Method for regulating welded deformations by local thermal extension in titanium alloys welding

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Abstract. The article presents the results of the study of the influence of welding conditions on welding deformations of Ti samples. Welding using a non-consumable electrode in shielding gas was aimed at obtaining thin ribbed samples used in the aircraft building industry. The difficulty of welding a sheet with a stiffener is due to the occurrence of defects: changes in the surface geometry (angular deformations). The article aims to assess capability of controlling welding deformations using a tail heat sink due to local thermal tension for Ti alloy welded joints. The effect of welding conditions on the value of angular welding deformations of samples was determined. The best results were obtained for parts produced using a device designed by the author. The device combines gas protection of the cooling section of the welding joint and contributes to local thermal tension. The X-ray control did not identify internal defects in the joints produced by the standard method and the method using a tail heat sink. The tests showed that the use of a tail heat sink does not affect the structure and properties of welded joints made from the Ti-Al-Zn system alloy. The experiments proved the efficiency of the method for controlling welding deformations using a tail heat sink.

Keywords. TIG welding, regulating welded deformations, by local thermal extension, titanium alloys welding.

1. Introduction
Straight-line extended welded joints in large-sized thin-sheet ribbed structures made of titanium alloys have found wide application in the aircraft, rocket, shipbuilding, and other industries.

In welding these joints, one of the most serious problems is displacement and deformations which affect the accuracy of shapes and dimensions of the structure and significantly reduce the technological strength of welded joints [1,2].

In thin-walled structures, sheet is joined with stiffeners by fusion welding on the side of the rib. Double-sided fillet welds are produced by an automatic argon-arc welding method using a tungsten electrode (TIG), EBW, or by a laser welding method [3,4].

Temporary deformations and displacement and residual deformations that distort the shape and size of the finished product can occur in arc welding [5].

Various methods have been developed to improve accuracy of welded thin-sheet ribbed structures. The Institute of Welding n.a. E.O. Paton suggested a technology involving preliminary elastic
stretching of joined parts and automatic electron-beam and arc welding at high speed rates [7-10]. There are ways to reduce deformations by attaching the welded web to the base plate along the contour or applying a method of through penetration welding from the panel cladding, when a tensile force is applied to the rib during the welding process. The T-joint is produced in one pass on the side of the sheet through penetration in thickness and partial penetration of the rib.

However, when arc welding thin-sheet panels, formation of the weld pool, heating of the heat-affected zone and penetration of the metal cause residual stresses and deformations of the product. Many works deal with their quantification, methods of reduction and elimination [11-13].

The methods for regulating welding deformations by thermal extension using a tail point heat removal have been developed [14]. The authors cite the research results demonstrating positive effects of these methods for non-ferrous alloy parts [15].

The relevance of this work is due to the aim to reduce welding deformations of large-sized thin-sheet ribbed structures made of titanium alloys and improve the accuracy and quality of products.

The aim of this work is to assess the feasibility and effectiveness of the method for regulating welding deformations by local thermal extension using a tail heat removal. The method is used for welding parts with stiffeners made of titanium alloys.

2. Materials and methods
To study the efficiency of the method for regulating welding deformations by local thermal extension, Ti alloy samples with dimensions H = 200 mm, length L = 200 mm, thickness = 1,3 mm, and stiffener with thickness = 1.8 mm dimensions 20x200 mm were produced. The chemical composition of the alloy is presented in Table 1 [16].

| Element | Fe  | C    | Si   | Mo  | V   | N   | Ti  | Al   | Zr   | O    | H    |
|---------|-----|------|------|-----|-----|-----|-----|------|------|------|------|
| Content |     |      |      |     |     |     |     |      |      |      |      |
| %       | up to | up to | up to | 0.5 - 2 | 0.8 - 2.5 | up to | 85.15 - | 5.5 - 7 | 1.5 - 2.5 | up to | up to |

T-joints (imitating elements of ribbed panels) were welded using a non-consumable electrode in inert gas (TIG) on ADSV-6M (see Figure 1) according to standard technology and the developed method.

Figure 1. The unit for argon arc welding using a non-consumable electrode.

