http://www.moderntechno.de/index.php/meit/article/view/meit16-01-001
DOI: 10.30890/2567-5273.2021-16-01-001

EXPERIMENTAL STUDY OF THE INFLUENCE OF VIBRATION ON THE MICROSTRUCTURE OF THE WELD OF A PIPE BILLET

ЕКСПЕРИМЕНТАЛЬНЕ ДОСЛІДЖЕННЯ ВПЛИВУ ВІБРАЦІЇ НА МІКРОСТРУКТУРУ ЗВАРНОГО ШВА ТРУБНОЇ ЗАГОТОВКИ

Balakin V.F.
Doctor of Science, Professor. ORCID: 0000-0003-0876-7516.
National Metallurgical Academy of Ukraine, Dnipro, Ukraine.
Kadylnykova T.M.
Doctor of Science, Professor. ORCID: 0000-0003-0817-9466.
Dnipropetrovsk State University of Internal Affairs, Dnipro, Ukraine.
Savkin S.V.
PhD student. ORCID: 0000-0003-0254-6544.
National Metallurgical Academy of Ukraine, Dnipro, Ukraine.
Kadylnykova A.V.
PhD student. ORCID: 0000-0003-2516-9825.
E.O. Paton Electric Welding Institute, Kiev, Ukraine.

Abstract. *The article discusses the results of an experimental study of the microstructure of the weld metal of pipe billets subjected to vibration processing during the welding process. The experimental study was divided into the following stages: welding of longitudinal preformed pipe blanks using vibration action; production of thin sections and study of their microstructure in the zones of the welded seam; processing of the data obtained during the experiment. When studying the microstructure, special attention was paid to the areas of overheating and normalization, as the areas of the heat-affected zone most characterizing the quality of the weld.*

The tendency of change in the grain size of the weld metal at various frequencies of vibration used in the welding process, as well as in its absence, has been investigated. An important place in the study was given to the study of the degree of graininess of the studied structure.

Key words: *vibration treatment, welded seam, heat-affected zone, microstructure, uneven grain size, pipe billet.*

Introduction. Analysis of the state of the pipe market over the past decades has shown that the requirements for the quality and reliability of products are constantly increasing on the part of world consumers of welded pipes. Particular attention in this matter is given to obtaining welded pipes with improved strength characteristics, which is achieved by improving the quality of the weld structure.

Formulation of the problem. The coarse-grained structure of the metal in the area of the weld joint, together with the heterogeneity of the structure, negatively affects the physical and mechanical properties of the tubular product as a whole. Annealing after welding of electric-welded pipes in the current technological process is required not only to remove residual stresses, but also to refine the structure and increase its uniformity.

However, any thermal components of the technological process are associated with large material costs for the enterprise, the duration of the heating process in time, and in some cases, with the non-environmental friendliness of certain operations.

Analysis of publications on the topic of research. Known scientific works [1, 2], which provide reliable information about the positive effect of vibration on the refinement of the crystal structure of ingots from steel and alloys, reduction or complete elimination of the transcrystallization zone due to the growth of equiaxed crystals, reduction of zonal and dendritic heterogeneity, increase in mechanical and special properties of metals and alloys.

Also, according to well-known studies [3], vibration treatment of welded samples made of low-carbon steel in modes that ensure the flow of elastic-plastic deformations makes it possible to reduce stresses of the first kind, measured by the tensothermal method, by 50 - 60%, and during heat treatment, the decrease occurs by 70 % and more. The stresses of the second kind in the fusion zone, determined by the X-ray method, after vibration treatment are reduced by 45%, and after heat treatment - by 65%.

However, in the works described above, vibration treatment was used in relation to the crystallized metal of the weld, in which the formation of total residual stresses has already been completed, while in works [4-11], the positive effect of vibration on the molten metal during crystallization was proved.

These studies create real prerequisites for an experimental study of the effect of vibration processing in the process of welding a pipe billet on the microstructure of the weld metal.

The purpose of this study is to identify patterns of change in the size and uniformity of weld metal grains in the heat-affected zone (HAZ) at various frequencies of vibration used in the welding process, as well as in its absence.

Presentation of the main material. To study the microstructure, 5 samples of welded pipes were presented, presented in Table 1. The chemical composition and manufacturing technology of the initial hot-rolled strip are the same, the differences were only in the conditions of welding, namely in the frequency of vibration applied to the samples.

Tab. 1.

Samples for the study of the microstructure.

Sample number	1	2	3	4	5
Vibration frequency, Hz	0	25	50	125	200

The initial billet was obtained at the enterprise of PrJSC "DMZ KOMINMET", the molding was carried out in the electric pipe shop No. 2 using the pipe profile electric welding unit TPESA 20-114. As an initial billet for the experiment, a formed pipe billet without applying a weld seam was selected, produced according to TU 14-236-15-93 "Electric-welded steel pipes for domestic needs". The main characteristics of the blank for the experiment are presented in Table 2.

Table 2.

Characteristics of the original workpiece

Parameter	Value
Outside diameter, mm	89
Wall thickness, mm	4
steel grade	3PS (GOST)
Swim number	1010610

It should be noted that the quality of welds made in laboratory conditions, in the total mass, did not correspond to international standards for welded joints, however, this fact did not affect the results of the study. However, it will not be correct to compare the obtained data with experimental welding modes.

