Structure and properties formation of hot-rolled steel 01UT after high preassure torsion

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Abstract
The study results of ultra-low carbon steel 01UT after several plastic deformation (SPD) by high pressure torsion (HPT) are shown at present paper. Nanostructures with crystallites which are less than 100 nm were observed in steel 01UT after HTP. The possibility of raising nanohardness and lowering elastic modulus for steel 01UT is guaranteed to provide better tendency to deep stretch forming comparing with the initial hot-rolled state.

Key words: SEVERAL PLASTIC DEFORMATION (SPD), HIGH PRESSURE TORSION (HPT), NANOSTRUCTURE, IF-STEEL, NANOINDENTATION

Introduction

A thin sheet of low carbon steels is widely used in mechanical engineering and automotive in the manufacture of cold formed parts of the car body. Vehicle body consists of 90 percent of high-strength steels, which must have high plastic properties during the manufacture car parts [1, 2].

The problem of improving of ability to deep stretch forming of the punching cold sheets while maintaining the strength in the industrialized countries is solved by using IF - steels (Interstitial Free Steels). According to the literature, favorable microstructure and ability to the deep stretch forming can be achieved during processing in the ferritic temperature range in the finishing mill with continuous broadband of IF-steels with a carbon content less than 0.02% [3].

IF-steels are high-plastic and their structure is stabilised by the titan microadditives. They contain low carbon quantity (less than 0,02 %) which is completely connected with nitrogen in carbides, nitrides and carbonitrides. Durability is caused by the hardening of the firm solution by silicon, manganese and phosphorus [4, 5].

These studies are aimed to increasing of complex mechanical properties and improving of ability to the deep stretch forming of ultra-low carbon steel for producing high-quality rolled products. To achieve this goal the following tasks are solved: establishing of regularities of microstructure formation of ultra-low-carbon steel 01UT after HTP.

Material and method

The object of research is cards of the ultra-low-carbon steel 01UT, with thickness of 3,5 mm. The chemical composition of the steel 01UT is resulted in Table 1.The temperature-deformation modes of rolling of 01UT are resulted in Table 2. Cooling of samples after the rolling is carried out on air with average speed ~ 8°C/s. Hot-rolled steel samples subjected to HPT. The HPT mode is shown in the Table 3.

Table 1. Chemical mixture of steel 01UT

Chemical composition, mass %											
C	Mn	Si	P	S	Cr	Ni	Cu	Al	Ti	N	Ca
0,003	0,12	0,01	0,005	0,011	0,01	0,01	0,02	0,05	0,07	0,004	0,0003

Table 2. Temperature –deformation mode of rolling steel 01UT

T_{warm}	T_{1rol}	h_0	h_1	Δh_1	e	T_{2rol}	h_2	Δh_2	e	$\sum \Delta h$	$\sum \varepsilon$
°C		mm			%	°C	mm		%	mm	%
1000	970-980	3,5	1,80	1,70	48,6	730-740	1,3	0,5	27,8	2,2	62,9

Notes: T_{warm} - heating temperature of sheet steel; T_{1rol} - rolling temperature of sheet steel during the first pass;h_0- initial thickness of the sample; h_1 - thickness of the sample after the first pass; Δh_1 – absolute punching of metal of the first pass; ε_1 - relative extent of the metal deformation of the first pass; T_{2rol} - rolling temperature of sheet steel during the second pass; h_2 - thickness of the sample after of the second pass; Δh_2 – absolute punching of metal during the second pass; ε_2 - relative extent of the metal deformation during the second pass; $\sum \Delta h$ - the total punching of metal after two passes; $\sum \varepsilon$ - the total extent of the metal deformation after two passes.

