Complex technology of production of three-ply titanium composite sheets

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Abstract. The mechanical properties of the explosion welded three-ply compositions of titanium alloys in dependence on the conditions of the subsequent rolling and heat treatment were studied.

1. Introduction
A well-known feature of high-strength titanium alloys and hardened steels is a low ductility and high propensity to brittle fracture. So alloy VT5 in comparison with the technical titanium BT1-0 has almost twice as high tensile strength and so much the less stretch ratio at five-fold decrease of the homogeneous deformation, which limits its application to critical structures [1, 2].

In [3 - 6] it is shown, that significantly improve of the ductility of high strength steels can be made by creating with the help of thermal operations surface decarbonized layers, and double-sided facing of steel 30HGSA with layers of steel 12H18N10T with a total thickness of 30% of the base layer increases the elongation of a three-ply composition to 7 - 8% in comparison with 3 - 4% of the steel 30HGSA, homogeneous deformation – from 0-2 up to 7% by lowering the tensile strength by 16%. And the improvement of properties of high strength steels is achieved in case of strong connection of layers, which is easily realized by using the explosion welding layered compositions [7].

Explosion welding in combination with the subsequent rolling is advisable to use to enhance the resistance to brittle fracture of high-strength titanium alloys [7]. This technology allows not only to obtain compositions with high-strength layer interconnection, but also to avoid the use of expensive vacuum or inert atmosphere rolling equipment.

2. Materials and methods
We used commercial titanium VT1-0 and titanium alloys VT5 and VT14. Their initial properties before explosion welding are shown in table 1. VT5 alloy was cladded on both sides with titanium VT1-0 thickness of 1 mm side, VT14 alloy – with titanium VT 1-0 thickness of 1, 1.5 and 2 mm.

Operational sequence was: 1. The simultaneous explosion welding of three-ply compositions VT1-0+VT5+VT1-0 (CM1) and VT1-0+VT14+VT1-0 (CM2) in the optimal conditions (speed of the contact point of 1800-2000 m/s, impact velocity 480-520 m/s) to ensure strength uniformity of the welded joints to the least durable alloy VT1-0.
### Table 1. The mechanical properties of the alloys VT5, VT14 and titanium VT1-0

| Material | Tensile strength, MPa | Stretch ratio, % | Contraction ratio, % | Note |
|----------|-----------------------|------------------|----------------------|------|
| VT5      | 800                   | 12.0             | -                    | -    |
|          | 700                   | 15.0             | -                    | -    |
| VT14     | 1070                  | 1.9              | 3.1                  | -    |
| VT1-0    | 480                   | 25.0-40.0        | 45.0-55.0            | -    |

2. Hot rolling of the three-ply blanks of CM1 to the sheet thickness of 4 mm and CM2 to the sheet thickness of 2.5 mm at a three thickness ratios at the following order: rolling start temperature 850 – 900 °C, rolling closure 650 – 750 °C, number of passes - 4. For comparative studies simultaneously with the three-ply blanks the single-layer sheets of alloys VT5 and VT14 were rolled to the same thickness.

3. Tempering of the alloy VT5 and CM1 for 1 hour at 400, 600, 700, 800, 900 °C with the air cooling. Alloy VT14 and CM2 were tempered at 600 °C for 0.5 hours, quenched at 920 °C with water cooling, and the same quenching, followed by aging at 400 °C for 16 hours.

4. Cutting from one- and three-ply heat-treated sheets the standard samples and their subsequent mechanical testing. In addition, the notched samples and samples with pre-formed cracks from the alloy VT14 and CM2 were produced and tested for impact strength with the registration of the fracture.

### 3. Results and Discussion

To determine the influence of the direction of rolling on the mechanical properties of the composite material rolling of the welded samples was made across and along the direction of welding. Since the boundary between the layers in the titanium composition is irregular wavy surface, warped waves in the process of tensile tests are stress concentrators. Rolling across the direction of welding provides a lower variation in thickness of cladding layers, so the influence of the waves irregularity on the mechanical properties is smaller than when rolling in a direction similar to the direction of welding (Table 2).

Mechanical tests shown that at 15 percent of the total thickness of the cladding layers strength of CM1 in the directions along and across the rolled is reduced by 1.5 - 2%, and the total elongation is increased by 15 - 20% (Table 2). Besides cladding of VT5 by plastic titanium alloy VT1-0 led to a twofold decrease of variation in individual strength values along the rolling direction and two - three times decrease in the across rolling direction. At about the same extent variation of values of total elongation and uniform strain decreased.

