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# IMPROVEMENT OF PROPERTIES OF HEAVY PLATES BY SECONDARY STEELMAKING TECHNOLOGIES AND ROLLING CONDITIONS

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## ABSTRACT

*In order to obtain the mechanical and technological characteristics required for controlled rolled plates it is necessary to realize a very low content of sulphur by desulphurized mixtures using CaO-$Al_2O_3$-$CaF_2$ and injection of powdered SiCa or core wire SiCa. This paper presents the influence of rolling conditions on mechanical properties, the influence of the rolling schedule and the temperature range of the end rolling of the microstructure.*

KEYWORDS: heavy plates, secondary metallurgy, rolling schedule, impact strength, fractures strength

## 1. Introduction

As a result of the progress made in the industrial manufacture of micro-alloyed steels, their application area has been extended to fields where requirements include high strength and toughness characteristics at low temperatures, on the one hand, and an adequate weldability in harsh ground conditions, on the other **[3, 4, 5]**.

The fulfillment of the mechanical and technological characteristics required for controlled rolled plates designed for pipes with a large diameter of 1420 mm for transporting oil and natural gas from the arctic regions calls for a high technological level of the whole manufacture flow: steelmaking, treatment in the ladle, casting, heating and rolling.

## 2. Industrial experiments

The steel was produced in the 180t BOF furnace.

The chemical composition of the experimental heats is shown in Table 1.

***Table 1.*** *Chemical composition of experimental heats*

| No. | Elements, % | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **C** | **Mn** | **Si** | **P** | **S** | **Al** | **Nb** | **V** | **$C_E$** |
| 1. | 0.08 | 1.65 | 0.27 | 0.010 | 0.008 | 0.025 | 0.040 | 0.06 | 0.3670 |
| 2. | 0.08 | 1.74 | 0.27 | 0.010 | 0.012 | 0.025 | 0.042 | 0.07 | 0.3040 |
| 3. | 0.08 | 1.43 | 0.25 | 0.018 | 0.008 | 0.038 | 0.033 | 0.07 | 0.3323 |
| 4. | 0.07 | 1.65 | 0.32 | 0.020 | 0.010 | 0.050 | 0.043 | 0.05 | 0.3550 |
| 5. | 0.08 | 1.63 | 0.51 | 0.022 | 0.0045 | 0.028 | 0.042 | 0.07 | 0.3657 |
| 6. | 0.07 | 1.56 | 0.38 | 0.023 | 0.0035 | 0.010 | 0.031 | 0.05 | 0.3400 |
| 7. | 0.06 | 1.57 | 0.43 | 0.018 | 0.0035 | 0.040 | 0.020 | 0.06 | 0.3337 |
| 8. | 0.08 | 1.55 | 0.42 | 0.020 | 0.0035 | 0.090 | 0.040 | 0.06 | 0.3503 |
| 9. | 0.07 | 1.60 | 0.50 | 0.020 | 0.0035 | 0.068 | 0.033 | 0.05 | 0.3467 |
| 10. | 0.06 | 1.50 | 0.42 | 0.017 | 0.0035 | 0.045 | 0.024 | 0.04 | 0.3180 |
| 11. | 0.06 | 1.58 | 0.38 | 0.018 | 0.0038 | 0.030 | 0.067 | 0.05 | 0.3333 |
| 12. | 0.07 | 1.55 | 0.35 | 0.018 | 0.0038 | 0.025 | 0.074 | 0.05 | 0.3383 |
| 13. | 0.07 | 1.48 | 0.37 | 0.013 | 0.0025 | 0.030 | 0.046 | 0.05 | 0.3267 |
| 14. | 0.11 | 1.48 | 0.43 | 0.022 | 0.005 | 0.062 | 0.044 | 0.07 | 0.3707 |
| 15. | 0.10 | 1.48 | 0.44 | 0.016 | 0.004 | 0.09 | 0.04 | 0.06 | 0.3587 |
| 16. | 0.09 | 1.53 | 0.40 | 0.020 | 0.004 | 0.04 | 0.04 | 0.05 | 0.3550 |

In order to achieve the lowest sulphur content possible, the steelmaking practice was based on the principle of sulphur removal in each possible stage, as follows:

a) sulphur removal from pig-iron in the ladle with soda, reaching sulphur contents of 0.020% maximum;

b) a high degree of descaling of the pig-iron surface in the transfer ladle;

c) use of scrap of known origin with a low sulphur content;

d) use of lime with a minimum content of 90% CaO and a high reactivity;

e) the practice of elaborating a high alkalinity scale, the achievement of a maximum distribution scale/scale ratio and high degree of retention in the furnace;

f) sulphur removal in the ladle using de-sulphurized mixtures of $CaO\text{-}Al_2O_3\text{-}CaF_2$ by using lumps of SiCa in spouts and continuous argon bubbling through a porous plug (heats 5-16);

g) injection of powdered SiCa, about 1.5kg/t (heat 13), and use of the continuous pipe with SiCa, about 1.2kg/t (heat 12).

