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Laser Welding in Different Spatial Positions of T-joints of Austenitic Steel

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Abstract. It has been selected the most industry perspective laser welding technological implementations of the welded T-joints made of fine-sheeted heat resisting steel AISI 321 by identifying the influence of technological parameters on formation quality, level of mechanical properties and structural peculiarities of the welded T-joints obtained by laser welding in different spatial positions.

1. Introduction
Industry of many industry-developed countries has progressing fast in space industry, shipbuilding, instrument manufacturing, sectoral and precision engineering, etc. of late in view of many important factors, including a very important one that of wide introduction of innovative technologies of materials processing at manufacturing complex spatial structures [1-7]. It is done due to both updating of the existing technologies and developing the new ones [8-10].

At the present period of materials processing when manufacturing complex spatial structures there is a demand for application of local methods of processing as the most progressive welding processes, namely laser [4, 6, 7, 11-14], hybrid and combined laser-arc and laser-plasma [4, 8, 15, 16] and electric-beam ones [17-20]. It is related to a substantial reduction of the heat affection on the units which are joined by welding [8, 15, 21]. Due to this the level of residual strength and deformations of both separate units and the welded structures in a whole reduces [21-24].

The biggest challenge of reduction of residual strength and deformations is faced when manufacturing fine-sheet geometrically complicated structures, for example, panels [3, 12, 21, 25], or the closed section units of different configuration which are used in: shipbuilding to manufacture internal ship structures; aircraft industry to manufacture aircraft fuselage and wings [7, 11, 14, 18]; chemical and food industries to manufacture containers and vessels, etc. The mass of those structures is reduced by decreasing the thickness of materials which are the most frequently joined by different methods of welding. And the specified strength characteristics of the structures are achieved by using both new materials with a higher level of the necessary characteristics and certain structural elements.

T-joints are the most accepted forms of structural elements which are used in fine-sheet geometrically complicated structures to render them necessary characteristics of stiffness and strength [1, 6, 11-14, 22-27] when their weight is not very big. When producing T-joints by different methods fusing welding, the most accepted is a technological implementation (TI) shown on Figure 1,a [24], when welding is produced from the side of the stringer under a certain angle. The advantages of this T-joints welding TI include the following: a relatively simple technical equipment; possibility to produce welding in one or two passes under one-side welding; when doing welding in one pass under both-side welding as shown on Figure 1,b [28] (when using two sources of heating at the same time) formation of fillets is guaranteed in the zone of joining skin and stringer and symmetrical spread of heat fields and stresses; possibility to distribute in time and space of sources of heating under both-side welding; etc.

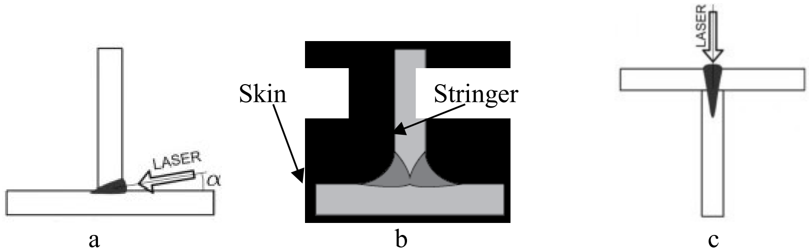


Figure 1. Implementations of laser welded T-joint: a − one-side butt welded joint [24], b − formation of fillets under both-side welding [28], c − I-core T-joint [24]

However there are many structures [3, 12, 21, 25], in which access from the stringer side of the welded T-joint is restricted or impossible. It does not allow use the welding TI shown on Figure 1,a. In that case they use the welding TI shown on Figure 1,c [24]. According to that TI welding is produced from the skin side of the T-joint by a through penetration and melting down of a certain section of the stringer. But in that case there is no possibility for visual control of positioning of the edges of the welded joint when preparing for welding. That complicates and makes more expensive the phase of preparation of the welded T-joints as it needs using additional technological and organizational facilities, like using more precise and, consequently, more expensive technological tools to assemble welded joints.

