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Analysis of the Effect of Mechanical Oscillations Generated During Welding on the Structure of Ductile Constituent of Products Made of Steel 10G2FB

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Abstract. Under open construction, the requirements to welding processes are very critical since reliable connections requires complex, costly and sometimes impossible processes that involve fixed machines and devices. Therefore, in such cases it is important to carry out welding work using mechanical vibrations. Elastic oscillations in the weld metal result in uniform crystallization of the melt and formation of a dispersed structure. This also results in enhancement of diffusion processes while promoting degassing process in weld metal.

Introduction

The use of vibration treatment in the welding process has a positive effect on the physical and mechanical properties of materials in different areas of the welded joint of dissimilar steels, increasing their impact and yield strength.

Moreover, due to the formation of additional centers of crystallization, the structure of the metal becomes more dispersed, resulting in improvement of formed metal properties. Elastic oscillations in the weld metal result in uniform crystallization of the melt and formation of a dispersed structure. This also results in enhancement of diffusion processes while promoting degassing process in weld metal. We also assume that elastic oscillations can contribute to positive changes in the formation of the structure in the metal of the fusion area and in the metal of heat-affected area (HAA). Due to effect of elastic oscillations, which are purposefully formed in the joint already at the stage of its welding, it is possible to reduce the residual stresses. Thus, due to elastic vibrations, it is possible to influence the formation of the weld metal structure and HAA, regulate their diffusion processes and change the stress state in the welded joint. These components are the main factors that significantly affect the resistance of welded joints of high-strength steels to slow and brittle fracture.

Analysis of Publication

The crushed structure of the weld metal and heat-effected area after the welding process significantly improves the properties of the welded joint as a whole in comparison with the coarse-grained structure.

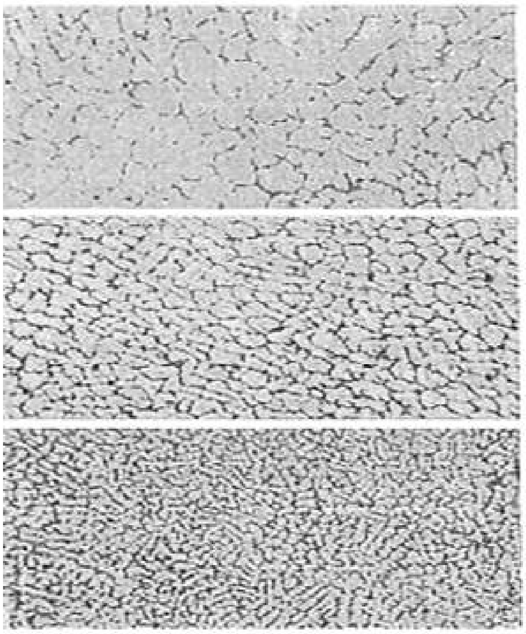
It is possible to distinguish two main methods for affecting the process of crystallization of welding bath metal: metallurgical, which is associated with the properties of the metal and technological, which determines the methods of influencing the metal.

The metallurgical method is based on the use of metal with natural fine grains or modification of the welding bath with chemical elements through filler wire, fluxes or special pastes, or by introducing the appropriate powder materials directly into the tail part of the bath. In some cases, it is necessary to limit the content of impurities that promote grain growth upon heating.

However, it is not possible to use the seam modification process in all cases. For example, in some magnesium alloys, modification results in grain growth. There is a need to look for other ways, due to the complexity of metallurgical phenomena that occur in conditions of non-uniform crystallization of liquid metal during fusion welding.

Methods for pre-treatment of base metal before welding are also considered, including, for example, mechanical pre-hardening or hardening of the edges of the weld metal. The recrystallization process takes place in the deformed metal area, which promotes the formation of very fine grains [1].

Technological methods include not only methods for optimization of process parameters of welding, but also methods of external force, heat or electromagnetic influence on the melt during its crystallization (Fig. 1.)



a

b

c

Fig. 1. The influence of the frequency of external arc vibration on refining of the elements of the primary structure of the weld metal during welding of steel 30HGSNM2A (q/Vw = 4 kJ/cm) x50: a - welding without oscillations; b - welding with an oscillation frequency of 1.0 Hz; c - oscillations with a frequency of 2.0 Hz

These methods include:

- use of vibrations of the welded product;
- input of energy from a pulsed heat source;
- the use of pulsed feed filler wire in different spatial positions;
- the use of sources with modulation of the welding current, which affects the liquid metal of the tail part of the bath;
- in some cases, the introduction of individual heat sources that affect heat-affected area near the centerline of the seam;
- application of external electromagnetic influence (EMI) on the melt in continuous mode and reversible or pulsating influence with different frequency of the magnetic field.