The steel was continuously cast with spout protection in refractory tubes from the ladle to the tundish, obtaining slabs of 250x1500x(2800-4200) mm. The refractory lining of the ladle and the tundish was basic, so as to get a high degree of exogene inclusions.

The slabs were heated before rolling in the gravity – discharge furnace; the trimming temperature being about 1150°C, with temperatures of about 1220°C being reached.

The slabs were rolled into plates, to establish:

- the rolling pattern, with two (pattern No. 1), and three (pattern No. 2) strain times;

- the condition of the temperatures at the end of rolling and of the associated degrees of reduction that would assure the tensile characteristics specified for X 70 grade steel plates.

The patterns and the temperatures at the end of rolling, experimentally used, are shown in Fig. 1. The final thickness ranged between 15.7 and 23.2mm and the plate width between 2400mm and 4600mm.

After rolling the plates, the samples were taken to test for the following:

-microstructural analysis;

-tension with the determination of $R_m$, $R_{po,2}$ A5%;

-Charpy V notch impact strength on transverse specimens tested at -20°C ($KCV_T$ -20°C);

-impact strength on U-notched test specimens taken transversally and tested at -60°C ($KCU_{3T}$ -60°C).

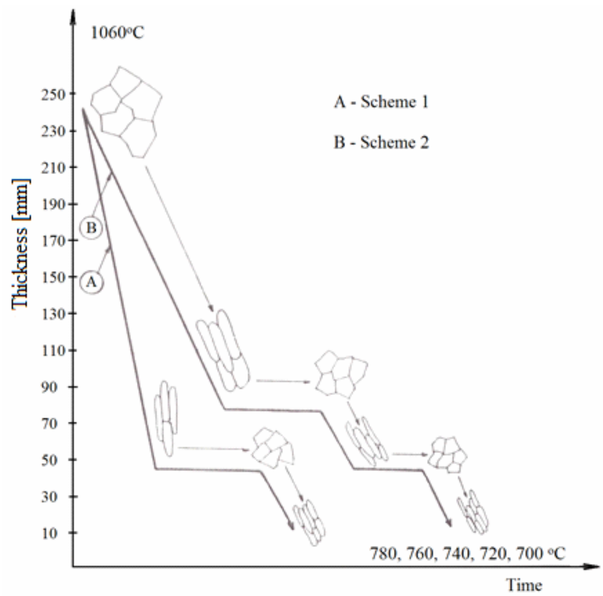


***Fig. 1.*** *Rolling scheme applied within the industrial scale experiments*

The results obtained were processed and shown graphically indicating the influence of different technological factors on the degree of tensile characteristics.

## 3. Influence of sulphur content

Literature data **[1, 2, 4]** show the deleterious influence of sulphur on the mechanical properties of the steel, particularly on the toughness; for this reason the quantitative settling of this effect was kept under observation during working. The experimental values of the toughness obtained for the 1-16 heats in optimum rolled conditions, depending on the sulphur content, are mentioned in Fig. 2 ($KCV_T$ -20°C) and Fig. 3 ($KCU_3$ -60°C).

