POLISH ACADEMY OF SCIENCES - MATERIALS SCIENCE COMMITTEE
SILESIAN UNIVERSITY OF TECHNOLOGY OF GLIWICE
INSTITUTE OF ENGINEERING MATERIALS AND BIOMATERIALS
ASSOCIATION OF ALUMNI OF SILESIAN UNIVERSITY OF TECHNOLOGY
Conference Proceedings
11th INTERNATIONAL SCIENTIFIC CONFERENCE
ACHIEVEMENTS IN MECHANICAL & MATERIALS ENGINEERING

# Influence of controlled rolling condition on microstructure and mechanical properties of low carbon micro-alloyed steels

P. Korczak

Technical University of Częstochowa
Al. Armii Krajowej 19, 42-200 Częstochowa Poland

The paper presents results of initial semi-industrial research on implementation new technological processes of controlled rolling of thick sheets of micro-alloyed steels intended for conveying pipes of large diameter in Częstochowa Steelworks.

## 1. INTRODUCTION

In the past few years intensive research is devoted to introduction of new technologies of rolling sheet steels and improvement of existing ones, intended for conveying pipes of large diameter. Current world standard is exemplified by sheet metal made of steel X70 (according to API – American Petroleum Institute), class L480MB, thickness up to 25.4 mm, which can be used for construction of pipelines with working pressure up to 15.3 MPa. The purpose of taking up investigations described in the paper is constant increase of orders for this type of product, which cannot be accomplished due to insufficient mastering of technologies of thermoplastic rolling of micro-alloyed steels. Laboratory research and industrial practice have shown that simultaneous acquirement of high durability, high impact resistance and good weldability (fulfilment of conditions for X65, X70, X80 kinds according to API) is possible by keeping the lowest possible level of carbon, sulphur and phosphorus, generally low level of non-metal intrusions and gases and selection of Mn and micro-additions (Mo, V, Nb, Ti, Al) percentage assuring achievement of required yield point after applying selected thermal-plastic rolling technology [1-4]. Imposition of condition for carbon equivalent $C_e < 0.43$ according to norms eliminates the possibility of application maximum permissible contents of carbon and manganese. More significant reason of keeping low percentage of carbon is - however – the need of accomplishment of uniform, one-phase, fine-grained structure after thermal-plastic rolling. Currently produced steels X70 and X80 according to API are manufactured only as non-perlite steels with carbon content less than 0.1 %. It follows from literature sources that optimum set of durability, impact resistance and weldability properties for X60, X65, X70, X80 steels according to API, under the condition that the process of thermo-plastic welding was carried out correctly, is obtained for the following percentage range of elements: C < 0.10 %, most often in the range 0.02 % - 0.06 %; S < 0.005 %, most often in the range 0.003 % - 0.005 %; P < 0.015 %; Si < 0.30 %; Mn in the range 1.4 % - 1.8 % and appropriately selected set of micro-additions: Mo, V, Nb, Al, Ti, and B, which has the impact on thermal-plastic rolling conditions. Properties of sheets of low-carbon steel with micro-additions Nb, V, with carbon content below 0.1 % - equivalent to X65, X70 categories according to API, can be obtained by intensive controlled rolling, but only for thickness up to 15 – 19 mm. For larger sheet thickness as well as for X80 steel sheets supervised cooling is required after controlled rolling. Controlled rolling of thick sheets is a particular case of thermo-plastic treatment in high temperatures, which is directed towards achievement of ferrite-perlite or ferrite-bainite-perlite fine-grained structure. Grain pulverization and eduction processes are mechanisms influencing improvement of both durability and plasticity properties. The principle of controlled rolling consists in choice of thermo-plastic rolling conditions in such a way, that kinetics of phenomena occurring in metal i.e. recrystallization, eduction process is supervised. In the simplest case controlled rolling for X70 steel may consist of two phases: - initial rolling phase, carried out in high temperatures, i.e. above recrystallization stop point; the aim of this phase is achievement of recrystallized polygonal austenite microstructure, - finishing rolling phase, carried out below recrystallization stop point, but above $Ar_3$ in order to obtain deformed non-recrystallized austenite structure and to control eduction processes in austenite and ferrite. In low carbon steels, characterized by very good weldability, decrease of durability due to decrease of carbon content is compensated by micro-additions of niobium, vanadium, titanium. Hardening caused by eduction of carbon-nitrogen compounds of these elements sums up to hardening effect due to grain pulverization. The influence of these elements on eduction hardening depends on controlled rolling conditions.