Table 3 - HPT mode for steel 01UT

Steel	T,°C	D,mm	S_0, mm	N	P, kgs/cm^2	S_1,mm	e	g
01UT	25	15	0,7	5	200	0,3	3,8	44,85

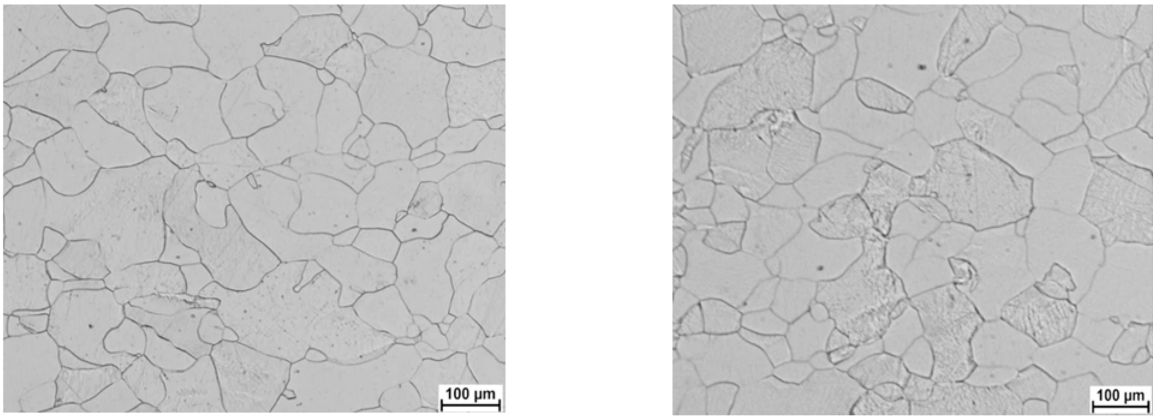
Note: T - test temperature, S_0 - thickness before the test; S_1 - thickness after the test; N - number of revolutions;
D - diameter of the sample; P - pressure; Ɛ - true strain in torsion, γ - shear deformation

The grains size of ferrite was measured on samples along and aslant rolling directions with the microscope «Neophot-21» with a method of casual secants, and also by means of software – programs Adobe Photoshop CS2. The measurement of mechanical properties carried out by means of universal car «Instron». X-ray analysis was performed on DRON-3M CuKα - radiation.

Nanohardness measurements were performed by using «Nanoindenter G200» manufactured in the USA with the use of diamond triangular pyramid Berkovich. The most common method of data analysis in the nanoindentation is the Oliver-Pharr methodology, which finding the hardness and elastic modulus of the sample size without measuring its direct methods [6].

Experiment results and their discussion

The steel 01UT microstructure after treatment on a mode with endurance at 1000°C and rolling in the austenitic and ferritic temperature areas with deformation in two passes extent of 62,9% (Figure 1, Table 2) is specified. The following variation in grain size takes place: the fine grained ferritic grains are formed in the superficial zone of sheet (Table 4). Some grains have the extended form with a parity of axes 1:2 (1:3).

