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Processing and properties of C-Mn steel with dual-phase microstructure

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Abstract: Effect of applied thermomechanical rolling and heat treatment on dual-phase and multi-phase microstructure formation in steel 15 (formerly 15GA) and achieved mechanical properties was studied. Thermomechanical rolling was made in full austenitic range. After rolling steel was held in the air for 145s to 250s in α+γ temperature range then quenched in water. The heat treatment of steel was based on annealing in (α+γ) range at temperature 1063K for 3600s, quenching in water and tempering at temperature 913K for 5400s. Microstructures after these treatments were composed of ferrite matrix and martensite – bainite – austenite islands. Volume fraction of islands was in the range 19÷37% for steel after thermomechanical treatment and 22÷29% after heat treatment. High mechanical properties were achieved: after thermomechanical rolling: TS = 910MPa, YS = 760MPa and El = 14,4%; after heat treatment: TS = 510MPa, YS = 328MPa and El = 37,27%.

Keywords: Dual-phase microstructure, Thermomechanical rolling

1. INTRODUCTION

The development of new structural materials with good strength impact and plasticity, which allow for mass reduction of the cars, is still an open task for manufacturers. Up till now 63% of car body weight are steel structures. [1]

Contemporary investigations concern IF steels with high susceptibility to deep pressing, microalloyed ferrite- martensite dual- phase steels DP and TRIP – martensite transformation induced plasticity during deformation of the steel. Residual austenite is one of the important microstructural features in the latter steels. DP and multiphase microstructure steels are produced mainly with thermomechanical rolling or heat treating in α+γ temperature range followed by quenching in water [2-4]. Dual-phase microstructure with martensite- austenite islands allows for high strength, substantial uniform elongation and large hardening rate of steel [5].

2. EXPERIMANTAL PROCEDURE

The steel 15 composition used in the experiments was consisting of: 0,16% C; 1,23% Mn, 0,023% P; 0,018% S; 0,03% Cr; 0,02% Cu, 0,005% Al, 0,02% V in weight percent. In Figure 1 the thermomechanical processing and heat treatments cycles used during the experiments are shown. Mechanical properties of the plates 12-mm in thickness were tested.