## 2. RESEARCH CARRIED OUT IN THE PAPER

Technical specification of sheet steels binding sheet metal producers must include all requirements submitted by pipe producer, which have to be fulfilled in the scope of chemical composition, steel production and rolling technologies and usefulness for post processing – forming and welding. Rising quality demands, quoted more and more often as obligatory – vacuum steel treatment and non-metal intrusion modifications, as well as strongly diversified dimensional range offer a chance for steelworks with full production cycle and equipped with modern installation for extra-furnace treatment of steel. The aim of recent research carried out in Częstochowa Steelworks was production of sheet metal of X70 steel, thickness 16 and 20 mm, designed for conveying pipes of large diameter, with the use of extra-furnace treatment and controlled rolling technology. Carried out research can be divided into two parts: Stage 1, **a)** within this stage optimum content of alloy was determined: Casting temperature: 1669 $^{O}$C, hydrogen percentage after LF treatment – 9.4 ppm in temperature 1666 $^{O}$C, hydrogen temperature after VD treatment – 1.2 ppm, treatment time (high vacuum 0.9 hPa) – 25 min. Total treatment time – 57 min. Amount of applied core wire CaSi – 160, repeated reheating during LF, end temperature 1567 C. As a result of metallurgical processes steel with percentage composition given in Table 1 was obtained.

Table 1

Chemical composition of steel used during research, [%]

| C | Mn | Si | P | S | Cr | Ni | Cu | Mo |
|---|---|---|---|---|---|---|---|---|
| 0,09 | 1,56 | 0,28 | 0,015 | 0,005 | 0,08 | 0,07 | 0,12 | 0,07 |
| Nb | V | Sn | $AL_m$ | $AL_c$ | N | Ca | [H] | |
| 0,031 | 0,07 | 0,012 | 0,029 | 0,038 | 59 | 12 | 1,2 | |

Carbon equivalent for chemical composition of steel from Table 1 is equal to $C_E$=0.41 %.

**b)** selection of rolling technology, For initial rolling of steel batch strategy 2 – stage controlled rolling – was adopted: initial rolling: end of rolling in roughing stand above

$T_{RST}$=916 $^{O}$C for assurance of full austenite recrystallization, finishing rolling: end of rolling in finishing stand above $Ar_3$=750 $^{O}$C in the one-phase austenite zone. Continuous castings with dimensions 225x1600x3220 mm and mass 7560 kg were used as charge for rolling process. Charge heating was carried out from hot state (temperature 500-600 $^{O}$C) in a shove furnace. Heating zone temperature 1220 $^{O}$C, Compensatory zone temperature 1180 $^{O}$C, Heating time 20 min. Stage 2 - the aim of this stage was takeout of check-up laboratory experiments: metallographic experiments: testing mechanical properties, testing brittleness cracking sustainability, DWTT tests.

## 3. ANALYSIS OF RESEARCH RESULTS

In Tables 2 and 3 process parameters, recorded by finishing stand control system during rolling, are given.

Table 2
Rolling pattern A, thickness of transfer from initial stand H=49,77 mm

| No | Adjustment of thickness, mm | Thickness after roll pass, mm | Direct draft, mm | Pressure, Mg | Calculated temperature,°C | Measured temperature,°C |
|---|---|---|---|---|---|---|
| 1 | 31,46 | 39,11 | 10,66 | 5104 | 815 | 795 |
| 2 | 23,65 | 31,30 | 7,81 | 5079 | 810 | - |
| 3 | 18,83 | 25,86 | 5,44 | 4569 | 804 | 798 |
| 4 | 17,43 | 22,84 | 3,02 | 3625 | 798 | - |
| 5 | 15,73 | 20,56 | 2,28 | 2998 | 783 | 780 |
| 6 | 15,97 | 19,40 | 1,16 | 2366 | 772 | - |

Table 3
Rolling pattern A, thickness of transfer from initial stand H=46,74 mm

| No | Adjustment of thickness, mm | Thickness after roll pass, mm | Direct draft, mm | Pressure Mg | Calculated temperature °C | Measured temperature°C |
|---|---|---|---|---|---|---|
| 1 | 28,08 | 36,09 | 10,65 | 5110 | 824 | 810 |
| 2 | 19,63 | 27,93 | 8,16 | 5155 | 819 | - |
| 3 | 13,89 | 22,08 | 5,85 | 5057 | 814 | 810 |
| 4 | 12,46 | 18,94 | 3,14 | 4254 | 806 | - |
| 5 | 11,23 | 16,83 | 2,11 | 3299 | 794 | 795 |
| 6 | 10,69 | 15,40 | 1,43 | 2825 | 780 | - |