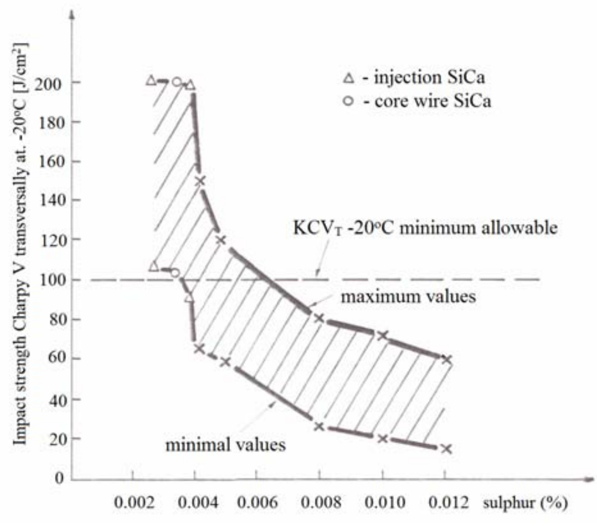


**Fig. 2.** *Influence of sulphur content on impact strength $KCV_T$ -20$^o$C*

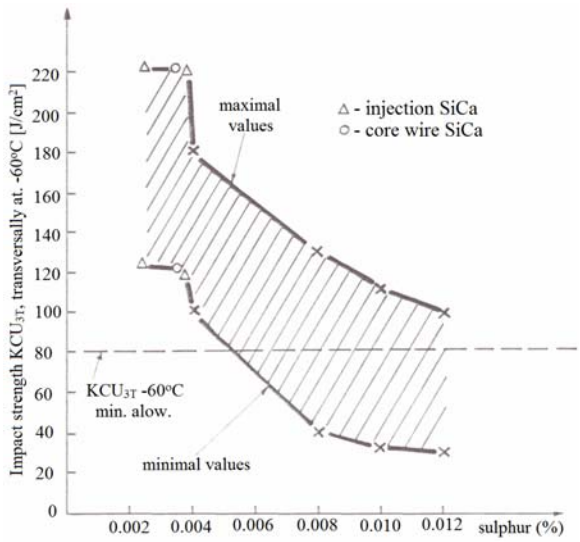


**Fig. 3.** *Influence of sulphur content on impact strength $KCU_{3T}$ at. -60$^o$C*

The data analyses presented in Figs. 5 and 6 confirm the following:

- stress decreasing of the toughness values $KCV_T$ -20$^o$C and $KCU_{3T}$ -60$^o$C due to increased sulphur content, particularly over 0.004%;

- stress sensitivity of the toughness values determined on the V notch test pieces, in ratio to the increase of sulphur;

- necessity of achieving a sulphur content under 0.004%.

Evidently, to meet these conditions some supplementary technological measurements must be taken for steel melting and casting.

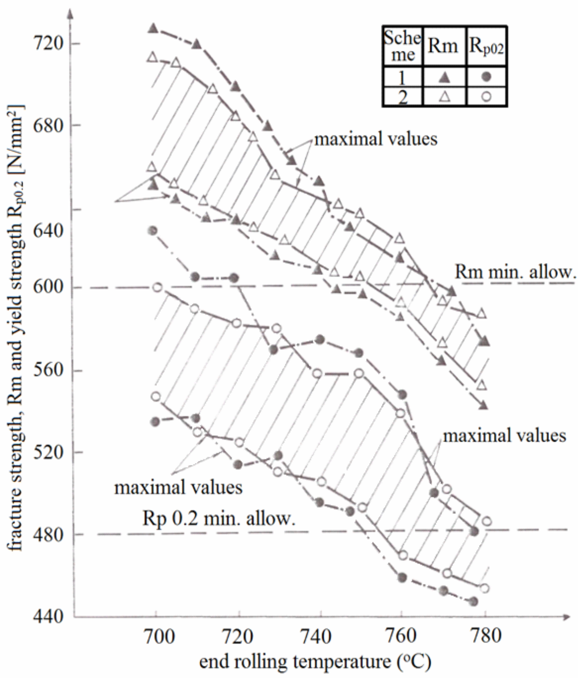


**Fig. 4.** *Influence of rolling scheme and end rolling temperature on fractures strength and yield strength*

## 4. Influence of rolling conditions on mechanical properties

Rolling methods and technological parameters used:

- heating temperature for plastic deformation;
- plastic deformation temperature;
- practicable reducing degree;
- temperature range of ultimate plastic deformation;
- deformation degree associated with the final temperature of the deformation determines the kinetic process of the:
  - dissolving and precipitation of the micro-alloying element combination, V and Nb with those of the interstice, C and N;
  - phase transformation γ-α at cooling after deformation resulting in the required microstructure and mechanical characteristics.

For these reasons, the aim of the experiments was to determine the influence of the rolling condition on the structural and mechanical properties and hence, the adoption of the optimum rolling technology.

### *4.1. Influence of the Rolling Schedule and Temperature Range of the End Rolling on the Microstructure*

Metallographic test pieces were taken from the rolled plates in accordance with the scheme of Fig. 1 with a range of temperature between 700-780°C for the rolling. The test pieces were prepared in accordance with classic methods and X 200 analyzed, in longitudinal section to the rolling direction.

The analyses of the microstructure show the more advanced degree of fineness for the same temperature during end rolling when schedule N 2 with three times of deformation was used.