Besides, problem occurs to ensure necessary strength characteristics of the welded T-joints which are obtained by the welding TI shown on Figure 1,c. For the welded T-joints that work under different loading on the skin of the welded joint from the stringer side, a necessary quality requirement and achievement of the specified long-term strength characteristics is formation of fillets on each side from the stringer. The fillets must have a certain transition radius from the stringer metal to the skin metal as shown on Figure 1,b. If there are no fillets on both sides of the stringer or existence of not welded sections in the zone of stringer and skin joining, creation of defects as undercuts is possible. It may result in big rise of stress in this section of a welded joint, and later, after a long-term exploitation of the welded joint and excessing of a certain stress values, in its destruction.

2. The purpose and objectives of the study

In this connection obtaining of the welded T-joints with a guaranteed formation of fillets with specified radius when producing welding according to the TI shown on Figure 1,c becomes important. This task is more difficult when the units of the welded joints (stringers and skins) are about 1 mm thick. The task may be solved by developing of the welding TI of T-joints as shown on Figure 1,c, using different technological approaches, namely:

- mode of generation of laser radiation;
- changing of the number of passes;
- spatial position;
- position of the focus plate relative to the skin surface.

The objective of the research is the study of the TIs of laser welding of the welded T-joints made of fine-sheeted heat resisting steel AISI 321 and selection of the most innovative solutions for the industry application. It will be based on identification of the technological parameters influence on formation quality, level of mechanical properties and structural peculiarities of the welded T-joints obtained by laser welding in different spatial positions.

3. Research methods and equipment

T-joints were obtained by a laser welding from the samples made of sheet corrosion- and heat-resisting steel AISI 321. To manufacture stringers of the welded T-joints they used AISI 321 sheets 1.2 mm thick, and to manufacture a skin of the welded T-joints – 0.8 mm thick.

For the research Nd:YAG-laser «DY044» produced by «ROFIN-SINAR» (Germany) with the radiation wavelength $\lambda = 1.06$ μm was used.

The samples were fixed in the clamp and welded in the lower and vertical spatial positions. The weld was along the rolling direction of AISI 321 steel which was used as a skin of the welded T-joint. Welding both "on rise" (with moving of the laser head upwards relating to the unmovable clamp with the fixed sample) and "on descent" (with moving of the laser head downwards relating to the unmovable clamp with the fixed sample) was studied.

The quality of the obtained welded T-joints was assessed according to ISO 13919-1:1996 and guaranteed obtaining of fillets of 2…10 mm in radius on both sides of the stringer of the welded joint. To obtain the welds of high – B- or medium – C- quality level (in accordance with ISO 13919-1:1996) the edges of the stringer were mechanically processed (fine milling). Shortly before welding (before fixing in the welding clamp) the samples were degreased by gasoline and later cleaned by acetone. A preliminary heat treatment of the samples before welding was not carried out.

The units of the T-joint were assembled in clamps with edges clamping in 2…5 MPa. The clearance between stringer and skin did not exceed 0.1 mm (the check was done by a tool probe). When assembling the T-joints for a laser welding the tack welds were not used.

The visual control of the obtained welded joints was carried out on the previously mechanically cleaned samples. When carrying out the visual control the combined lighting was used (day and local lighting using filament lamp) – about 1000 lx. Measuring devices and tools was used such as: magnifier glasses 4× and 10×zoom, measuring magnifier 10×zoom with accuracy of 0.1 mm, trammel ShTs140 (class 2), ruler, portable measuring profiler of watch type with accuracy of 0.01 mm, portable microscope and luxmeter U-116. The following parameters were evaluated by visual inspection results: weld width; flakiness; existence and geometrical size of fillets; existence of craters (shrinkage cavities in craters) and other characteristics as provided by ISO 13919-1:1996.

The radiographic (X-ray) test was carried out on the previously mechanically degreased samples. The following devices were used: X-ray machine RAP 150/300; penetrameter – grooved №1 GOST 7512-82; 240×100 mm radiographic film KODAK - AA400; intensifying screens – metal - Pb-0.027. Radiographic mode: U = 80 kV, I = 10 mA, t = 120 s, focal distance – 1000 mm. Number of expositions – 2 (one on each side, on the part of the stringer side of the T-joint). The length of the controlled area of the welded joint during the radiographic test was 220 mm. Based on the radiographic test the appearance of internal defects in the form of cracks, pores, inclusions, and lack of penetration were assessed.