Method of external periodic influence is the most common, as suggested by analysis of literature sources, among the most currently used methods [2].

However, the use of many methods of external periodic influence on the bath melt during curing often does not provide any positive effect, and in some cases leads to a negative result. This fact indicates the complexity of the crystallization process, the controllability of which is not determined only by external disturbances. In many cases, negative results suggest the presence of internal causes that effect independently of external influences. The layered structure in the cast metal and the formation at the cooling stage of chemical inhomogeneity in the structure, of course, is the reason for the periodicity of the crystallization process.

One of the methods for improvement of crack resistance of alloys is the external influence on the metal that crystallizes. Electromagnetic, ultrasonic, low-frequency and other types of oscillations are used as sources of external influences [3 - 5]. Their effect results in microcrystalline structure, which has increased mechanical properties that reduces the probability of crack formation [6].

The group of contacts includes methods of ultrasonic high-frequency oscillations of the welding bath, product or electrode, or mechanical low-frequency oscillations of the product or electrode.

Non-contact methods include welding under external electromagnetic field, modulated current welding, as well as the use of radiant heat sources operating in pulsed mode in the form of light, laser or electron beam [7].

To refine the structure and improve the properties of the weld metal vibration induction melting technology [8 - 11] is used. According to this technology, the part is subjected to vertical or horizontal vibration when the powder mixture is in the molten state.

Object and Problem Statement

Having analyzed the considered works, we came to conclusion that application of various methods of influence on steel welding process in order to increase the performance is very actual. However, the most noticeable effect is reached when m metal hardening. Therefore, they can be considered as the most effective methods for improving certain properties of metals and alloys.

Therefore, the aim of the work was to increase the mechanical characteristics of the weld and heat-affected area by changing their structure under the action of mechanical vibrations.

Main solved tasks

- evaluate the effect of vibration on the structure of ductile constituent of steel ;
- to establish the dependence of the mechanical characteristics of the weld and heat-affected area from frequency of oscillations generated during welding.

Material and Methods of Study

Low-carbon industrial steel 10G2FB, which is widely used in metallurgical, oil, gas and other industries, was chosen as a material for research.

Low-carbon microalloyed steel 10G2FB used for controlled rolling refers to steels of high strength class (σT≥550 MPa). The main initial material was sheets of steel 10G2FB produced by Ilyich Iron and Steel Works. The chemical composition of steel 10G2FB was determined on samples taken from the finished steel (table 1).

Table 1. Chemical composition of steel 10G2FB

C	Mn	Si	S	P	V	Nb	Fe
0.10	1.83	0.18	0.005	0.015	0.088	0.022	Et al.

Technological process for manufacture of sheets from steel 10G2FB (strength group X70 according to API 5St) at Ilyich Iron and Steel Work in accordance with TU 14-1-52 - 93 and TU 14-1-40 - 34 is shown on the diagram (Fig. 2).

Mechanical vibration at power of 250 W and frequency of 60 was transmitted to the welded joint, where elastic oscillations were excited.

Studies of elastic vibration oscillations on the structure of welded joints were performed by mechanized welding of 10G2FB steel joints with Megafil 821 R wire 1.2 mm in diameter in a mixture of argon and carbon dioxide (82% + 18%).