To assess the effect of welding modes on the quality and changes in the microstructure, transverse sections were made. The study of the microstructure of thin sections was carried out after etching in a 4% alcoholic solution of nitric acid (nital).

For the welded joint, the classification was carried out by zones: the deposited metal zone, the heat-affected zone and the base metal zone. The deposited metal zone is represented by columnar crystallites formed from the deposited metal (melt of the base metal and filler wire or electrode), while the direction of crystal growth always coincides with the direction of heat removal. This is followed by a heat-affected zone, consisting of areas of incomplete melting, overheating and normalization.

The study of the effect of welding modes on the microstructure was carried out by assessing the morphology and quantitative characteristics of the structural components of the most sensitive and characteristic zones - deposited metal, overheating and normalization.

The sizes of the deposited metal crystallites in all samples have a similar grain size, therefore, they will not be considered in detail in the future. The base metal has the classic ferrite-pearlite structure of hot-rolled metal (Fig. 1). The average grain size of ferrite is 17 microns.

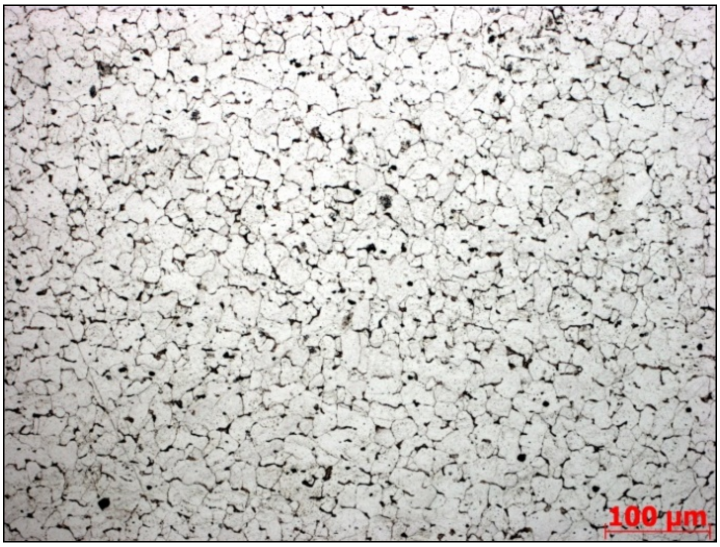


Fig. 1 - The structure of a hot-rolled billet for the manufacture of welded pipes, steel grade 3PS

Research results. Next, each of the samples presented for analysis will be analyzed. **Sample #1** was obtained without vibration treatment. The welded joint zones of this sample are clearly shown in Figure 2.

The structure of the joint has a characteristic appearance of a welded seam, however, attention is drawn to the presence in the area corresponding to the zone of incomplete melting of an extremely fine-grained structure (the grain size of ferrite does not exceed 8 µm, while the average grain size is 3.2 µm), closes its framing from large grains of ferrite, elongated in the direction of heat removal. The presence of ferritic framing in the structure of the weld, as a rule, is characteristic of medium- and low-carbon steels when welding is performed correctly. It should be noted that a similar feature of the weld was found only in the first sample; in the remaining samples, there is no ultrafine grain section under the molten metal layer.

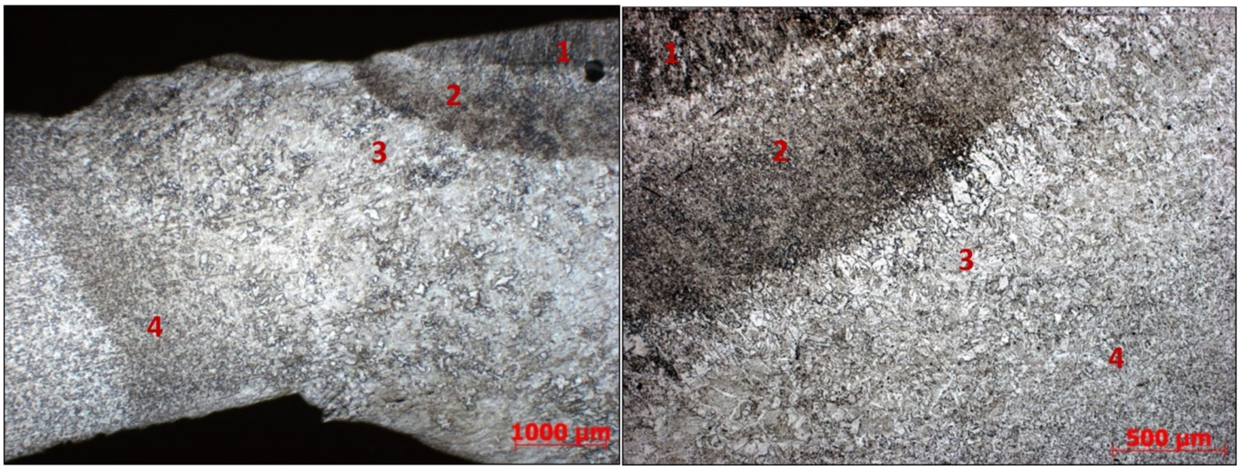
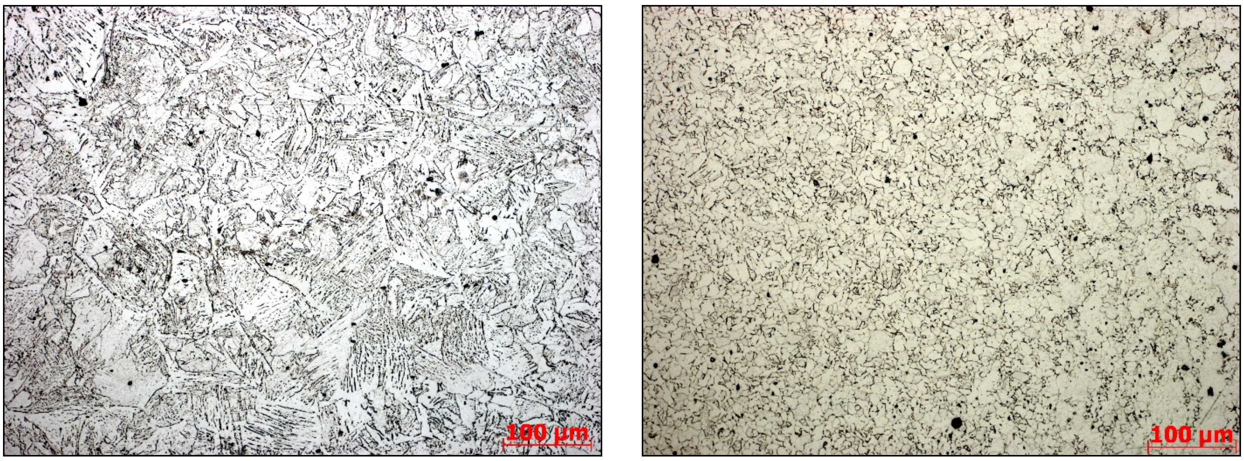