Metal macrograph study of the welded samples was carried out according to ISO 17639:2003 using optical microscopy (microscopes Versamet-2, Neophot-32). The study was carried out on each section (weld – heat affected zone (HAZ) – base metal) of each sample.

Static tensile strength testing of the welded T-joints samples was carried out on servo-hydraulic machine MTS 318.25 according to ISO 6892-1:2016 on five samples cut out from each welded joint.

The testing objective was to identify loading necessary to destroy a sample of the T-joint under static tension and localization of a break in the welded T-joint.

4. Results and Discussion

4.1. Laser welding in the lower spatial position

Initially, a variant of one-pass welding of a T-joint in the lower spatial position in the continuous mode of generation of laser radiation was considered. It is the most simple as regards realization. However, to achieve a stable formation of fillets of a specified radius on both sides of the welded joint under the circumstances of the experiment failed. Due to the variation of the values of the parameters of the technological modes (laser radiation power; welding speed; the position of the focal plane, with respect to the position of the surface of the skin of the T-joint, etc.), a number of technological variants of the process realization were tested. However, any minor deviations (less than 5%) from the above technological process parameters, or deviation of the laser head during welding from the symmetry plane of the stringer of the welded T-joint lead to uneven shaping of fillets on both sides of the welded stringer, or even to the formation of only one fillet on one side of the stringer of welded joint.

Therefore, for laser welding in the lower spatial position, more than ten advanced welding TIs were considered, from which three of the most perspective, distinguished by the parameters of the technological modes, were determined, and the industrial application of each of them makes it possible to obtain a control welded T-joint, which meets the requirements for obtaining welds of the specified geometrical sizes (with guaranteed fillets forming) and high B or medium C quality levels (according to ISO 13919-1: 1996).

In all cases, the welding in the lower spatial position was produced with supply of argon as a shielding gas with different spending in certain areas: in the area of the welding pool − 25 l/min; bottom skin − 5 l/min (in total on both sides of the stringer); in the "tail" of the welding pool − 20 l/min.

Based on the results of visual and radiographic tests, no samples were welded in the lower spatial position had defects, but there was insufficient strengthening of the upper bead of the weld. Despite the identified drawback, all samples welded in the lower spatial position correspond to the "high B" quality standard according to ISO 13919-1: 1996.

4.1.1. Welding technological implementation #1 (TI#1)

In order to guarantee the formation of fillets of specified geometric sizes on each side of the stringer of the welded T-joint, a variant of the TI#1 was considered, according to which the laser welding was produced in two passes, produced one after the other, indented at a specified distance Δ from symmetry plane of the stringer of the welded T-joint. The value of this parameter varied within Δ = 0.2...0.5 mm. The welding was produced in the continuous mode of generation of laser radiation with the power of P from 3.0 to 4.4 kW with the defocusing ΔF = −4...+4 mm, at the welding speed V = 50...300 mm/s.