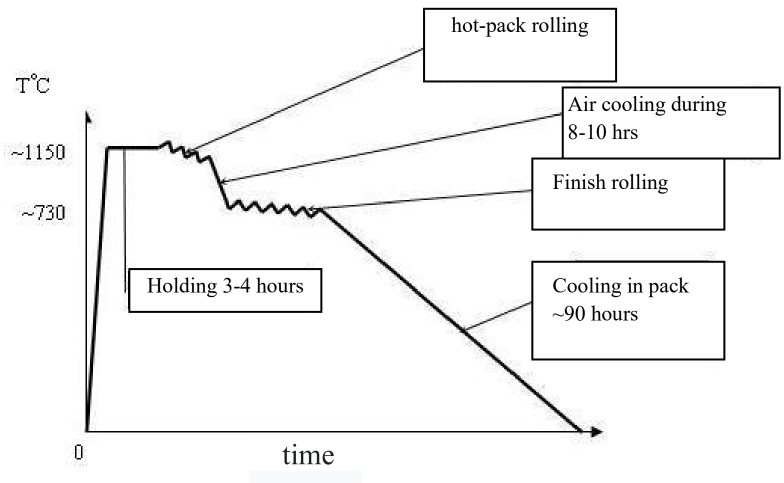


Fig. 2. Scheme of rolling sheet steel 10G2FB at Ilyich Iron and Steel Works

Butt joints with a V-shaped opening 90 × 140 × 18 mm. weld heat input 9.5 kJ/cm (IHA = 160 - 180 A, UD = 26 - 28 V, VHA = 11.4 - 13 m/g).

The parameters of elastic vibration oscillations that were excited during welding of the above connection are shown in table 2.

Table 2. Modes of vibrational elastic oscillations during welding of butt joints of steel 10G2FB

Steel type and weld joint size	Engine speed **n**, [rpm]	Vibrating movement **S_{PC}**, [μm]	Speed of movement **V_{PC}**, [mm/s]	Frequency of oscillations **N**, [Hz]
10G2FB, 290×140×18 mm	3500	10.0…11.1	4.3…5.2	60

Main Material of Study

It is known that during the crystallization of melts vibration processes can lead to breaking of dendritic branches and even axial formations, affect the capillary properties of melts, resulting in reduced grain size, reduced porosity and size of shrinkage shells, as a result, improvement of mechanical properties.

Figure 3 shows the microstructure of a 10G2FB weld, which was welded under the action of frequencies of 60 Hz, and Figure 4 shows distribution of metal hardness of steel joints 10G2FB when measuring the length and height of its cross section

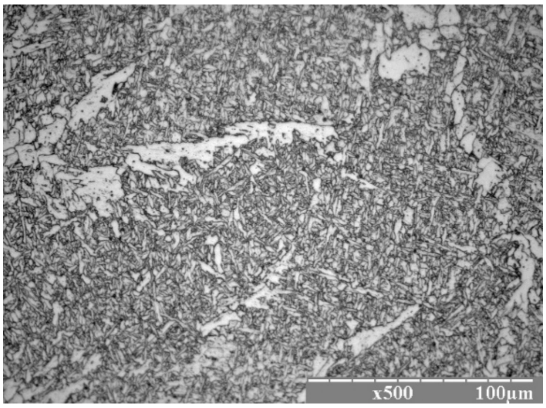
Upon mechanized welding of butt joints of 10G2FB steel with Megafil 821 R wire, the structure of the weld metal consists of a dendritic structure with lower bainite in the middle. Pre-eutectoid ferrite is formed at the boundaries of dendritic grains.

In metal overheated area, HAA microstructure consists of a dispersed ferrite-perlite structure. There are no non-metallic inclusions inside ferrite grains.

Welding under vibration elastic oscillations results in refining of weld metal, but the hardness of the structural components does not change significantly.

In root of metal overheated area (section I-I in Fig. 4), the hardness of the structure increased slightly (from 185 HRA to 198 HRA). In the middle and upper parts of the joint (sections II-II and III-III) the hardness of the metal decreases from 198 HRA and 208 HRA to 178 HRA and 186 HRA, respectively.

The results of studies of the effect of elastic vibrations during welding of butt joints of high-strength low-alloy steel on the mechanical properties and cold resistance of the thermal impact zone are shown in table 3.



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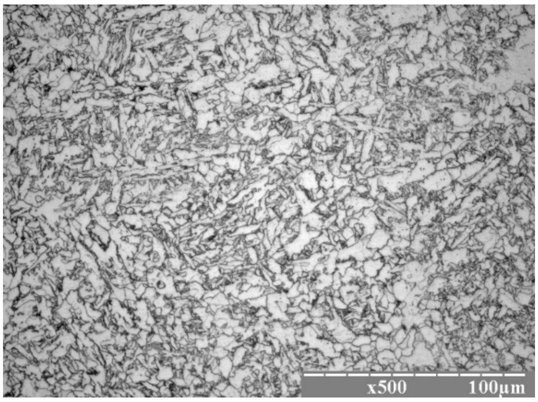