Fig. 2 - Structure of the weld, Sample #1: 1 - deposited metal zone, 2 - area with ultrafine grain, 3 - overheating area, 4 - normalization area

After the ferrite framing, an overheating section follows, which looks like a needle-like structure, which passes into a normalization section. The average size of Widmanstätt bags is 93 µm. The score of the Widmanstätt structure in the overheating section of the heat-affected zone of the weld: 2-3.

The average size of the normalized grains is 8 µm. According to well-known literature data, the normalization section is characterized by the smallest ferrite grain when welding low-carbon steels, but here the structure is noticeably larger than the fine-grained structure discussed above. The degree of unevenness in the section of normalization of the heat-affected zone of the weld is 0.44. Typical photos of the microstructure of overheating and normalization areas are shown in Figure 3.



a b

Fig. 3 - Structure of the weld, Sample #1: a - overheating section, b - normalization section

Sample #2 was obtained using vibration treatment with a frequency of 25 Hz. Structural zones typical for the structure of this weld are shown in Figure 4. The structure of the weld zones is characterized by the smallest extent of the heat-affected zone in comparison with all other samples presented for analysis.

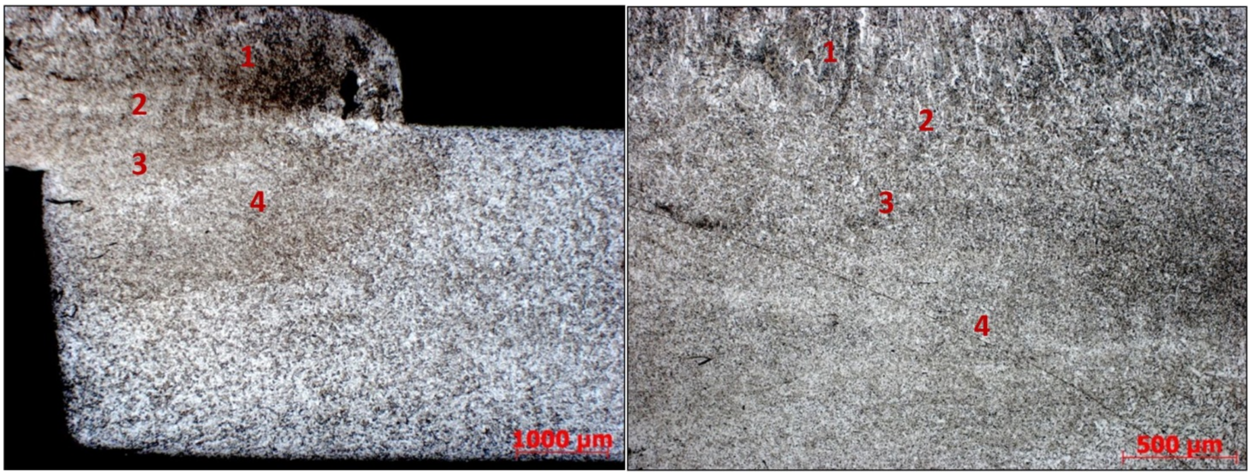
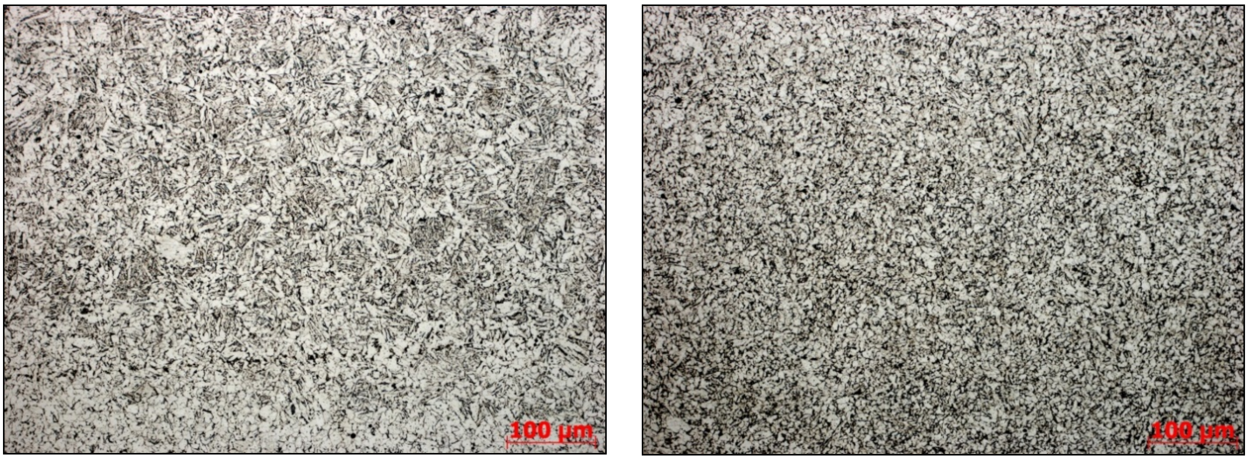