Concerning rolling temperatures, it was noted that the grain becomes finer as the temperature is lowered during rolling to between 780 and 740°C.

The decrease of temperature during and rolling to under 740°C, particularly under 700°C, leads to the partial refining of the grain **[6]**.

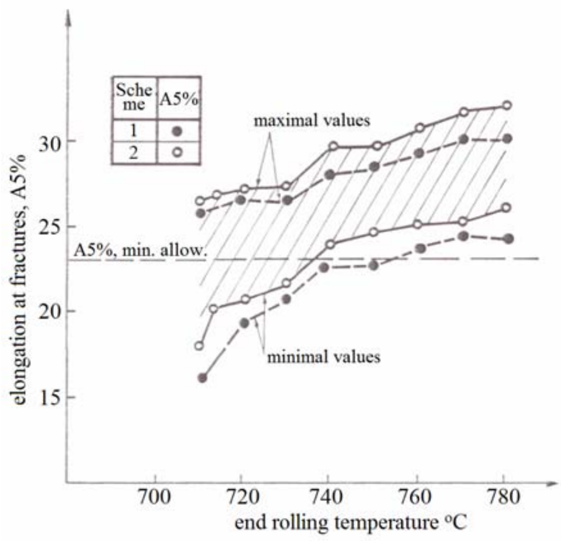


***Fig. 5.*** *Influence of rolling scheme and end rolling temperature on elongation at fracture*

### *4.2. The Influence of Rolling Conditions on Such Mechanical Characteristics as Resistance, Plasticity and Toughness*

From controlled rolled plates in different conditions some test specimens were taken for tension and toughness tests.

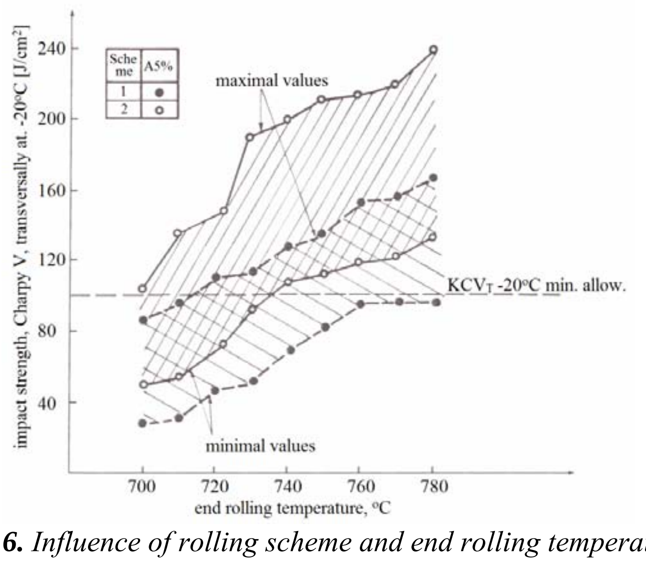


***Fig. 6.*** *Influence of rolling scheme and end rolling temperature on impact strength $KCV_T$ -20°C*

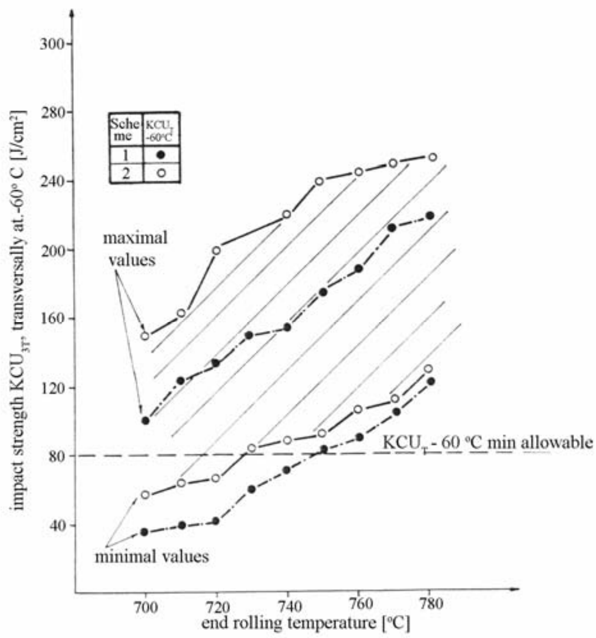


***Fig. 7****. Influence of rolling scheme and end rolling temperature on impact strength $KCU_{3T}$ -60$^o$C*

Figs. 4, 5, 6 and 7, for heats 5-13 with sulphur content of max. 0.0045%, present the dependence on characteristics such as: resistance, plasticity and toughness in the rolling schedule with deformation time 1 and 2 and 2 and 3 for each schedule, temperature of rolling being in the range of 700-780$^o$C.

