Modification of Structure and Strength Properties of Permanent Joints Under Laser Beam Welding with Application of Nanopowder Modifiers

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Abstract. In the paper we present the results of experimental study of specially prepared nanosize metal-ceramic compositions impact upon structure, microhardness and mechanical properties of permanent joints produced by laser-beam welding of steel and titanium alloy plates.

1. Introduction

Laser beam welding of various materials has been widely studied in Russia and abroad since 1980s [1-6]. It has been established that heat efficiency of laser beam welding significantly exceeds that of arc welding and strength of the weld joint does not differ much from the strength of the metal. Ultrahigh rates of heating and cooling after laser implementation reduce the width of the heat affected area, reduce thermal deformation and gas saturation of titanium alloys especially under reliable shielding of fusion area with inert gases [7-8]. Production of permanent joints of iron-titanium alloys is an important technologic process when manufacturing parts and mechanisms which are widely applied in petrochemical engineering, power production and ship building. One of the main tasks here is improvement of strength, plasticity and resistance to cyclic loads in the process of their operation.

A well-known practice of weld strength improvement is increasing dispersion of structure and chemical homogeneity of the weld joint. Application of nanomodifying additives in the process of welding is one of the possible ways to solve this problem. Introduction of activated nanopowder particles of high-melting chemical compounds into the molten metal leads to atomization of matrix grains and proeutectoid constituents resulting from artificial increase of the number of crystallization centers in the molten metal. This leads to formation of highly dispersed globular structure in the molten metal during the cooling process which improves strength and plastic properties of the weld joint [9-14].

To study the peculiarities of structure, phase composition and mechanic properties formation in weld joints of “titanium-titanium”, “steel-steel” with application of nanopowder modifiers (NM) we completed experimental work on laser beam welding of titanium alloy and steel plates.

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2. Results of the study and their discussion

Weld joint titanium – titanium. Samples produced by welding cold rolled 3 mm sheets made from VT 1-0 and VT 20 alloys were applied as the objects of study. Analysis of reference data shows that titanium alloys are highly prone to porosity under increased temperatures. Porosity is mainly caused by oxygen and hydrogen. Under laser treatment the molten metal absorbs gases due to convective motion. High crystallization rate does not allow gas bubbles come to the surface. That is why special attention was paid to protection of weld against oxidation during the welding process.

Helium was applied as shielding gas. It was supplied not only to the weld cup but also to its root. The power of the laser beam was 2.0 kW and the rate of welding was v=2 m/min. High-melting TiN, Y_2O_3 compounds and their mixture as well were used as modifying nanopowder materials. To improve the wettability the powders were previously treated in centrifugal planetary-type mill with addition of Cr powder with the ratio 1:3. Weight-part concentration of the modifying composition introduced into the weld pool was ~ 0.1% counting for the high-melting constituent, the size of particles was within 40-80 nanometer. The prepared composition was spread as suspension over the surface of the welded plates, its amount being ≤. 0.1% of the fused metal mass. It was established that application of nanopowder modifiers allows increasing the welding rate under the same power of the beam due to increasing the laser beam intensity absorption coefficient when metal is heated and begins to melt. The quality of the joint improves (morphology and structure of the weld), its mechanical properties significantly improve as well. Table 1 presents the results of mechanical tests of experimental and control samples modified with various powder compositions.

Table 1. Mechanical properties of the weld joint produced from VT 1-0 alloy

Composition of NM	Temporary strength σ_u, MPa	Yield strength σ_y, MPa	Percentage elongation, δ%
Without NM	288.1	134.6	0.1
TiN + Cr	365.8	277.1	0.197
TCN + Cr + Y_2O_3	4000	246.38	0.446

From table 1 we can see that all modifying compositions improved the properties of the weld joint. Thus, percentage elongation increased by 2 – 4.9 times, strength limit – by 1.23 – 1.35 times, yield strength – by 1.8 – 2.0 times.

In the similar manner we produced test samples of weld joints from VT 20 alloy. Figure 2 presents photographs of weld morphology and macrostructure made when welding VT 20 alloy with optical microscope NEOPHOT-21, without nanomodifying additive and with addition of TiN + Cr.

It can be seen that application of NM TiN + Cr notably changes the weld morphology and reduces the macrostructure of the hardened metal in the weld joint.

Fatigue tests of the welded samples produced from VT 20 alloy were carried out with universal servohydraulic test table “Instron 8810” equipped with software module for data acquisition and processing “Wavematrix”. The testing was completed according to pulsating soft cycle of loading with the frequency of 5 Hz. The weld joints were being tested under the load varying from zero to 1500 N. Strain amplitude under such loading conditions was approximately 0.2 … 0.25 mm. During the test the time of complete destruction of the sample was recorded. Welding conditions: P = 3kW, v = 1 m/min. Average values of lifetime obtained from testing 3 samples are presented in Table 2.