Fig. 4 - Structure of the weld, Sample #2: 1 - deposited metal zone, 2 - fusion section, 3 - overheating section, 4 - normalization section.

Crystallites have a size corresponding to the size of the entire weld metal. In the overheating area, a Widmanstätt structure is observed, the grain size is 40 µm, the maximum size does not exceed 57 µm. The score of the Widmanstätt structure in the overheating section of the heat-affected zone of the weld: 1-2.

In the normalized section, the hot-rolled grain structure was refined (the average grain size is 6 µm). The degree of unevenness in the area of normalization of the heat-affected zone of the weld is 0.41. Typical photos of the microstructure of overheating and normalization areas are shown in Figure 5.



a b

Fig. 5 - Structure of the welded seam, Sample #2: a - overheating section, b - normalization section

Sample #3 was obtained using vibration treatment with a frequency of 50 Hz. Typical microstructure in general is shown in Figure 6. The structure of the welded seam is similar in characteristics to the joint of Sample #2, but differs in a slightly larger length of the heat-affected zone.

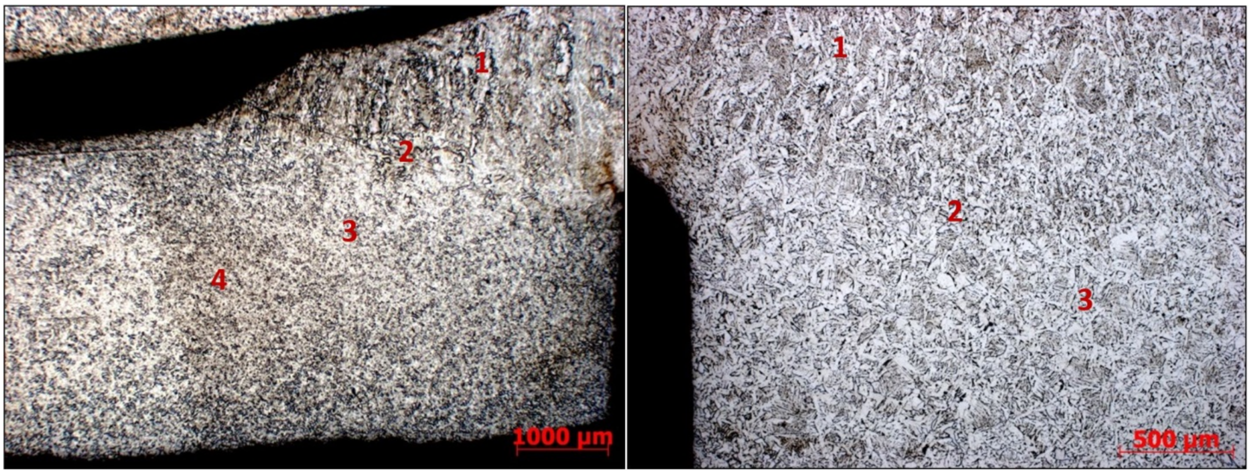
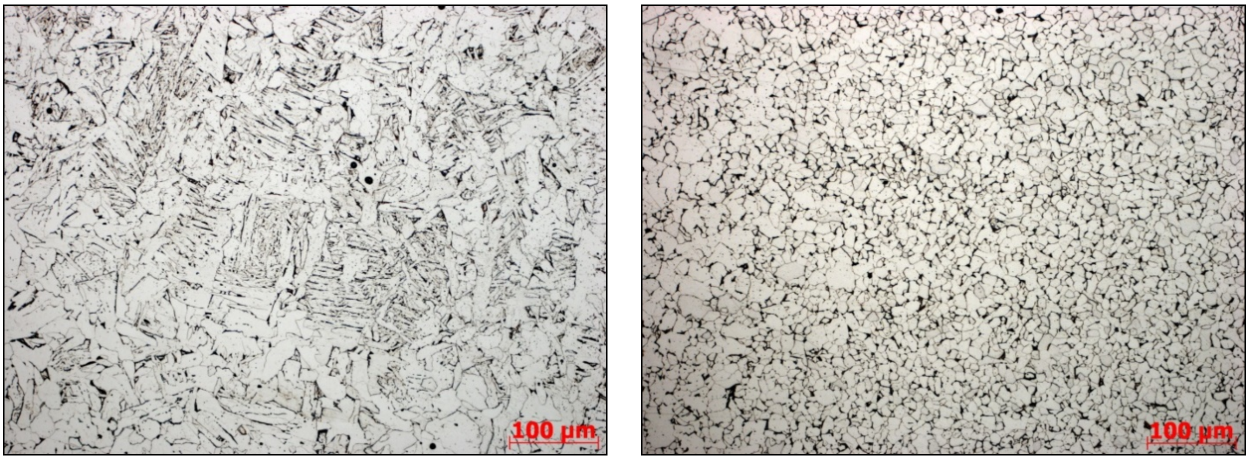