Irrespective of the rolling chart, the results obtained indicate a close relationship between values of mechanical characteristics and end rolling temperatures; the strength properties ($R_m$, $R_{po,2}$) increase, and those of plasticity (A 5%) and toughness ($KCV_T$ -20$^o$C, $KCU_{3T}$ -60$^o$C) decrease from 780 to 700$^o$C.

Regarding the rolling scheme used with 2 or 3 deformation times, one can note a certain influence on the plasticity characteristics (Fig. 5) and toughness (Figs. 6 and 7). Higher values of these characteristics can be obtained for all end rolling temperature in the case of application of scheme No. 2 with 3 rolling times, probably in accordance with a greater degree of fineness of the ferritic grain.

In reference to the minimal allowable values for mechanical characteristics, one can state that a whole assembly of completely satisfactory properties is achievable only in the case of scheme No. 2 of rolling, for rolling temperatures situated in the range of 740-780$^o$C.

Thus, the industrial manufacture of plates of grade X 70 is tied in with keeping within very close limits during the whole rolling process **[7, 8]**.

## *4.3. Influence of Slab Heating Temperature on the Level of Mechanical Characteristics*

To examine the influence of this parameter slabs pertaining to heats No. 5-13 were heated with a view to rolling at temperatures of about 1150$^o$C and 1220$^o$C.

All slabs, irrespective of their heating temperature, were rolled according to the scheme No. 2 with 3 deformation times, the end rolling temperature being situated in all cases in the optimal range of 740 – 750$^o$C.

The results obtained, statistically processed, are presented in Table 2.

The analysis of data in Table 2 points to the influence of slab heating temperature on the level of mechanical properties, this probably being in relation with differences in the processes of the precipitation of both nitride and carbonitrides of Nb and V and the process of austenitic grain growing.

In the case of slab heating to a temperature of 1220$^o$C, there is an advanced dissociation of precipitates. Depending on these conditions, there is stronger growth of austenitic grain compared with the case of heating up to 1150$^o$C.

The initial structural characteristics before deformation affect final results after deformations; for the same conditions of rolling a coarser initial austenitic grain leads; to the formation of austenitic grains of larger size, causing a reduction in plasticity and toughness properties.

***Table 2.*** *Influence of slab heating temperature on the level of mechanical characteristics*

| **Heating temperatures of slabs** | **Values of mechanical characteristics** | **Mechanical characteristics** | | | | |
|---|---|---|---|---|---|---|
| | | **$R_m$** | **$R_{po,2}$** | **A5** | **$KCV_T$ -20°C** | **$KCU_{3T}$ -60°C** |
| [°C] | | [N/mm$^2$] | | [%] | [J/cm$^2$] | |
| 1150°C | Maximum | 640 | 540 | 30 | 210 | 260 |
| | Minimum | 605 | 490 | 25 | 115 | 165 |
| | Mean | 625 | 518 | 27.5 | 157 | 207 |
| 1220°C | Maximum | 675 | 550 | 26 | 185 | 225 |
| | Minimum | 635 | 510 | 22 | 87 | 103 |
| | Mean | 653 | 538 | 23.5 | 110 | 148 |

The increase in impact strength characteristics at a heating temperature of 1220°C, as compared with 1150°C, is explainable through differences in the development of dissolution and precipitation processes. In the case of temperature up to 1220°C, the dissolution of nitrides and carbonitrides is complete, and the precipitation is accomplished during cooling after rolling, and after phase transformation γ-α, resulting in a hardening by precipitation of the ferritic grains.

In connection with minimal imposed values for mechanical characteristics, one can state that an adequate complex is obtainable only in the case of heating temperature of maximum 1150°C.

## 5. Conclusions

A. The experiments on an industrial scale in the manufacturing of plates of steel X 70 have proved the necessity of achieving steel with maximum sulphur content of 0.0045% and with a high grade of purity in exogenous and endogenous inclusions as a result of the adopting of certain technological measures adequate for both steel melting and pouring.

B. The achievement after rolling of the entire complex of structural and mechanical properties imposed on plates of grade X 70 requires the control within precise limits of all technological parameters, such as:

-heating temperatures of slabs;

-succession of deformation and recrystallizations operations (rolling chart);

-degrees and temperatures of deformation;

-end rolling temperatures;

-deformation degrees associated with end rolling temperatures.

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