As we can see from the table fatigue strength of weld joints NM modified significantly (by 1.5 – 2 times) exceeds that of the plates welded without nanomodifying additive.

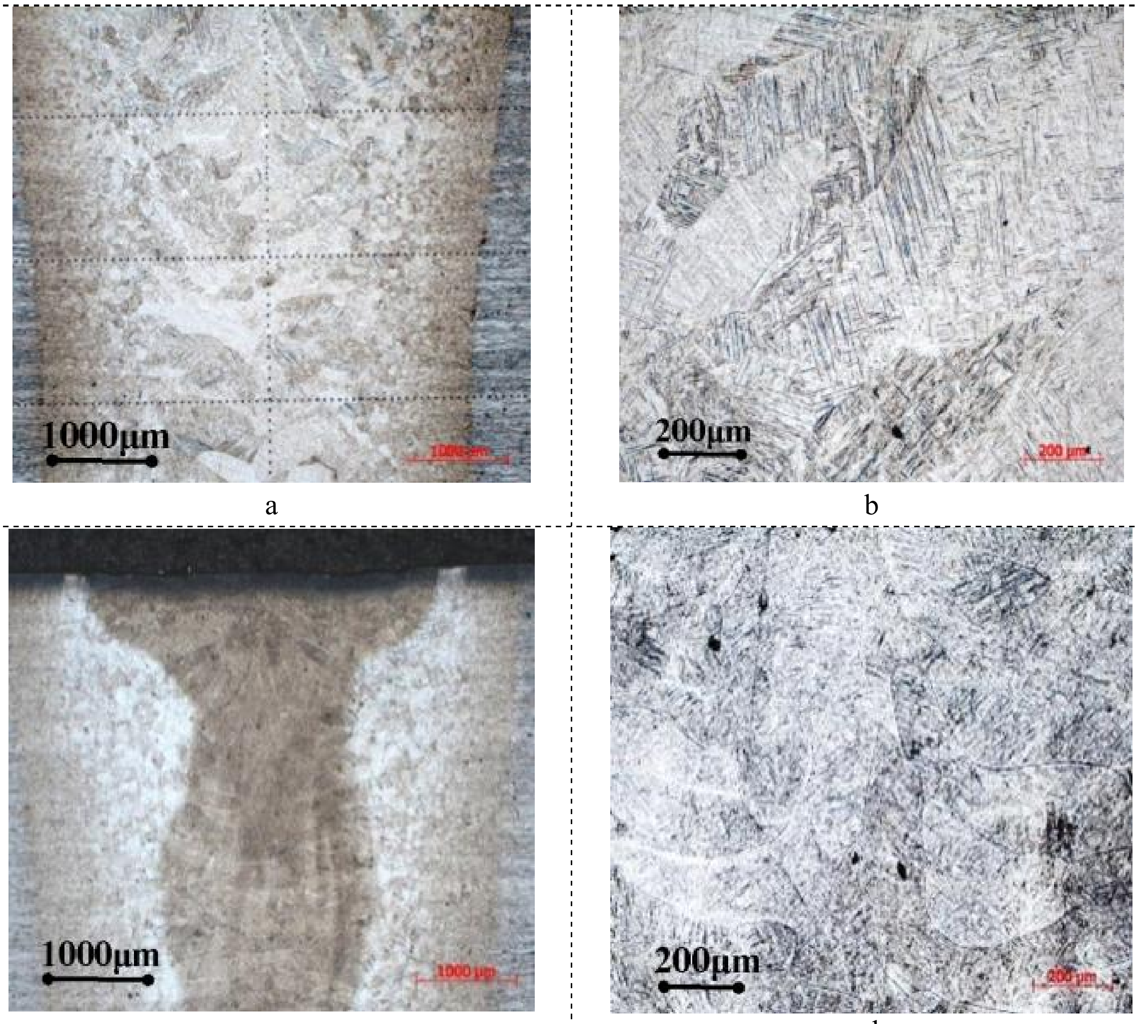

Figure 1. Weld morphology and structure without NM application (a), (b) and with NP application TiN + Cr (c), (d).

Table 2. Results of fatigue testing for VT 20

Sample №	Type of material	Lifetime τ before destruction, min
1	VT 20 alloy without the weld joint	τ = 220.5
2	Welded specimen without NM	τ =48
3	Welded specimen with additive TiN + Cr	τ = 130

Weld joint "steel – steel". We have studied the impact of nanostructured powder compositions $TiC_{0.5}N_{0.5}$ + Fe и $TiC_{0.5}N_{0.5}$+Cr upon the quality of weld joints produced from carbon steel 20. The thickness of the welded plates was 3 mm. Mechanically activated nanopowder $TiC_{0.5}N_{0.5}$, plated with Fe was spread as suspension on the top of the edges of welded plates. Welding was completed in helium atmosphere. The workpieces were butted. Power of the laser irradiation was 3.05 kW, welding rate – 1.7 m/min. Structure and microhardness of experimental and control samples were studied. In

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Figure 2 we present photographs of morphology and structure of the weld produced without modifying additive (a, b) and with NM additive $TiC_{0.5}N_{0.5}$ + Fe (c, d) accordingly.