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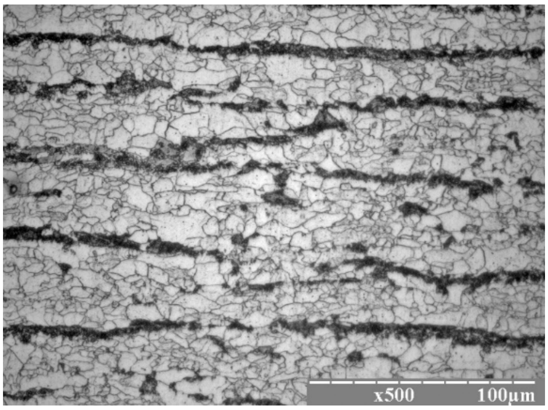

c

Fig. 3. The structure of steel 10G2FB upon vibration welding at frequency of 60 Hz: a - weld (bottom); b - HAA structure (middle); c - the structure of the base metal (middle)

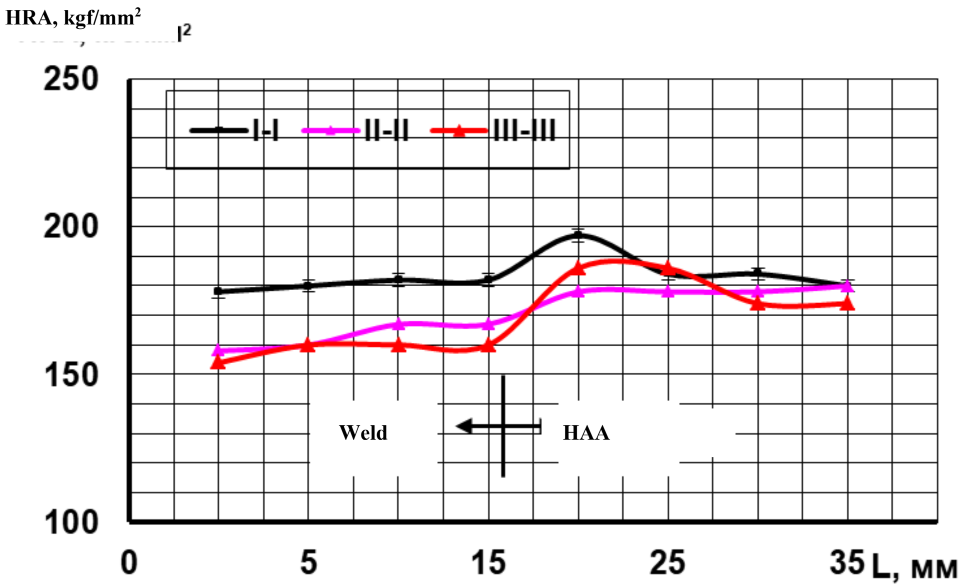

Fig. 4. Distribution of metal hardness of the joints of high-strength steel 10G2FB during mechanized welding with Megafil 821 R wire under vibration (60 Hz)

Table 3. Influence of elastic oscillations on mechanical properties of metal of heat-affected area

Weld joints	Frequency of oscillations, Hz	σ B, [MPa]	σ T, [MPa]	δ 5, [%]	Ψ, [%]	KCU +20, [J / cm²]	KCU -40, [J / cm²]
10G2FB, Megafil 821 R	-	580	510	27.0	76.5	203	115
	60	620	541	27.5	78.5	181	184.5

The conducted researches allow establishing the influence of elastic vibration oscillations of low specific power on the change of the metal structure of welded joints of high-strength low-carbon steel 10G2FB. The obtained results indicate that elastic oscillations in the frequency range of 60 Hz do not lead to deterioration of the structure, but contribute to its refining as well as formation of a more homogeneous structure in the weld metal. Moreover, the structure of metal HAA does not change significantly.

To detect the effect of low specific vibration on the change of toughness values during welding, dynamic tests of 10G2FB steel sheets were performed.

Samples were cut so that the incision lay in the plane of the welding area. This arrangement of the notches was chosen in order to study the conditions of occurrence and propagation of the crack along the welded joints, as well as the planes of the perlite strips.

The samples were tested at positive +20 °C and negative -40 °C temperatures.

Figure 4 shows the fractography of the fracture at + 20 ºC: a - the left part of the fracture, the picture clearly shows that the nature of fracture is ductile; b - the left part of the fracture with a shift to the left, the nature of the fracture is also ductile; c - the left part of the fracture, to the left of the "cornice", the nature of the fracture is brittle and ductile; d - right part of the fracture (lower part of the slope), fracture is ductile; e - right part of the fracture (middle part of the slope), fracture is brittle-ductile ; f - right part of the fracture (upper part of the slope), fracture is brittle-ductile.