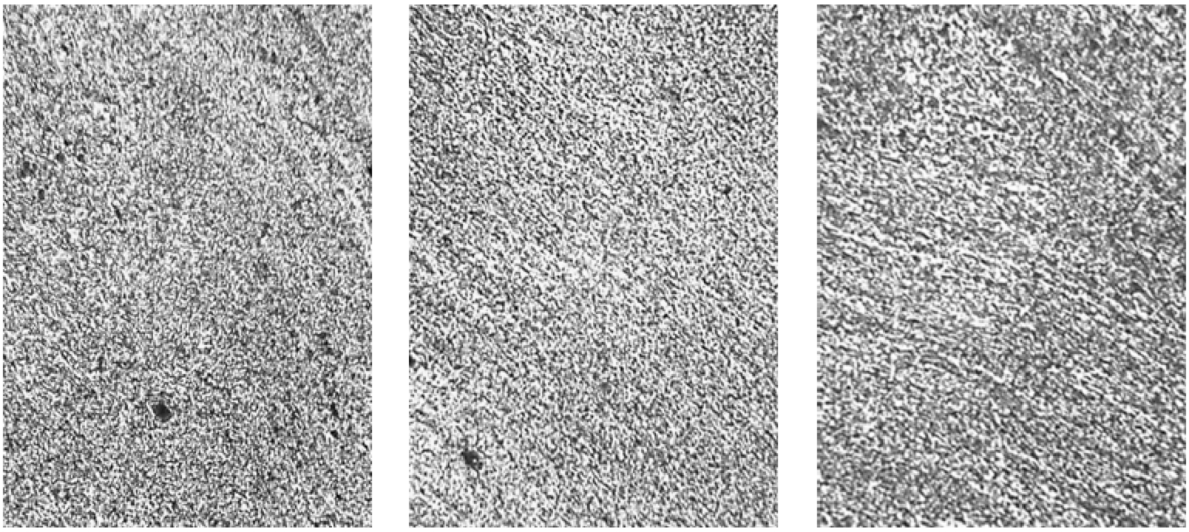


a) b)

Figure 1. Microstructure of 01UT in superficial (a) and central (b) strip zones after hot rolling for two passes

Table 4. The average grain size of ferrite and layer thickness of fine structure steel 01UT

The total extent of metal deformation, %	Ferrite grain size, mkm				The thickness of layer of fine-grained, mkm		The final thickness of sheet, mm
	Along the direction of proskating rinks		Across the directions of proskating rinks		Along the direction of proskating rinks	Across the directions of proskating rinks	
	Superficial zone	Central zone	Superficial zone	Central zone			
62,9	15-25	20-130	10-30	10-115	100-200	200-250	1,3



a) b) c)

a - central part, b – middle part, c – periphery part

Figure 2. Microstructure of 01UT after HPT N=5, d=15 mm; ×250

The termination of rolling in the ferritic steel 01UT contributed to the formation of zonal assorted structure. This may be due to the occurrence of static recrystallization process. The decomposition of austenite with the ferrite release took place during a pause between the passes. In the surface areas which were cooled with higher speed recrystallized fine grained ferritic structure is observed, the structure of central zone is consequence of incomplete austenite decomposition. In this way, the results have shown that the largest nonuniform ferritic structure is observed during the processing of samples after rolling in two passes in the austenitic and ferritic temperature ranges during the deformation of steel 01UT.

The microstructure formation along the sample radius of the steel 01UT after HPT is present in the Figure 2.

Steel 01UT after HTP has uniform structure from the centre to the mid-range of sample (Figure 2) and only on the sample periphery strongly pronounced deformation bands, which are coinciding with the direction of torsion (Figure 2c), are formed. When torsional deformation scheme is implemented by the type of simple shear, which is characterized by a constant change in the angle between direction of action of maximum shear stress and direction of greatest elongation. During torsion all new slip systems, and motion of dislocations developing in previously untapped systems are switched on [7].

X-ray diffraction data for the steel 01UT after HPT are presented in Table 5.

Table 5. X-ray diffraction analysis data for steel 01UT after rolling and HPT

Steel grade	a, nm	L_{110}, nm	L_{220}, nm	L, nm	M, 10^{-3} N/m^2	D_{110}, 10^{10}, cm^{-2}	D_{220}, 10^{10}, cm^{-2}
01UT (rolling)	0,287	91,3	61,8	119,4	1,6	6,65	5,61
01UT (HTP)	2,8648	75,7	49,3	99,1	1,51	9,67	46,2

Note: a - lattice parameter, L - crystallite size, M - tension, D - density of dislocations.

Analysis of the X-ray diffraction data (Table 5) has shown that after HPT crystallites size are near to nano size - L <100 nm, and microstrain is decreasing to the value 1,51 N/m^2. Dislocation density is increasing at the both planes: by 1,5 times - plane (110) and by 8 times - plane (220).

Figure 3 shows the ratio between the depth of penetration and nanohardness for steel 01UT in the initial state and after HPT.