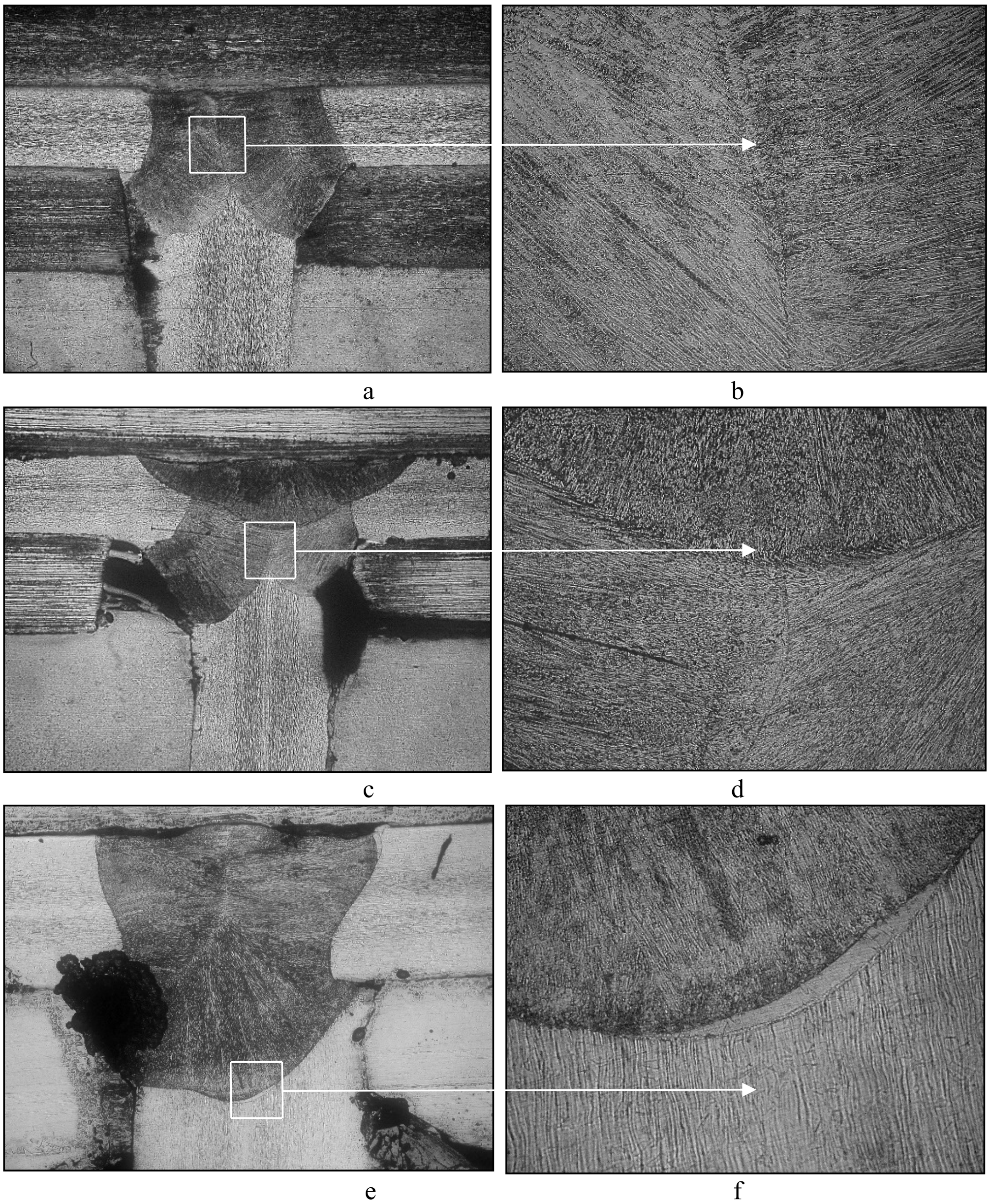


Figure 2. Welded T-joints obtained in the lower spatial position: macrograph, ×25: a − TI#1, c − TI#2, e − TI#3; micrograph: b – zone of overlapping of the welds upon two passes; TI#1, ×320; d − zone of overlapping of the welds upon three passes TI#2, ×156; f – transition zone between weld and stringer TI#3, ×320.

The results, which are better in terms of the formation of welded joints, in particular stability of fillets formation along the weld, were obtained by welding in a continuous mode of generation of laser radiation with a power of 4.4 kW without defocusing (ΔF = 0 mm), at a speed of 100 mm/s indented from the symmetry plane of the stringers by a value of 0.3 mm for each pass.

On Figure 2,a,b it is shown the welded joint produced according to the TI#1. The results of the metal macrograph study of the parameters of the structural features of the welded joint obtained by the TI#1 are given in Table 1.

It is worth noting that according to the results of the mechanical tests on the static tension given in Table 2 it was determined that the welded joints obtained according to the TI#1 ensure a sufficiently high resistance to the destruction force (the average value was calculated based on the results of tests of 5 plates cut off from one sample, without taking into account the maximum and minimum value). Destruction of all samples took place on the base metal of the stringer of the welded T-joint #1 for all experiments carried out. This also indicates the achievement of high strength values of the obtained welded joints.

Producing welding in two passes with a displacement from the symmetry plane of the stringer by 0.3 mm allowed ensure the specified configuration of the welded T-joints and obtain relatively high strength values.