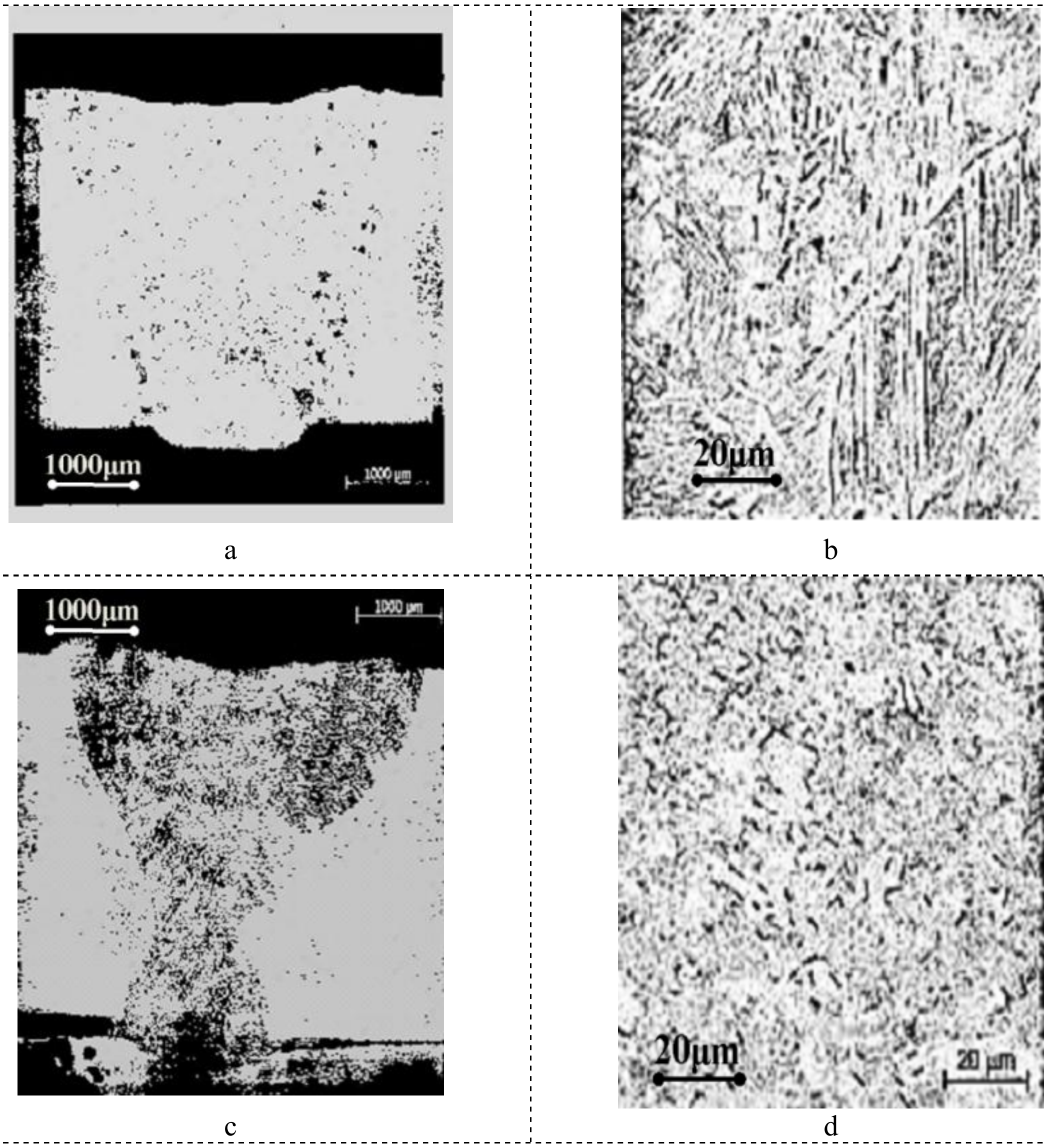
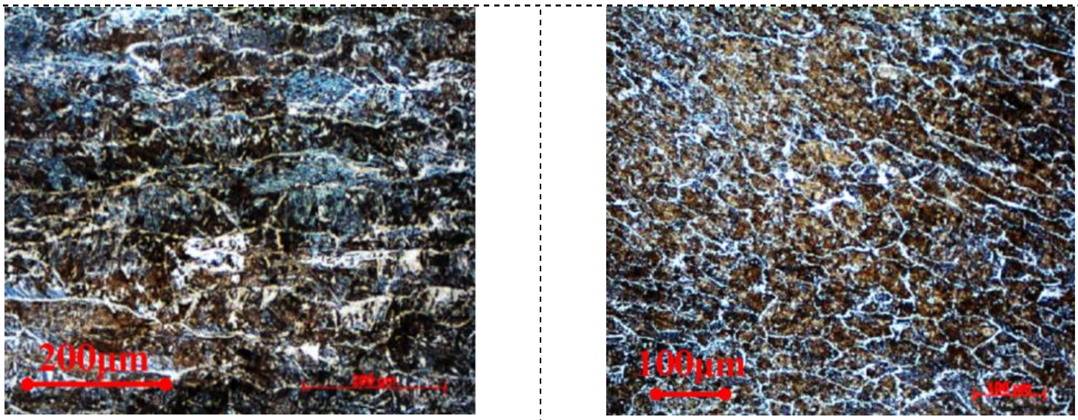


