Characteristics of High-Strength Sheet Steel after Subsequent Heating

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Abstract. The influence of controlled rolling and the parameters of subsequent technological heating on the processes of structure formation in high-strength sheet steels EN36 and X70 is investigated. It has been established that when redistributing a thick sheet into products, it is necessary to minimize the temperature-time parameters to prevent softening processes. Welding, as one of the sources of technological heating, leads to a change in the structure in the zone of thermal influence and uneven distribution of hardness over the cross section of welded joints, which reduces the uniform strength of the structure as a whole. Short-term heating (about 15 minutes) even to temperatures above Ac1 (760 °C) and cooling in air in the weld zone do not lead to significant changes in structure and hardness, but the degree of uniformity of the welded sheets increases.

The quality of sheet steel is determined by many factors – chemical and physical homogeneity, minimum content of contaminants and non-metallic inclusions, high surfacequality and the density of metal in general. It has been observed on numerous occasions that after controlled rolling there is an inhomogeneous structure in particular areas of sheets, predominantly with the size of ferritic grain 8-10 μm across, however, there are bigger ferritic grains up to 30 μm across. Besides that, over the thickness of the sheets there is often inhomogeneous crystallographic texture and especially strong ferrite-pearlite banding. Inhomogeneity of microstructure and of crystallographic texture in the state after controlled rolling inherently leads to anisotropy, decrease in impact strength and brittle fracture resistance of the metal [1-6].

The purpose of this study was to research the peculiarities of structure formation in high-strength sheet steels EN36 and X70 after controlled rolling and after subsequent technological heating.

The high-strength steels EN36 and X70 were researched, which are fine-grained ferrite-pearlite steels. The chemical composition of the steels under study is specified in Table 1.

| Table 1. Chemical composition of steels under study, % wt. |
| Steel grade | C   | Si  | Mn  | S   | P   | Cr+Ni+Cu | N   | V   | Ti  | Nb  | Mo  | C_{equivalent} |
|------------|-----|-----|-----|-----|-----|----------|-----|-----|-----|-----|-----|----------------|
| EN36       | 0,11| 0,21| 1,18| <0,005| <0,014| 0,08     | 0,003| 0,25| 0,015| 0,04| 0,05| <0,37          |
| X70        | 0,10| 0,35| 1,20| <0,004| <0,012| 0,47     | 0,008| 0,050| 0,010| 0,04| 0,1 | <0,41          |
The microstructure of steels EH36 and X70 after controlled rolling (Figure 1 (a) and (b) respectively) is predominantly a ferrite-pearlite mixture with strong pearlite banding, but there are also ferrite grains elongated along the rolling direction, in which the recrystallization processes did not finish in time. The main reason of banded structure formation with elongated ferrite and pearlite bands is supposed to be the inherent impact of deformed uncrystallized or partially recrystallized austenite on its decomposition during overcooling below critical points.

![Figure 1](image)

**Figure 1.** Microstructure of steels EH36 (a) and X70 (b) after controlled rolling, x400.

It is known that the higher the overall degree of deformation of austenite at temperatures at which its recrystallization is hindered, or substantially restrained and the higher the elongation of its grains in the direction of metal deformation process, the longer the elongated bands of pearlite sectors will be after pearlitic transformation is finished.

The presence of pearlite banding leads to high anisotropy of mechanical properties. Along the normal to sheet surface plane the tensile strength, yield strength and percentage of elongation are almost twice lower than in directions in the plane of the sheet [5].

To study the influence of subsequent technological heating for heat treatment on the structure and properties of sheet steel EH36 the samples were heated up to 200 – 900 °C and held at those temperatures for up to 2 h and subsequently cooled by ambient air. The microstructures after additional heating are shown at Figure 2.

While heating up to 200 °C (Figure 2 (a)) the initial stage of the ageing process is happening, the microstructure and properties basically do not change, but in the process the carbides coherently bound with the matrix are precipitated, pearlite banding is maintained, and the hardness increases to 124 – 130 HB.

While heating up to 400 °C (Figure 2 (b)) substantial changes in microstructure are observed, which consist of rupture of pearlite bands, release of strain hardening after deformation; the level of residual stresses lowers and there is uniformly distributed equiaxial structure formed, which makes the hardness increase up to 136 – 145 HB.