The welded joints obtained according to the TI#1, meet the requirements for obtaining welds of the average quality level C, according to ISO 13919-1: 1996. To the main drawbacks of this welding TI of T-joints made of thin-sheet austenitic steel AISI 321, the following should be considered:

1. the technological complexity of the implementation of the indentation at a specified distance from the symmetry plane of the stringer;
2. existence of a weakened zone in a welded joint with a double-melted metal of weld and an additional HAZ in the specified area (see Figure 2,a);
3. two times lower welding process productivity compared to a one pass welding TI;
4. no strengthening of the upper bead.

Table 1. Structure parameters and mechanical features of the welded T-joints

	Value of structural components (µm)				Microhardness (MPa)		
WTI[a]	$h_1 \times L_1$[b]	$h_2 \times L_2$[c]	D[d]	δ[e]	HV_{WB}[f]	HV_{TZ}[h]	HV_{FL}[g]
#1	4…10×30…120	3…8×30…50	10…20	40…50	2510…2740	2280…2380	2340...2380
#2	2…8×10…100	2…5×20…50	8…20	40…50	2240…2470	2280…2320	2260...2300
#3	5…12×15…100	4…6×30…50	10…20	25…35	2510…2540	2610…2670	2410...2450
#4	10…15×30…120	5…10×30…50	10…20	40…60	2360…2680	2280…2450	2300...2540
#5	8...12×20...100	3…8×30…50	10…20	40…50	2360...2490	2450...2700	2480...2540
#6	15...25×20...100	3…8×30…50	10…20	30…45	2450...2670	2480...2660	2450...2640
#7	10…20×20…100	3…10×20…50	10…20	40…60	2540...2740	2560...2740	2360...2660

[a] WTI – Welding technological implementation.
[b] $h_1 \times L_1$ – Sizes of crystal grains in weld.
[c] $h_2 \times L_2$ – Sizes of crystal grains in transition zone.
[d] D – Size of the austenitic grain from the side of the base metal of stringer in the fusion line.
[e] δ – Width of the transition zone.
[f] HV_{WB} – Microhardness of crystal grains in a weld.
[g] HV_{TZ} – Microhardness of crystal grains in transition zone.
[h] HV_{FL} – Microhardness of austenitic grain from the side of the base metal of stringer in the fusion line.

Table 2. Results of mechanical testing of the welded T-joints

	Q[b] (H)		N[c] (%)	
WTI[a]	Value range	Average range	On the metal of the weld	On the base metal of the stringer
#1	20289...21240	20951	0	100
#2	19590...21830	20460	60	40
#3	18044...19504	18714	100	0
#4	20944...21829	21566	40	60
#5	18500...21882	20883	40	60
#6	15234...18763	17587	100	0
#7	21394...23232	21887	0	100

[a] WTI – Welding technological implementation.
[b] Q – Resistance of the welded joint to the breaking tension.
[c] N – Number of samples that were destroyed in the corresponding location of the welded T-joint.

4.1.2. Welding technological implementation #2 (TI#2).

Unlike the TI#1, laser welding according to the TI#2 included a third pass, except for two main passes, indented from the symmetry plane of the stringer by 0.3 mm (in modes identical to the TI#1 modes) that were produced for a proper formation of fillets on both sides of the welded T- joint. The third pass was produced to melt the surface to ensure a proper formation of the upper bead of skin of the welded joint. The third "smoothing" pass was carried out in the continuous mode of generation of laser radiation in the variation of the parameters of technological modes in the following ranges: P=1.0…3.0 kW; ΔF=+10...+30 mm; V=1…50 mm/s.

Figure 2,c,d shows the welded joint carried out according to the TI#2, according to which the third pass was carried out in the continuous mode of generation of laser radiation with the power of P = 1.5 kW, at defocusing of ΔF = +20 mm, and welding speed 25 mm/s. The position of the focus of laser radiation was deepened with respect to the surface of the sample by 4 mm. Welding was carried out at a speed of 75 mm/s. According to the data of the metal macrograph study, the metal in the fusion zone after welding the formation of austenitic dendritic structure with an increased crystallite size (Figure 2,c,d and Table 1) is characteristic. The microstructure study has also shown that as regards the depth of the transition from melted metal to the weld (in the transition of the skin-stringer) in the size of the structural components the dendritic structure has a uniform character.