Fig. 6 - Structure of the weld, Sample #3: 1 - deposited metal zone, 2 - fusion section, 3 - overheating section, 4 - normalization section.

The Widmanstätt grains are larger in comparison with the grains of Sample #2. The average grain size in the area is 68.5 µm. The point of the Widmanstätt structure in the overheating section of the heat-affected zone of the weld: 2.

In the normalization section, the average ferrite grain size is 11 µm. Although the average grain size increased slightly, the structure became more uniform. The degree of unevenness in the area of normalization of the heat-affected zone of the weld is 0.37. Typical photos of the microstructure of overheating and normalization areas are shown in Figure 7.



a B

Fig. 7 - Structure of the welded seam, Sample #3: a - overheating section, b - normalization section

Sample #4 was obtained using vibration treatment with a frequency of 125 Hz. Sample 4 was also interesting in terms of research. The welded seam is characterized by a short length. The part of incomplete melting practically merges with the overheating part. There are huge grains with a Widmanstätt structure. The grains are surrounded by a clear ferritic frame. Their size is extremely uneven and reaches 395 µm (the average size is 125 µm). In this case, the Widmanstätt needles have a smaller structure in comparison with other samples. The score of the Widmanstätt structure in the overheating section of the heat-affected zone of the weld: 4.

A fine-grained structure is located directly under the abnormally large grains. The normalization zone is short, the average ferrite grain size is 10 µm. The degree of unevenness in the area of normalization of the heat-affected zone of the weld is 0.43. Typical photos of the general view of the weld are shown in Figure 8. Photos of the microstructure of the overheating and normalization areas are shown in Figure 9.

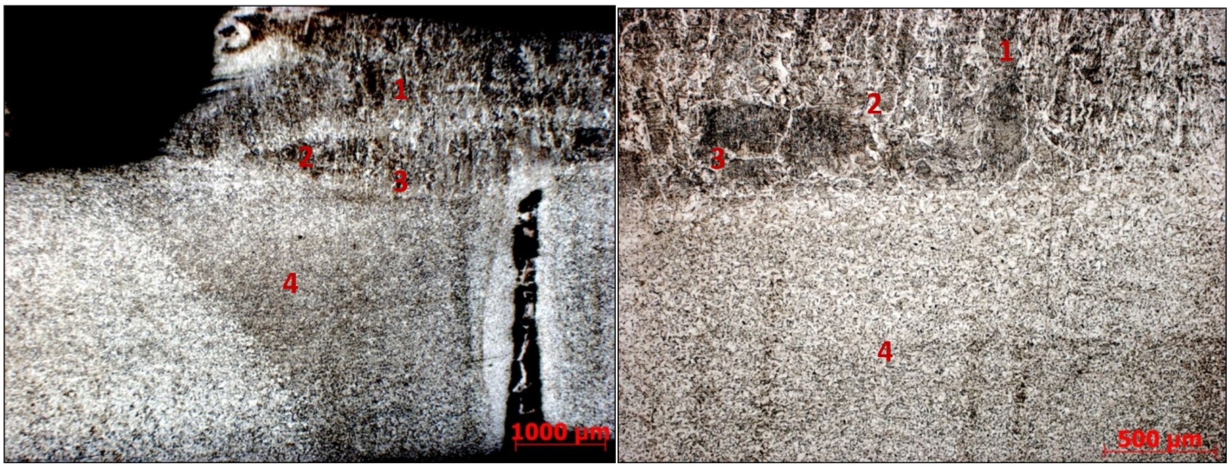
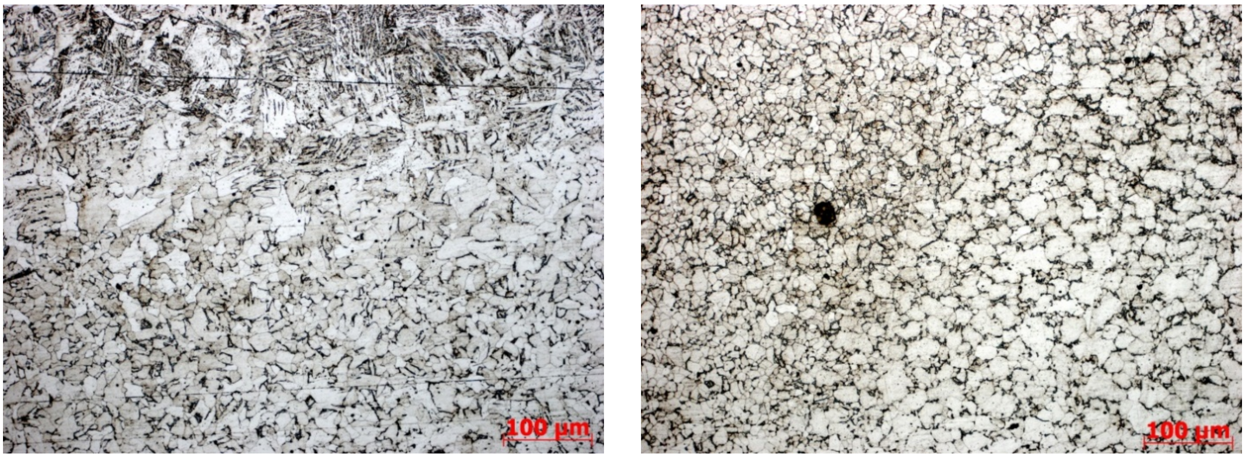