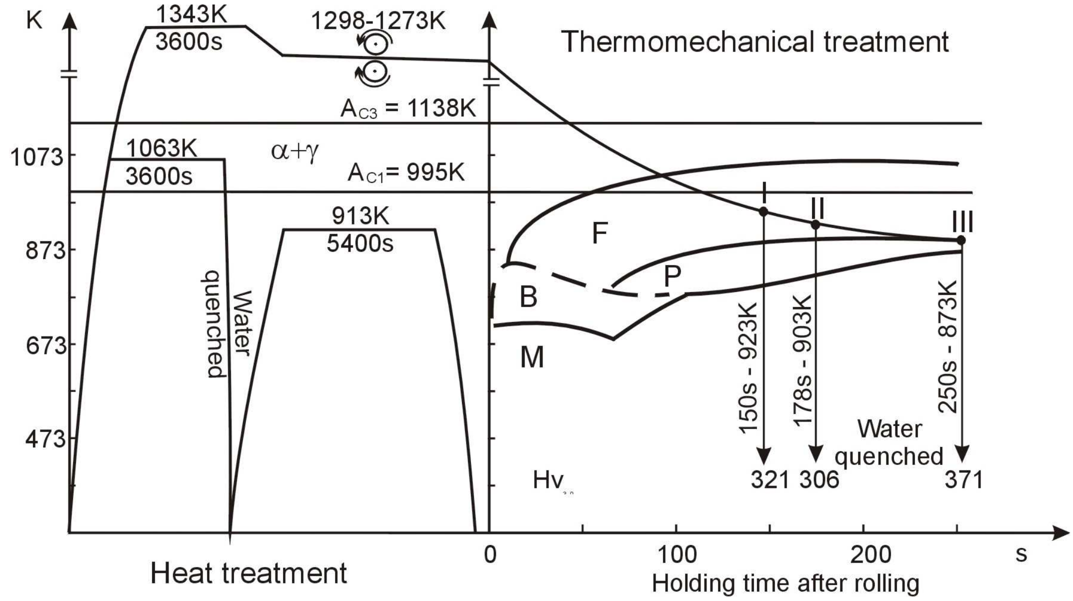


Figure 1. Treatment cycles in the experiments

The dual – phase microstructure was obtained by two-way procedure: thermomechanical rolling and annealing in (α+γ) range. After austenitizing at 1343 K for 3600 s, steel was rolled at temperature range (1273÷1298) K, cooled in air: 145s (I) 175s (II) and 250s (III) (the cooling rate was for 1,67 to 2,2 K/s) and quenched in water to ambient temperature. Second treatment was consisting of the annealing the specimens at 1063K for 3600s and quenching in water. After quenching steel was heated up to 913K and held for 5400s then cooled in water.

3. RESULTS AND DISCUSSION

Microstructure of the steels was investigated after thermomechanical and heat treatment processing with use of optical and transmission electron microscopes. The characteristic microstructure after thermomechanical rolling is shown in Figure 2.

a) b)

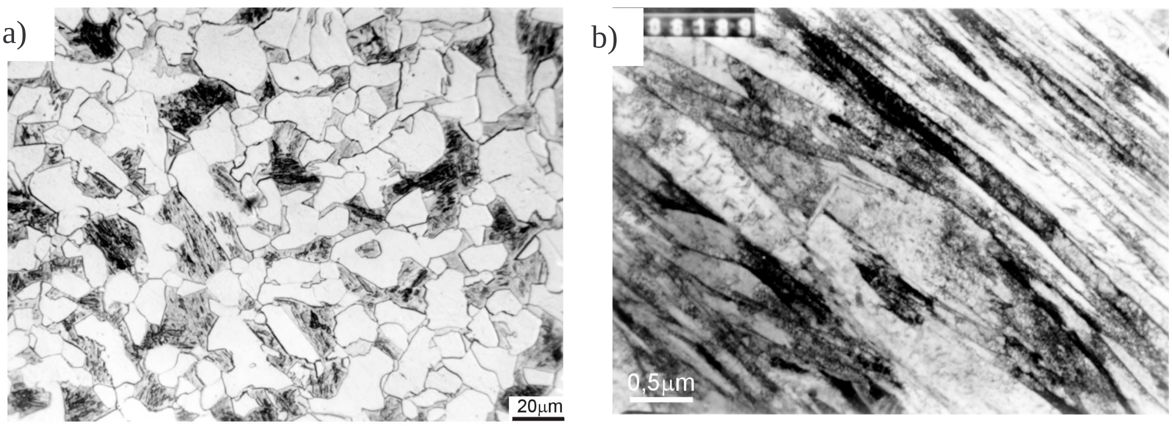
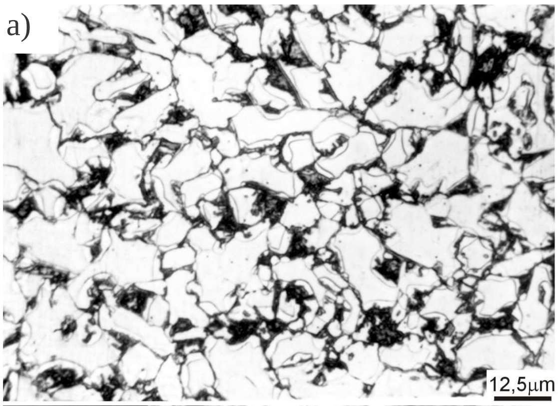


Figure 2. Ferrite–martensite microstructure of steel 15 after thermomechanical rolling, treatment in variant III (250s holding and quenching in water from 873K)
a) optical structure, b) TEM – lath martensite self-tempered (thin foil)