An additional pass allows obtain samples with geometric sizes that meet the requirements of high level B of quality (according to ISO 13919-1:1996). However, according to the results of mechanical tests on a static tension, it was found that the samples welded according to the TI#2, showed a large scattering of the values of resistance to the destruction force. Such conclusions are confirmed by the fact that the destruction of 60% of the samples as a result of mechanical tests occurred on the metal weld, and only 40% of the samples were destroyed by the base metal of the stringer of the welded T-joint.

4.1.3. Welding technological implementation #3 (TI#3).

In order to eliminate the negative influence on the structure and mechanical properties of welded joints, as a result of reheating and cooling in the course of additional passes during the formation of welded T-joints in accordance with TIs #1 and #2, laser welding of samples according to the TI#3 was produced in one pass in the pulsed mode of generation of laser radiation. This allowed ensure a uniform formation of fillets on both sides from the stringer of the welded T-joint using more than two times the extended range of parameters of the technological modes, compared with welding in the continuous mode of generation of laser radiation. The parameters were the following ones: pulsed power P_{Max}=3.0…4.4 kW, pulse frequency 100…250 Hz, and fill factor ξ=50…75%. The focus of the laser beam has been deepened on 2.0…4.0 mm relative to the surface of the sample. The welding speed was 50…100 mm/s.

Figure 2,e,f shows the welded joint obtained by the TI#3 in modes that are as close as possible to the optimal, according to the criteria of ensuring the two-sided forming of fillets, the specified sizes and the maximum level of mechanical characteristics of the welded T-joint: at maximum pulsed power P_{Max}=4.4 kW, pulse frequency 250 Hz, and filling factor ξ=75%. The focus of the laser beam has been deepened on 4.0 mm. The welding speed was 75 mm/s.

Summing up the consideration of TIs based on laser welding in the lower spatial position, note the following: according to the results of mechanical tests on a static tension (Table 2) it was established that the samples welded according to the TI#3 ensure a relatively low value of the resistance of the weld joint to the breaking force. We emphasize that the destruction of all samples took place on the metal weld of the welded T-joint TI#3 for all tests carried out. Thus, the features of the joints obtained in accordance with the TI#3 include the unevenness in the formation of fillets on both sides of the welded joint and low level of strength characteristics, which does not give us reason to recommend it for use in industry.

4.2. Laser welding in a vertical spatial position

In case of laser welding produced in a vertical spatial position, the welding modes were considered and the welding variants were investigated as "on rise" (with the laser head moving along the vertical upwards, relative to the unmovable clamp with the fixed sample), and "on descent" (with the moving of the laser head downwards, relative to the unmovable clamp with fixed sample). It should be noted that the general positive tendency of expansion (almost two times) of the range of technological parameters of the modes, at which the stable reception of the specified form and geometrical sizes of the weld of the welded joint with the guaranteed formation of fillets on both sides of the stringer is achieved. It distinguishes welding in the vertical space position from welding in the lower spatial position.

For laser welding in the vertical spatial position, four welding TIs have been identified, the application of each implementation allows obtain the control welded T-joint meeting the requirements for obtaining welds of high B or medium C quality levels (according to ISO 13919-1:1996). They used the same equipment to protect the metal of the welded joint by argon from the influence of the environment, as that was done for welding in the lower spatial position.

According to the results of the visual test it was established that all samples welded in the vertical spatial position correspond to the "high B" quality level, according to ISO 13919-1:1996.

In all samples, welded in a vertical space position, lone pores with dimension not more than 0.5 mm are detected. According to the results of X-ray test it was established that all samples welded in the vertical spatial position correspond to the quality level "C moderate" according to ISO 13919-1:1996.

4.2.1. Welding technological implementation #4 (TI#4).

The TI#4 differed from the TI#1 only by a change of the spatial position from the lower to a vertical one. Welding was carried out downwards. Other parameters of the technological modes were not changed, as in TI#1.

The best results from the point of view of obtaining the geometric sizes of the welded joint and the stability of the forming of fillets were obtained by welding in a continuous mode of generation of laser radiation with a power of 4.4 kW without defocusing $\Delta F = 0$ mm, at a speed of 100 mm/s indented from the symmetry plane of the stringer by 0.3 mm for each pass.