Similar results were obtained in the test of sheet CM2. As seen from the graphs of Figure 1, the increase in the total thickness of the cladding to 40% of the thickness of the base layer decreases strength of CM2 in comparison with the alloy VT14 after quenching and aging at 7.5%, after tempering - at 13% (Figure 1a) and increases total elongation and contraction after thermal operations in 2 - 3 times (Figure 1 b, c). The specific work of fracture of samples with pre-applied crack under impact bending increased with an increase of the thickness of the cladding, in all cases, roughly equally: the $\delta_{pl}/\delta_0 = 25\% - 50\%$, and $\delta_{pl}/\delta_0 = 40\% - 100\%$ (Figure 1d).
Table 2. The results of mechanical tests of unclad and cladded sheets of alloy VT5 depending on the rolling direction and tempering temperature

| Cutting directions | Tempering temperature, °C | 1-layer sheets | Three-ply sheets |
|--------------------|---------------------------|----------------|------------------|
|                    |                           | Tensile strength, MPa | Uniform strain, % | Total elongation, % | Tensile strength, MPa | Uniform strain, % | Total elongation, % |
| Along rolling      | -                         | 750-830          | 0-5             | 10-20             | 750-790          | 2-4              | 15-20            |
|                    | 400                       | 740-830          | 1-5             | 9-21              | 760-790          | 3-5              | 15-22            |
|                    | 600                       | 740-810          | 1-7             | 10-21             | 720-760          | 4-7              | 15-20            |
|                    | 700                       | 630-710          | 2-9             | 9-22              | 660-700          | 5-9              | 16-22            |
|                    | 800                       | 620-750          | 2-8             | 8-20              | 660-690          | 5-9              | 15-24            |
|                    | 900                       | 610-740          | 2-8             | 7-18              | 590-680          | 5-8              | 15-22            |

| Across rolling     | -                         | 650-800          | 0-5             | 7-19              | 710-760          | 1-5              | 10-18            |
|                    | 400                       | 670-810          | 1-5             | 8-19              | 710-750          | 2-5              | 10-19            |
|                    | 600                       | 610-750          | 1-5             | 9-20              | 650-690          | 2-6              | 12-20            |
|                    | 700                       | 600-750          | 2-7             | 10-21             | 630-650          | 4-8              | 14-22            |
|                    | 800                       | 590-690          | 2-7             | 9-22              | 600-650          | 4-8              | 14-25            |
|                    | 900                       | 580-670          | 2-5             | 5-18              | 600-650          | 4-7              | 10-21            |

Figure 1. Changes of the mechanical properties of the alloy VT14 with the thickness of cladding layers: a - tensile strength; b - total elongation; c - percentage reduction; d - a relative reduction of the
specific work of fracture of samples with a crack under shock loading in comparison with not cladded. Curves legend: 1 – Tempering at 600 °C; 2 - in the state after rolling; 3 – quenching at 920 °C with water cooling; 4 - quenching and aging at 400 °C for 16 hours. δ_{pl} - total thickness of the layers of titanium VT1-0, δ_{o} - the thickness of the alloy VT14.

4. Conclusions
The complex technology of production by explosion welding and subsequent hot rolling of three-ply compositions VT1-0+VT5+VT1-0 and VT1-0+VT14+VT1-0 was developed. Compositions have the interconnection strength at the level of the strength of titanium VT1-0, which have in comparison with alloys VT5 and VT14 2 - 3 times less variation in individual strength values, total elongation and uniform strain with the considerable reduce of the tendency to brittle fracture.
To reduce variations in thickness of explosion welded cladding layers of three-ply the compositions of high-strength and ductile titanium alloys, following hot rolling must be done in the cross direction to the direction of the welding process.

Acknowledgments
The investigation was performed by a grant from the Russian Science Foundation (project № 14-29-00158).

References
[1] Glazunov S G, Moiseev V M 1974 Structural titanium alloys. (Moscow, Metallurgy)
[2] Kolachev B A, Livantov V A, Elagin V I 1981 Metallurgy and heat treatment of non-ferrous metals and alloys (Moscow, Metallurgy)
[3] Ioffe A F, Kirpicheva M V, Levitskaya M A 1924 Deformation and strength of crystals (JRFHO)
[4] Pashkov P O 1950 The ductility and fracture of metals (St. Petersburg, Sudpromgiz)
[5] Friedman Y 1946 Mechanical properties of metals (Moscow, Oborongiz)
[6] Katihin V D, Kofman A P, Javor A A 1965 Cladding as a means of reducing the tendency of hardened steels to brittle fracture (Volgograd)
[7] Cossack N N, Sedykh V S, Trykov Y P, Ulitin A I 1974 The mechanical properties of titanium multilayer composition after explosion welding and hot rolling Physics and Chemistry of Materials Processing 1 215-220