The main parameters of the inert gas welding mode are presented in Table 2. The assembly scheme of the welding unit is shown in Figure 2.
Table 2. TIG welding parameters.

| Mode options | Current (A) | Diameter of the W-th electrode (mm) | Arc voltage (V) | Welding rate (m/h) | Argon consumption (l/min) |
|--------------|-------------|-------------------------------------|----------------|-------------------|--------------------------|
| Value        | 80-100      | 1.6                                 | 10-12          | 25                | 15-18                    |

Figure 2. Assembly diagram: 1 – arc welding, 2 – pneumatic clamps, 3 – sheet, 4 – transverse edge of the backing support stand, 5 – longitudinal rib.

The quality of welds was checked by a visual-measuring method. Mechanical properties of the welds were tested. Internal defects were detected by the X-ray control using PHILIPS MG 452.

According to the developed welding method, a protective visor with a water-cooled heat removal was attached to the head. The visor sliding over the weld ensured intensive cooling of the zone located at some distance (20-50 mm) from the weld pool. The coolant (water) acted on the hardened surface of the weld through the copper case of the cooler.

After the beginning of the arc welding process, the water-cooled heat removal moved synchronously with the welding arc to the groove between the pressure plates. Its lower concave surface interacted with the convex surface of the weld removing heat behind the weld pool.

A high temperature gradient was created along the weld bead of the zone of 800–400°C near the rear tail part of the weld pool. The scheme of the local thermal extension effect (LTE) is shown in Figure 3.

Figure 3. The scheme of the local thermal extension effect: 1 - heat removal, temperature failure; 2 - center of the heating source (arc); 3,4 – isotherms; 5 - welding bath; 01- center of the heat removal, 01- center of the heating source; L - distance between centers of the heating spot and the heat removal.
Figure 4 shows the unit for effect implementation. Welded parts 1 are installed in the welding stand (the assembly scheme is shown in Figure 2) on copper layer 2 producing penetration. Copper pressure heat removal plates 3 are installed on parts 1 in the heat-affected zone. Using a keyboard presser mechanism, plates 3 and parts 1 are pressed to copper layer 2 forming penetration.

Protective visor 4 with heat removal 5 clings to burner 6 by means of grippers and fits into the groove between the ledges of pressure plates 3. The lower part of the heat removal fits into the groove between clamping plates 3 and lays down on the welded surface of the part.

![Figure 4](image1.png)

**Figure 4.** The scheme of the local thermal extension effect: 1 - heat removal, temperature failure; 2 - center of the heating source (arc); 3,4 – isotherms; 5 - welding bath; 01- center of the heat removal, 01- center of the heating source; L - distance between centers of the heating spot and the heat removal.

Argon is supplied to the nozzle of welding torch 6 and protective visor 4 to protect the weld pool and the joint section. Tap water is supplied to heat removal 5 (other coolants or gases N₂, CO₂, etc. can be used).

3. Results and discussion
   When welding with a non-consumable electrode in the protective gas environment using the described method, the following conclusions can be drawn.

   The angular deformation in the form of a “house” was observed after welding. The maximum gap f (mm) was produced after removing clamping forces P in the unit (Figure 6)

![Figure 5](image2.png)

**Figure 5.** The welded sample.
The samples produced using tail heat removals showed the best results. The average values of angular deformations having the maximum gap - f (mm) are as follows: for samples obtained by TIG welding using the basic technology of 5.8 mm; for samples obtained using the unit described above no more than 1 mm.

The X-ray control did not identify defects in joints. The standard tests of welded joints [18] have shown that the use of a tail heat-removal creating the local thermal extension effect does not affect the structure and properties of welded Ti-alloy joints.

When using a tail cooler, a deep temperature valley behind the welding pool was formed. This created a high temperature gradient. At 800 and 400°C, the isotherms deformed and moved closer to the welding pool forming a zone with a LTE effect.

**Figure 6.** Temperature fields and isotherms in a welded joint made by welding with a non-consumable electrode in inert gases with a tail heat sink.

4. Conclusion

Thus, by using a tail heat removal, it is possible to reduce welding deformations and ensure dimensional stability and geometric integrity of welded structures made of titanium alloys Ti-Al-Zn system.

It is necessary to provide local cooling of the seam (using the device designed by the author) and prevent temporary out-of-plane movements (using clamping elements of the assembly stand).

Compression deformations can be compensated for internal plastic tensile deformations by changing the thermal cycle of welding and applying a local heat sink along the weld bead.

By selecting the distance between the arc and the heat removal, changing water consumption or using another cooler, one can reduce or eliminate deformations. The closer the heat removal to the heating source, the stronger the effect.

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