Despite relatively high strengths (see Table 2), the samples obtained under the TI#4 were broken both by the base metal of stringers (60% of samples) and by the metal weld (40%).

The comparison of the samples obtained by TI#1 (Figure 2,a,b) and #4 (Figure 3,a,b) shows a slight increase in strength and microhardness values when the welding position from the lower to the vertical changes. At the same time, it should be noted increasing of instability in the formation of the weld, as well as the multivariance of position of the destruction location of welded joints.

4.2.2. Welding technological implementation #5 (TI#5).

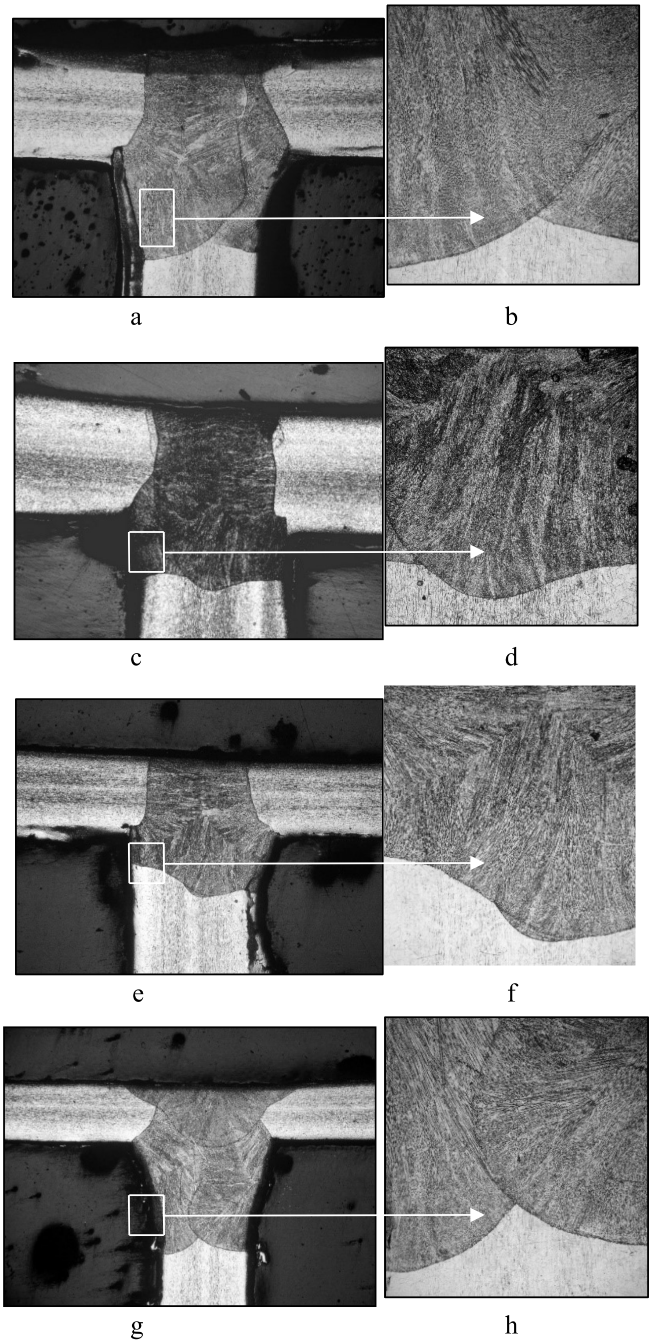
The TI#5 differs from the TI#1 and #4 by the parameters values of the modes, which are the best in view of the formation of the welded joint and stability of the fillets forming, namely by increasing the size of defocusing to $\Delta F = +4$ mm, increased from 100 mm/s to 113 mm/s speed of welding, as well as changing the spatial position from the lower to the vertical one. According to the TI#5 welding was produced upwards. Other parameters of the technological modes were not changed, as in TI#1.

As can be seen from the photos shown in Figure 3,c,d and from Table 1, the change in the focus position relative to the surface of the sample resulted in significant changes in the geometric sizes of the welded joints as compared to the samples obtained according to the TI#1.