At the temperature of 600 °C (Figure 2 (c)) there is partial recrystallization of the matrix, which is accompanied by the refinement of ferrite; during such heating the structure is formed in which fine particles of cementite (pearlite) are uniformly distributed in the ferrite matrix, and during that maximum hardness increase is observed (up to 150 – 155 HB), which is conditioned by the equiaxiality and dispersity of structure.

Heating and holding at the temperature of 750 °C (Figure 2 (d)) does not lead to substantial changes in the microstructure, but the initial partition processes of pearlite bands can be observed which, in turn, increases the hardness from 118 – 123 HB to 125 – 130 HB.
Heating up to 950 °C (Figure 2 (e)) leads to the manifestation of the influence of dendritic inhomogeneity and liquation, which substantially impacts mechanical properties, and the hardness lowers to 110 – 115 HB.

![Figure 2. The microstructures of EH36 steel after additional heating up to the temperatures: (a) – 200 °C, 2 h; (b) – 400 °C, 1 h; (c) – 600 °C, 30 min; (d) – 750 °C, 20 min; (e) – 900 °C, 15 min; x 400.](image)

The histogram Figure 3 shows that additional heating up to 200-900 °C with subsequent cooling by ambient air leads to non-monotonic change in hardness.

![Figure 3. Hardness of sheet steel EH36 after additional heating.](image)
Hardness increase while heating up to 600 °C can be conditioned by ageing and partial recrystallization, which is accompanied by the refinement of ferrite constituent.

The analysis of microstructural changes during additional heating showed the important role of structure formation during subsequent welding processes of different steel structures made of these steels.

The study of the influence of short-time heating during welding on the changes in structure and hardness over the weld section was done with the samples of sheet steels X70 and EH36, which underwent automatic hidden-arc welding and semi-automatic welding respectively.

The microstructure of a weld of sheet steel X70 is showed on Figure 4.

![Figure 4](image)

**Figure 4.** The microstructure of a weld of steel X70: (a) – weld metal; (b) – weld area; (c), (d), (e) – heat-affected area, x500.

From the analysis of the microstructure of the studied samples we can see that depending on the influence of temperature gradient there are three zones clearly distinguishable in the welded connections: weld area, heat-affected area and the area of weld metal. Heat-affected area, where metal undergoes a particular thermal influence, deserves special attention. When moving away from the weld area to the main metal, the structure of metal changes according to the heating and cooling thermal cycles and depends on the chemical composition of metal and preliminary thermal and thermomechanical treatment.

The microstructure of weld metal and weld area (Figure 4 (a), (b)) consists of the products of intermediate breakdown of austenite and ferrite in the form of streaks on the borders of the crystals. In the weld area (fig.4b) the structure of martensite and bainite is also visible. Rapid growth of austenite grains happens in this area by means of heating up to a high temperature (1100 – 1150 °C).

In the heat – affected area we can see the change of microstructure from martensite-bainite to ferrite-pearlite, that corresponds to the processes of normalization, incomplete recrystallization and complete recrystallization during thermal treatment with special heating, that means that pearlite banding basically
disappears in this area. Fine grains in the area of complete recrystallization are explained by the high speed of cooling down from the recrystallization temperature and the chemical composition of steel X70.

Figure 5 shows the dispersion of hardness by section of weld samples made of steels X70 and EH36. We can see on the graph that the highest hardness is observed in the central area of a weld seam. The reduction of hardness corresponds to the area of overheating and the sections of incomplete recrystallization.

Such uneven dispersion of structure and properties over the weld connections section may cause concentration of high thermal stress and increase the risk of cracks and structural breaks in general.

**Conclusion**

Microstructure of steels EH36 and X70 in a state after controlled rolling is ferrite-pearlite with expressive banding of pearlite clusters and ferrite grains elongated along the rolling direction, where recrystallization processes did not finish in time.

The presence of pearlite banding can lead to anisotropy of mechanical properties. Along the normal to sheets surface plane he tensile strength, yield strength and percentage of elongation are almost twice lower than in directions in the plane of the sheet; the correction of this structural imperfection of steel EH36 after controlled rolling by an additional thermal treatment is possible.

Additional heating up to 200 – 900°C with subsequent cooling by ambient air leads to non-monotonic change of hardness.

Welding, as one of the types of technological heating, leads to the change in structure in the heat-affected area and uneven dispersion of hardness over the section of welded samples. The weld metal area has the highest hardness; such a change of properties in a weld seam may increase the risk of cracks and structural breaks in general.

**References**

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