Figure 2. Morphology and structure of the weld: (a), (b) – without NM, (c), (d) – with NM $TiC_{0.5}N_{0.5}$ + Fe.

It can be obviously seen that application of nanomodifier changed both the weld morthology and the microstructure of the weld joint. The sizes of widemanstatten ferrite in the weld produced without the modifier reach 100÷150 micrometer lengthwise, while in the modified weld these grains do not exceed 30÷40 micrometer. This undoubtedly shows that application of NM additive leads to weld structure refining.

Figure 3 illustrates the grain structure of the weld when applying $TiC_{0.5}N_{0.5}$+Cr. Nanocomposition. As in the previous variant the structure of the weld produced without NM is coarse with large crystals extended in the direction of heat withdrawal. Application of NM additive leads to grain refinement, the length of crystallites reduces by 2-3 times.

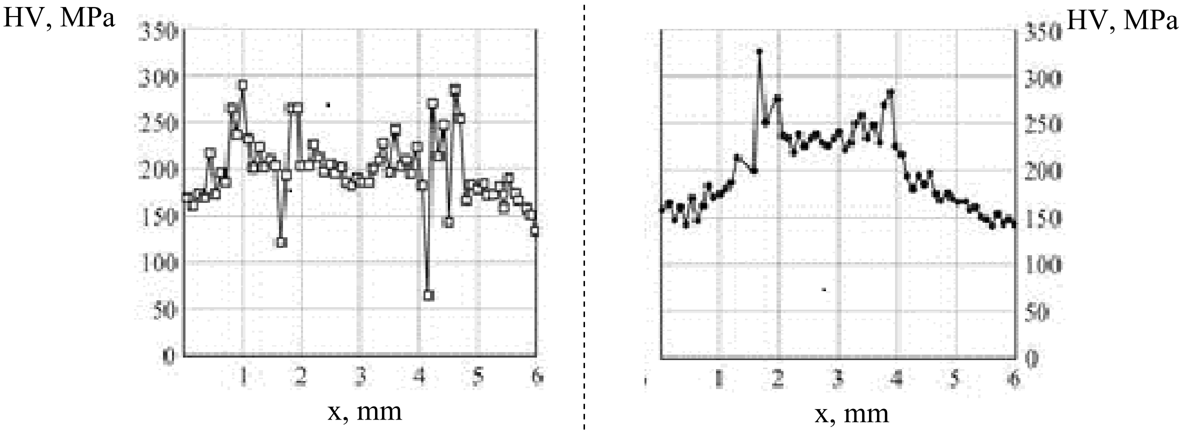


a b

Figure 3. Weld structure after laser-beam welding, a – without application of inoculator; b – with application of inoculator $TiC_{0.5}N_{0.5}$ + Cr.

Vickers microhardness distribution was studied under loading of 0.5N for the weld width and heat-affected zone (HAZ).

The results of the study are shown in Figure 4.



a b

Figure 4. Microhardness of welds without NM (a) and with addition of $TiC_{0.5}N_{0.5}$ +Cr powder (b).

Measurements of weld and HAZ microhardness showed notable smoothing of microhardness discontinuity observed under laser-beam welding without NM (Figure 4.b) which may be explained by improvement of structure homogeneity after introduction of the modifier into the weld pool.

3. Conclusions

Application of nanomodifying additive:

-improves welding rate under the same beam power due to increasing the laser beam intensity absorption coefficient when heating metal to achieve its fusion temperature;

-improves mechanical properties and quality of the joint due to changes in morphology and reducing the size of crystalline grains;

-changing of weld and HAZ microhardness showed significant smoothing of microharness discontinuity observed under laser-beam welding completed without NM application which is associated with structure dispersion and homogeneity increase resulting from application of modifier.

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