Unlike the samples obtained according to the TI#2, the welded T-joints obtained during the welding process according to the TI#5, demonstrate both high level of mechanical characteristics and high stability in the formation of welded joints. This is confirmed by the fact that all welded joints obtained according to the TI#5 were destroyed by the base metal of the stringer, as distinguished to the samples obtained in the lower spatial position according to the TI#2.

According to the results of mechanical tests on a static tension, it was found that the samples welded according to the TI#5, show a big dispersion in the values of resistance to the destruction force. This may indicate a lack of stability in the formation of welded joints.

The conclusions like these are confirmed by the fact that the destruction of most samples occurred on the base metal of the stringer of the welded T-joint.



a b c d e f g h

Figure 3. Welded T-joints obtained in vertical spatial position: macrograph, ×30: a – TI#4, c – TI#5, e – TI#6, g – TI#7; micrograph: b – transition zone between weld and stringer TI#4, ×100; d − transition zone between weld and stringer TI#5, ×100; f – central weld zone TI#6, ×100; h − central weld zone TI#7, ×100.

4.2.3. Welding technological implementation #6 (TI#6).

Laser welding of the welded T-joints according to TI#6 was produced in pulse mode, which according to its parameters was identical with the modes of the TI#3, except for the value of defocusing. For TI#6, the optimal value of the focus position was $\Delta F = 0$ mm. Besides, as distinguished to TI#3, the samples according to the TI#6 were welded in vertical position downwards.

The changes like those in the modes resulted in significant changes in the formation of welded joints (Figure 3,e,f), but only lightly affected structural changes (Table 1). At the same time, the lack of stability in formation of the upper bead of the welded joint according to the TI#6 affected the strength (Table 2). According to the results of mechanical tests on a static tension, it was found that all samples welded according to TI#6 were destroyed by a metal weld of the welded joint and showed the lowest strength of all TIs.

4.2.4. Welding technological implementation #7 (TI#7).
In a similar way to the TI#2, laser welding according to TI #7 was produced in two continuous passes "on descent" indented from the symmetry plane of stringer by 0.3 mm with different defocusing (the best value was fixed $\Delta F = 0$ mm) and the next third pass for slight melting of the welding zone at a speed of 25 mm/s and a power of 1.5 kW with a 20 mm of defocusing.

According to the results of mechanical tests of the welded joints obtained according to the TI#7 (Figure 3,g,h), it was defined that all samples were destroyed along the base metal of the stringer. The value of the resistance to the destruction is quite high.

According to the above data, in some cases as relates to the samples welded according to TIs (#2, #4 and #5), there is a destruction both on the base metal and on the metal of weld. This may be related to the lack of stability in the formation of welded joints, and in particular the structural elements as fillets. At the same time, for samples welded in the vertical position, the destruction of the sample on the stringer is more characteristic, while in the samples welded in the lower position this is not found. The results of mechanical tests show that in comparison with samples welded in the lower spatial position, the samples welded in the vertical spatial position less dispersion value is more characteristic. This may be related to a more stable formation of welded joints, as well to a higher average resistance value to the destruction force, which is higher by about 10...20% as compared to the welded joints obtained in the lower spatial position under similar TIs.

5. Conclusions
The studied technological implementations of laser welding of the welded T-joints made of fine-sheet heat resistant steel AISI 321 make it possible to select the most promising solutions for industrial applications.

The general positive tendency of the expansion (almost two times) of the range of technological parameters of the modes is defined, at which a stable obtaining of the specified form and geometrical sizes of the weld of the welded joint with the guaranteed formation of fillets on both sides of the stringer is achieved. This distinguishes the welding in the vertical spatial position from the welding in the lower spatial position.

According to the results of the comprehensive research, it has been defined that the most industry perspective technological implementations of laser welding of the welded T-joints made of fine-sheet heat-resistant steel AISI 321 are the technological implementation #1 (for welding in the lower spatial position) and the technological implementation #7 (for welding in a vertical spatial position). The selection of these technological implementations is justified by the most stable formation of fillets on both sides of the T-joint as well providing the necessary geometrical sizes of the welded joints and high level of mechanical properties.

When choosing between technological implementations #7 and #1, it is recommended to render preference to the implementation #7 since when producing welding in the vertical spatial position a comparatively higher values of mechanical characteristics are achieved.

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