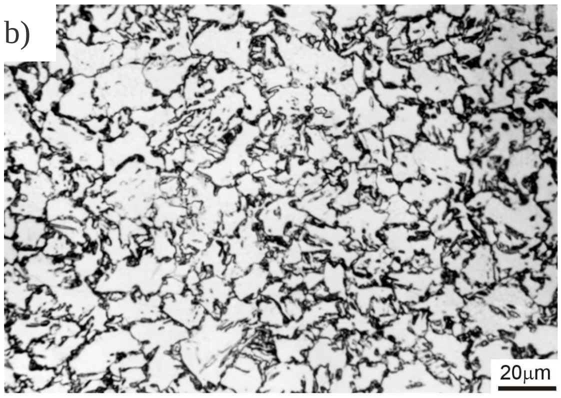


Figure 3. Microstructure of steel 15 after heat treatment processing

a) annealing at 1063K/3600s and quenching in water, (optical microscope)

annealing at 1063K/3600s and quenching in water and tempering at 913K/5400s

b) optical microscope, magnification. 500X

c) thin foil –TEM , magnification. 6000X

Microstructure of the steel after quenching from $\alpha+\gamma$ temperature range and tempering is shown in Figure 3. Observations of thin foils revealed existence of self tempered lath martensite and bainite-martensite-austenite islands (BMA) after thermomechanical rolling while after tempering little carbides were also visible. Using X-ray technique retained austenite (A) was detected within BMA islands in amount 5.4% for variant II TMT. Reduction of the amount of austenite to 1.94% for variant III TMT was due to formation of small amount of pearlite at the former austenite grain boundaries. The quantitative ratios of microstructural constituencies and tensile properties of steel are given in Table 1.

Table 1.
Volume fraction of the microstructure constituencies after thermomechanical treatment and tensile properties of the investigated steel grade 15

Variant TMT	Volume fraction, %			Tensile properties		
	Ferrite %	BMA %	A %	TS MPa	YS MPa	El %
I	76,94	23,06	3,25	892	740	14,6
II	80,69	19,31	5,42	863	687	17,9
III	74,1	25,9	1,94	959	795	9,9

After annealing at 1063K/3600s and quenching the multi-phase microstructure was achieved which contained small amount of pearlite and carbides. The amount of martensite and carbides totally was established on 22.4 %. The coagulation process of carbides in the former pearlite regions was observed after tempering 913 K / 5400 s. There was no residual austenite in the structure but deformation hardening similar to that of DP microstructures was detected for 15GA steel during tensile testing. The large elongation 37.3% at YS/TS ratio 0.64 was measured. In as annealed and quenched condition steel had YS = 696 MPa, TS = 856 MPa and El = 22.6% while after tempering YS = 328 MPa, TS = 510 MPa.

The highest tensile strength was achieved in steel processed according to the variant III of thermomechanical rolling YS = 795MPa, TS = 959MPa and El = 9,9%. The tempering procedure is recommended after TMT III to improve plasticity and ductility of the steel. High strength and toughness was obtained after the remaining processing: TMT II and I.

Tempering increases impact energy of Charpy V specimens, which at room temperature, has been risen from 40J to 146J and at 213 K adequately from 34 to 49J.

4. CONCLUSION

1. Thermomechanical and cyclic heat treatments shown in Figure 1 allows for dual- phase structure formation in steel grade 15.
2. After TMT procedures the received microstructures consisted of bainite-martensite-austenite islands in ferrite matrix while after heat treatment except ferrite the martensite and carbides and small fractions of pearlite were detected.
3. The tempering procedure is recommended after the variant III of thermomechanical rolling to improve plasticity and ductility of the steel with the highest tensile strength TS = 959MPa, YS = 795MPa and El = 9,9%.
4. Annealing at 1063K in ($\alpha+\gamma$) temperature range quenching and tempering at 913K improves fracture toughness of steel: Charpy V 146J at 293K and 49J at 213K which has YS =328MPa, Ts = 510MPa and El =37,3%.

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