Figure 5 shows the fractography of the fracture at –40 °C, the nature of the fracture is brittle. Figures show a large number of non-metallic inclusions (marked with blue arrows) and pores (marked with a red arrow), which are the cause of brittle constituent in the fracture.

Conclusions

The conducted studies allow establishing the influence of elastic vibrational oscillations on the structure of ductile constituent and mechanical properties of welded joints of 10G2FB steel during welding.

The obtained results indicate that depending on the oscillation parameters, the structure of the weld metal and HAA of welded joints may change. Elastic oscillations with a frequency of 600 Hz do not lead to deterioration of the structure, but contribute to its refining.

In the case of mechanical vibration at frequency of 60 Hz, the values of impact strength are within the limits established by GOST. However, it can be noted that the values of impact strength at lower temperatures are higher. This means that the vibration at 60 Hz lowers the threshold of cold brittleness.

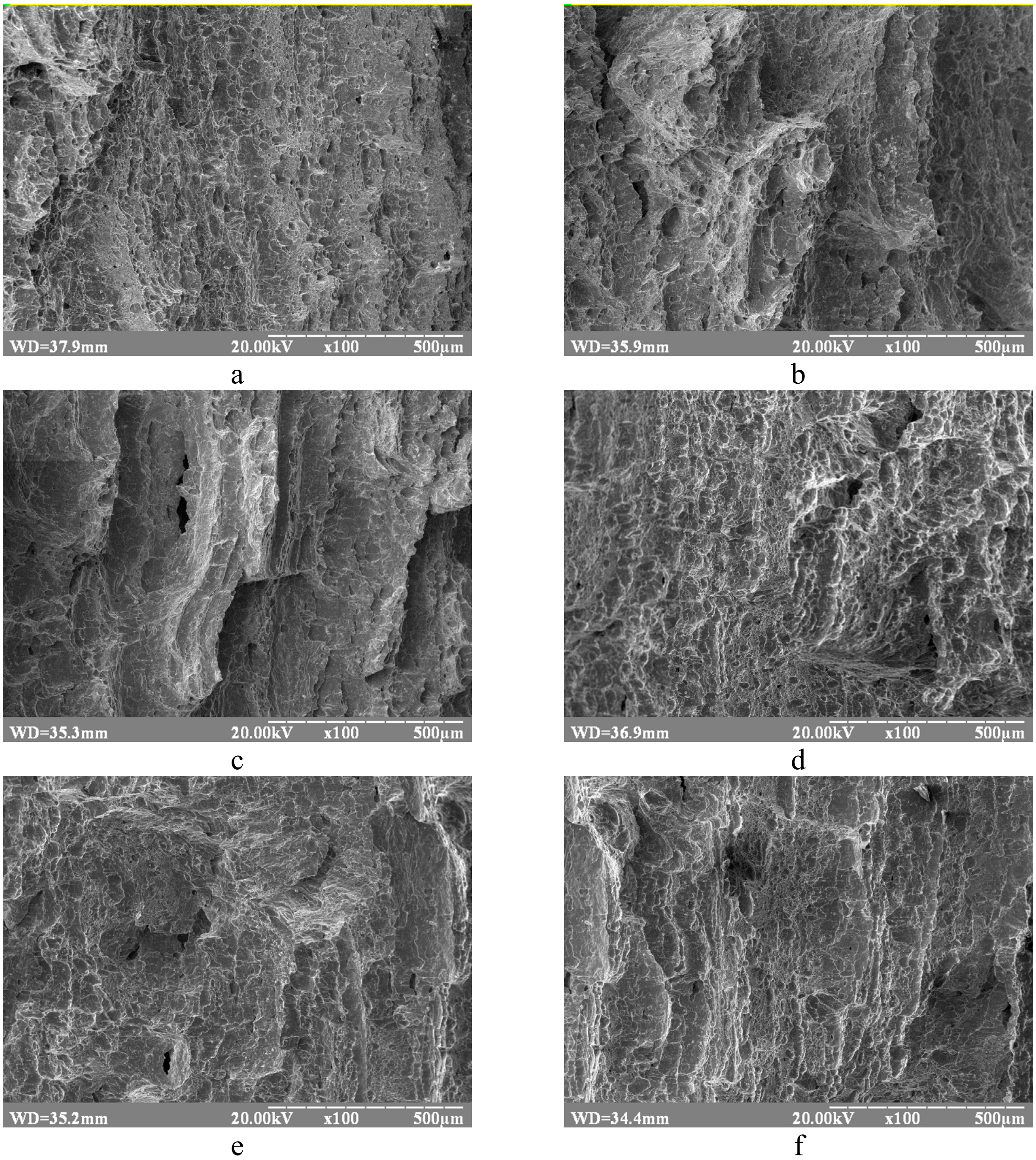

Fig. 4. Fractography of fracture at + 20 ºC: : a - the left part of the fracture (100%B); b - the left part of the fracture with a shift to the left(95%B) ; c - the left part of the fracture, to the left of the "cornice" (25%B); d - right part of the fracture (lower part of the slope), (100%B); e - right part of the fracture (middle part of the slope)(40%B); f - right part of the fracture (upper part of the slope) (60%B)

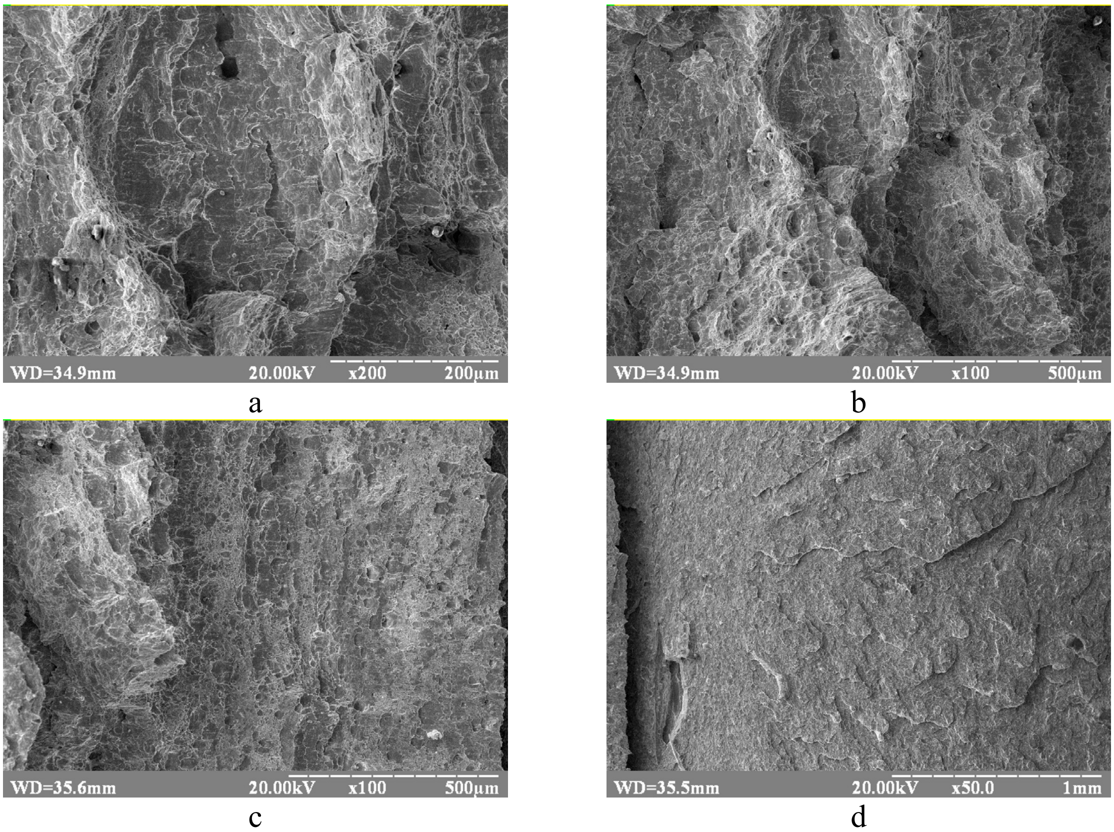

Fig. 5. Fractography of fracture at -40 ºC: a - the left part of the fracture (10% B); b - the left part of the fracture (image shift down) (40% B); c - the left part of a fracture (shift of the image to the right) (25% B); d - the right part of the fracture (5% B)

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