Fig. 8 - Structure of the weld, Sample #4: 1 - deposited metal zone, 2 - fusion section, 3 - overheating section, 4 - normalization section



a b

Fig. 9 - The structure of the weld, Sample #4: a - transition from the overheating area to the normalization zone, b - the transition of the normalized structure to the base metal

Sample #5 was obtained using vibration treatment with a frequency of 200 Hz. The weld is continuous, columnar crystals fill the entire section of the deposited metal zone. The structure of the weld is shown in Figure 10.

The size of large packages of Widmanstätt is 120-240 µm. The score of the Widmanstätt structure in the overheating section of the heat-affected zone of the weld: 4.

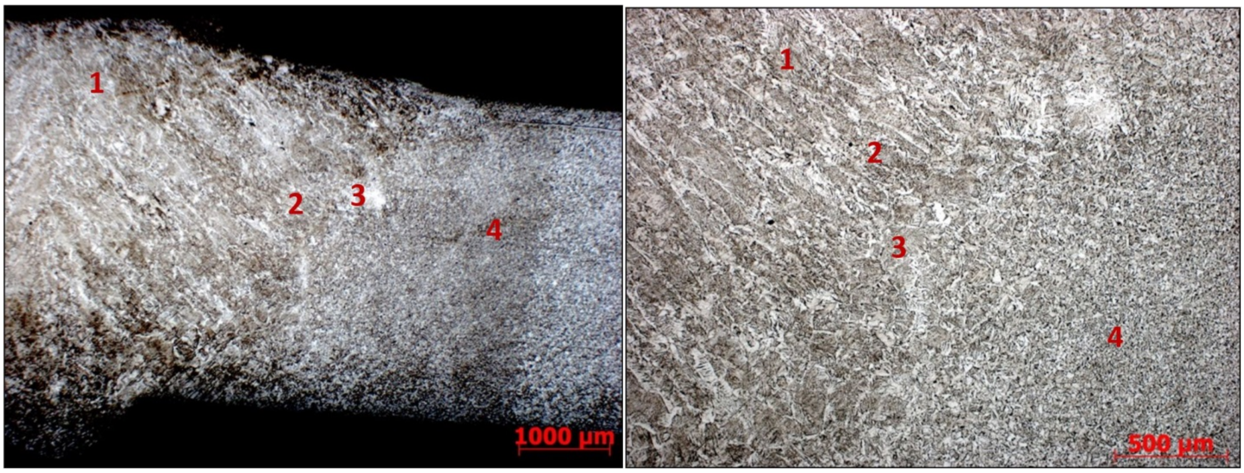
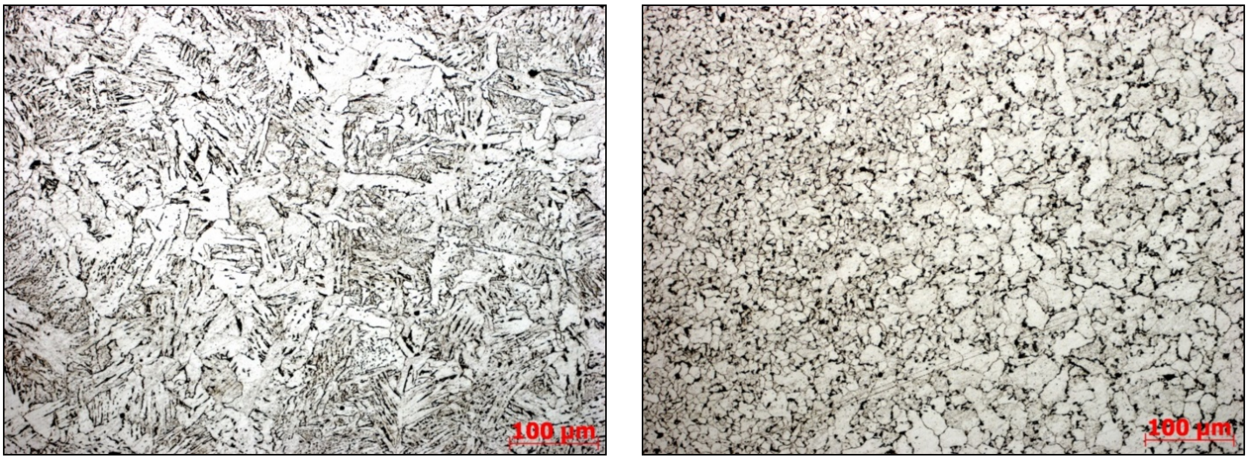


Fig. 10 - Structure of the welded joint, Sample #5: 1 - deposited metal zone, 2 - fusion section, 3 - overheating section, 4 - normalization section

In the normalization section, the ferrite grain size is 10.5 µm. The degree of unevenness in the area of normalization of the heat-affected zone of the weld is 0.49. Typical photos of the microstructure of overheating and normalization areas are shown in Figure 11.