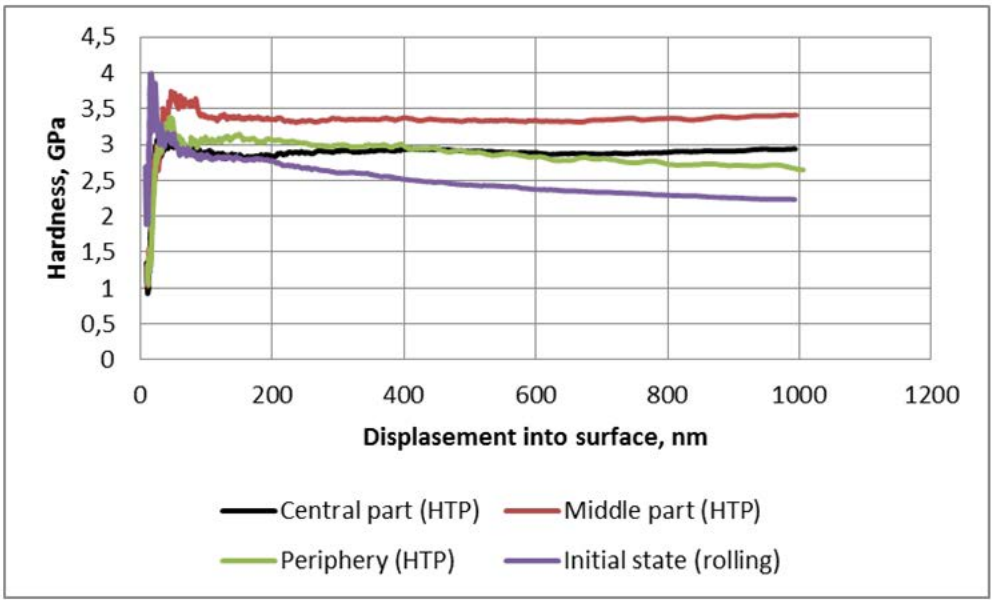


Figure 3. Nanohardness for steel 01UT with depending on penetration of indenter

Plastic flowing in all samples begins with h = = 150-200 nm (Figure 6), this control becomes possible with depth of hardness. Thus, the bend in the curve of hardness of movement corresponds to the transition from elastic to elastic-plastic deformation in the print zone. Determination results of nanohardness and modulus are shown in the Table 6.

Table 6 - The results of hardness and elastic modulus measurements by indentation for steel 01UT

h, nm	After rolling		After HPT					
	H_0, hPa	E_0, hPa	H_1, hPa	E_1, hPa	H_2, hPa	E_2, hPa	H_3, hPa	E_3, hPa
500	2,439518	214,0209	2,905051	199,7546	3,338867	188,2865	2,893071	43,98233
900	2,259315	203,2915	2,908607	188,9383	3,375022	176,2574	2,711111	29,09058

Note: h- penetration depth of indenter, H_0 - hardness after rolling, E_0 - modulus after rolling, changing the hardness $H_1 – H_3$ and elastic modulus $E_1 – E_3$ along sample radius.

These results suggest that the hardness of steel 01UT after HPT varies according to the radius of sample from the centre to periphery: hardness increases from H_1 = 2,9 GPa to H_2 = 3,3 GPa, respectively. Hardness changing confirms the localization of deformation at the periphery of sample. The values of the modulus are greatly reduced from the centre to periphery of the depth of penetration of indenter into sample material. Reduced modulus after HTP ensures improved formability of steel 01UT.

Conclusions

As demonstrated, zonal variation in grain size in structure of the sheet steel 01UT after deformation in two passes is consequence of incomplete recrystallization process in the central zone of sheet. As a result, low-carbon steel 01UT after HPT formed heterogeneous structure, which is characterized by the passage of metal in the direction of torsion. Such heterogeneity due to changes in the degree of deformation at periphery of HPT to the centre of sample.

Analysis of the X-ray diffraction data have become 01UT after HPT confirms the formation of nanostructures with crystallite size less than 100 nm.

It was found that hardness and modulus for steel 01UT after HPT are changed along the radius of sample. The hardness increases and modulus decreases from the centre to periphery. The research of the mechanical properties of steel 01UT showed that with increasing of degree of deformation increase of values of strength properties and decrease of plastic characteristics, and as a result, the ability to deep stretch forming are observed.

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Kinetics of phase transformations in chromium-manganese cast iron

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