescu N. Dumitrescu C. - *Tratamente termice si prelucrari la cald*, Editura Didactică și pedagogică, Bucuresti, 1983.

[10]. Schumann H. - *Metalurgie fizică*, Editura Tehnică, Bucureşti, 1962.

[11]. Shackelford F. J. - *Introduction to materials science for engineers*, Macmillan Publishing Company, New York, 1991.

[12]. Tripsa, I. - *Metalurgia oţelului*, Editura Didactică şi pedagogică, Bucureşti, 1972.

[13]. Truşculescu M. - *Studiul metalelor*, Editura Didactică şi Pedagogică, Bucureşti, 1977.

[14]. Vasilescu, E., Levcovici, S. M. - *Experimental Researches Concerning the Oxidation Resistance and Ovearheat Susceptibility of Certain Ship Plates, The* Annals of Dunarea de Jos of Galati, Fascicle IX Metallurgy and Materials Science, ISSN 1453-083X, 2002.

[15]. Vasilescu, E., Vasilescu, I. - *Calitatea produselor din oţeluri microaliate prelucrate prin procedee termice neconvenţionale,* Ed. AGIR Bucuresti 2010.

[16]. Ilut, S., E. Vasilescu - *„Studii şi cercetări privind susceptibilitatea la oxidare a produselor plate din oţel naval”* lucrare de licenta, Galati 2011.