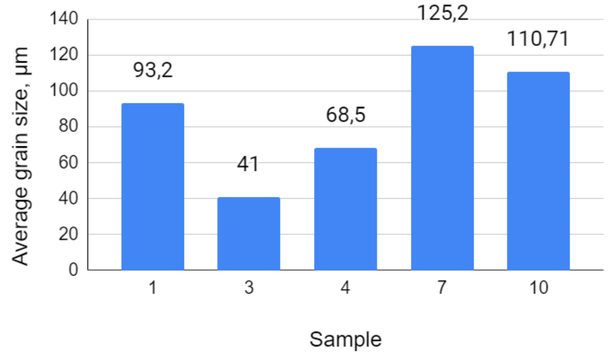
a b

Fig. 11 - Structure of the welded joint, Sample #5: a - areas of incomplete melting and overheating, b - transition of the normalized structure to the base metal

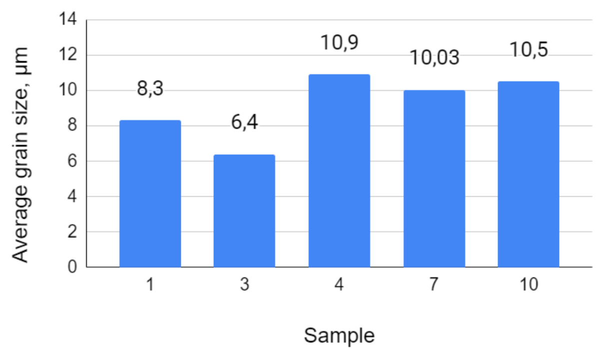
More clearly, the quantitative differences in the structural components of the experimental samples are shown in Figure 12.

As can be seen in the diagrams, Sample #3 is characterized by the smallest metal grain size both in the overheating area and in the normalization area. This fact is consistent with research in the field of vibration application during crystallization of ingots from steel and alloys given above.

Table 3 shows data on the degree of development of the Widmanstätt structure (according to GOST 5640 Steel. Metallographic method for assessing the microstructure of sheets and strips) of the overheating section of welded joints of the samples under study and the degree of grain variation in the normalization section.



a



b

Fig. 12 - Average grain size of characteristic sections of the heat-affected zone in the analyzed samples: a - overheating section (Widmanstätt structure), b - normalization section (ferrite-pearlite structure)

The degree of graininess was estimated using the coefficient of variation (proposed by S.A. Saltykov), which is calculated as the ratio of the standard deviation to the average grain diameter. The higher the coefficient, the higher the heterogeneity and unevenness of the grains.

Table 3.

Data on the structure variability.

Sample	Vibration frequency, Hz	Widmanstätt structure score in the HAZ overheating section of the weld	The degree of grain variation in the HAZ normalization section of the weld
1	0	2-3	0,44
2	25	1-2	0,41
3	50	2	0,37
4	125	4	0,43
5	200	3	0,49

The main fracture-sensitive zone of the weld is the heat-affected zone, namely, the overheating area due to the appearance of needle-like structures in it.

Annealing after welding of electric-welded pipes in the current technological process is required not only to remove residual stresses, but also to refine the structure and increase its uniformity.

The coarser the structure (in this case, the higher the development score of the Widmanstätt structure), the more difficult it is to be eliminated during subsequent heat treatment. Recrystallization annealing often does not completely eliminate the coarse Widmanstätt structure. And in the case of elimination of directionality (acicularity), in the places of overheating after annealing, a significant difference in grain size can be observed, which negatively affects the strength and operational properties of the welded product. Figure 13 shows the graph of the dependence of the level of graininess of the structure in the normalization section on the vibration frequency used in the welding process.

Analyzing Figure 13, it is obvious that the most homogeneous and uniform-grained structure both in the overheating area and in the normalization area was found in Sample #3, welded with vibration at a frequency of 50 Hz. According to data from parallel studies of residual stresses, Sample #3 is also characterized by the highest percentage of reduction in residual stresses relative to the sample welded without the use of vibration - 71.41%.