*Results of metallographic experiments and testing of mechanical properties*

During metallographic experiments average ferrite grain size and level of structure orientation were determined, for A - average ferrite grain size 7,4 μm, level of structure orientation 21,5 %, $R_{t0,5}$=498-565 MPa, $R_m$=590-645 MPa, $R_{t0,5}/R_m$=0,83-0,87, $A_2$=29,0-23,6 %, $KV_{0C}$=118 J and for B – 5,6 μm , 40,5 %, $R_{t0,5}$=545-548 MPa, $R_m$=636-623 MPa, $R_{t0,5}/R_m$=0,86-0,88, $A_2$=25,3-24,4 %, $KV_{0C}$=94 J

*Results of testing brittleness cracking sustainability*

Impact strength testing was carried out on impact strength full dimensional Charpy-V samples, cut out in lengthwise and crosswise directions. Tests were carried out in temperatures +20 C, -20 C, -40 C, -60 C, -80 C. In Table 6 collective results of cracking sustainability for analysed metal sheets are presented.

*Results of DWTT tests*

Results of dynamic tearing of material carried out according to ASTM E 436 “DROP-WEIGHT TEAR TESTS” norm on samples with dimensions 3x10x20 mm with burnished notch 45$^{o}$ – 2”. Results of DWTT tests: for temperature –60 $^{O}$C - the sample has cracked; 90

% of brittle fracture, for -40 $^{O}$C - the sample has cracked; 80 % of brittle fracture, -20, 0, +20 $^{O}$C - samples did not crack. After takeout of two-phase controlled rolling of steel with optimised chemical composition, average values $R_{t0,5}$=535 MPa for rolling pattern A and $R_{t0,5}$=546 MPa for rolling pattern B have been obtained. These values are higher by 50 and 76, respectively, than specified $R_{t0,5}$ for the pipe. The excess value seems to be large enough, with respect to available data, to compensate the decrease of yield point during pipe production. In the whole range of temperature during cracking sustainability testing, down to –80 C, laminated fracture did not appear to happen. In microfraction-graphic tests laminated fracture was revealed only on inner surfaces of tear appearing on brittle fractures of impact strength samples. Generally, acquired level of cracking energy is high – in reception temperature 0 C on crosswise samples cracking energy is about 100 J, and in temperature –80 C KV is about 70 J. No coincidence between test temperature and cracking energy anisotropy, which changes in the range of 1.44-1.86, was found. Microstructure of examined metal sheets is composed of strongly oriented fine ferrite grains and perlite aligned in bands. Higher level of orientation for sheets rolled according to pattern B was observed.

Table 5
Results of testing for X70 steel sheets after controlled rolling

| Test temperature C | Cracking energy KV, J | | | | Impact strength anisotropy coefficient | |
|---|---|---|---|---|---|---|
| | For samples rolled according to pattern A | | For samples rolled according to pattern B | | | |
| | Crosswise | Lengthwise | Crosswise | Lengthwise | A | B |
| +20 | 132 | 224 | 105 | 177 | 1,70 | 1,69 |
| 0 | 119 | 207 | 96 | 157 | 1,74 | 1,64 |
| -20 | 105 | 191 | 83 | 129 | 1,82 | 1,55 |
| -40 | 92 | 168 | 74 | 127 | 1,83 | 1,72 |
| -60 | 87 | 162 | 80 | 116 | 1,86 | 1,45 |
| -80 | 70 | 124 | 73 | 105 | 1,77 | 1,44 |

## 4. CONCLUSIONS

Chemical composition of steel designed in Częstochowa Steelworks allows production of sheet metal for conveying pipes according to controlled rolling technology within L480MB category up to 20 mm thickness, - applied pattern of two-phase controlled rolling guarantees achievement of metal sheets with properties fulfilling appropriate requirements for pipes specified in European norm EN-10208-2 and API 5L.

## REFERENCES

1. Sellars C.M., 1990, Modelling Microstructural Development During Hot Rolling, Mat. Sci. Techn., 6, 1072-1081.
2. Hodgson P.D. and Gibbs R.K., A Mathematical Model to Predict the Mechanical Properties of Hot Rolled C-Mn and Microalloyed Steels, ISIJ Int. 32, 1992, 1329-1338.
3. Korczak P., Dyja H.: Mekhanicheskie i mikrostrukturnyje svojstva tolstykh listov iz stali H70 posle kontroliruemoj prokatki, Metalurgicheskaja i gornorudnaja promyshlennost', 2000, Nr 8 – 9, (Ukraina), s.118 – 121.
4. Korczak P., Dyja H.**:** Prediction of microstructure changes during a multipass hot plate rolling, Rolling**,** Proceedings of 2nd European Rolling Conference at AROS Congress Centre, Vasteras, Sweden, May 24-26, 2000.