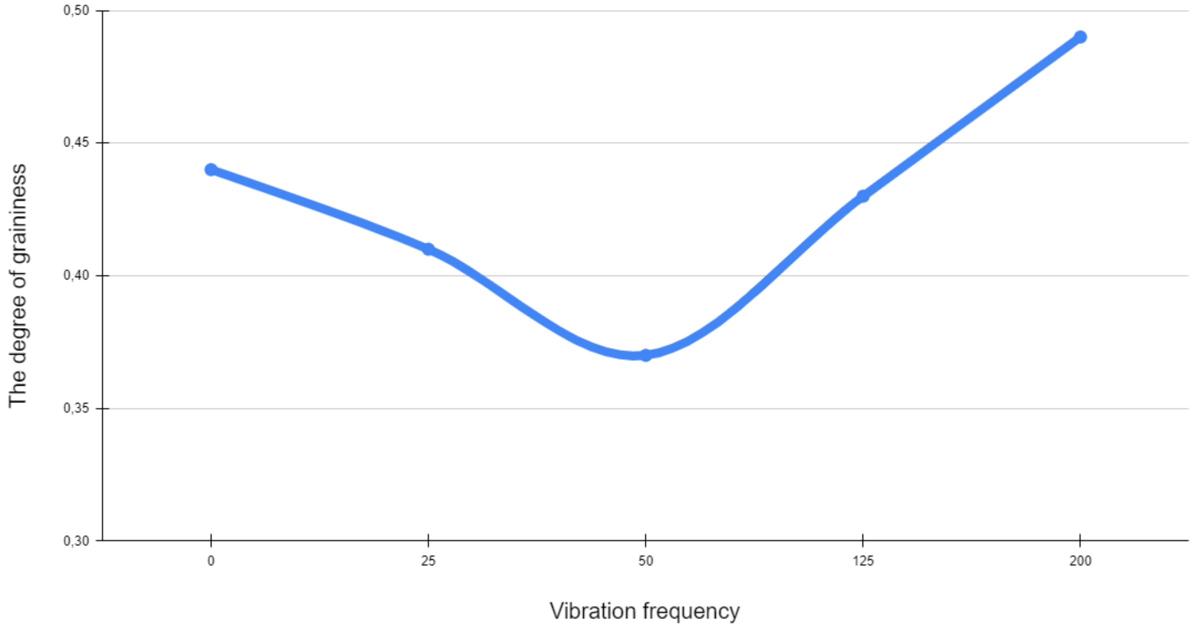


Fig. 13. Graph of the dependence of the level of graininess of the structure on the vibration frequency used in the welding process.

Thus, it can be concluded that the use of 50 Hz vibration in the welding process has a positive effect both on the level of residual stresses and on the uniformity of the metal structure. It should be noted that at a vibration frequency of 25 Hz (Sample No. 3), in spite of a more intensive grinding of grains, a large grain size difference and a high level of residual stresses were recorded.

Conclusions.

1. The conducted analytical studies of the effect of vibration on the microstructure of the welded seam showed the need for experimental studies aimed at changing the microstructure of the weld metal directly during the welding process.

2. As a result of an experimental study of the welding process on preformed tubular billets with the use of vibration exposure, the regularity of the change in the size of grains and grain size differences in the areas of overheating and normalization relative to the vibration frequency was established.

3. Investigation of the microstructure of the welded seams showed that the smallest grain size was recorded in the sample welded using vibration at a frequency of 25 Hz. The grain size in this sample was 41 μm in the overheating area and 6.4 μm in the normalization area.

4. The most homogeneous and uniform-grained microstructure was found in a specimen welded using vibration at a frequency of 50 Hz. The score of the Widmanstätt structure in the HAZ overheating section of the weld was 2 points. The degree of graininess in the normalization area is 0.37.

References.

1. Moroz LS. *Mechanics and Physics of Deformations and Fracture of Materials*. Leningrad: Mashinostroenie, 1984, p. 223.

2. Gorenko VG, Rusakov PV. Static and dynamic methods of reducing the level of residual stresses and stabilizing the size of olives. In : *Improving the reliability and durability of cast parts: collection of scientific works of the Academy of Sciences of the Ukrainian SSR Institute of Casting Problems*, 1987, pp. 23-39.

3. Skakovskiy VD. *Development of technology for vibration treatment of frame-type welded structures.* For a job. learned Degree, K.: Publishing house E.O. Patona IES, 1987.

4. Mezhidov VKh., Askhabov KhI., Eldarkhanov AS. and et al. *Vibration influence on crystallization of organic ingot. Influence of external influences on liquid and crystallizing metal*. For a job. learned Degree, Kiev: IPL of the Academy of Sciences of the Ukrainian SSR, 1983.

5. Taranov ED., Nuradinov AS., Kondratyuk SE. et al. Crystallization and structure formation of steel ingots under vibration impact. *Casting processes*,1998; 3-4: 84-90.

6. Balakin YuA., Gladkov MI. Energy intensity of external influence on solidifying metal from the standpoint of thermodynamics. Izv. universities. *Black metallurgy*, 2001; 6: 44-46.

7. Gladkov MI, Balakin YuA, Goncharevich IF. Thermodynamic analysis of the conditions of nucleation and growth of crystals during vibration treatment of metal. *Izv. universities. Black. Metallurgy* 1989; 9: 27-29.

8. Efimov VA., Eldarkhanov AS. *Technologies of modern metallurgy*. M.: New technologies, 2004, p. 784.

9. Servetnik VM, Solyanikov BG, Nosov VA. Improvement of the quality of steel ShKh15 by vibro-processing of ingots. *Steel* 1987; 4: 48-49.

10. Eldarkhanov AS. *Application of physical methods of modeling to study the effect of vibration on the solidification of alloys*. Dis. Dr. tech. sciences, Kiev, Ukraine, 1996.

11. Balakin YuA., Gladkov MI. Calculation of the parameters of vibration treatment of crystallizing metals. *Izv. universities. Black. Metallurgy* 2003; 9: 56-60.