INFLUENCE OF FILLER METAL ON STRUCTURE AND PROPERTIES OF WELDED JOINTS OF HIGH-STRENGTH TWO-PHASE TITANIUM ALLOYS PRODUCED USING ARGON ARC WELDING

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The welded joints of high-strength titanium alloys, produced using arc welding, have, as a rule, unsatisfactory values of mechanical properties, especially those of ductility in the as-welded state as compared to the base metal. In the work the effect of thermal welding cycle, type of filler metal and the post-weld heat treatment on the structure and properties of welded joints of two-phase high-alloyed titanium alloys having σ_t > 1000 MPa, were evaluated. The properties and structure of welded joints of high-strength titanium alloys VT23, T110 and experimental alloy Ti–6.5A1–3Mo–2.5V–4Nb–1Cr–1Fe–2.5Zr, made by argon arc welding applying the filler wires, differing by their composition from the base metal, were studied. It is rational to produce the joints of complex-alloyed titanium alloy Ti–6.5A1–3Mo–2.5V–4Nb–1Cr–1Fe–2.5Zr using argon arc welding applying filler wire VT1-00sv at modes, providing the through penetration and the content of wire components in the weld metal at level of 10 % in combination with the subsequent high-temperature annealing. 6 Ref., 1 Table, 6 Figures.

Keywords: *titanium alloys, argon arc welding, filler wire, properties, structure*

The welded joints of high-strength titanium alloys, produced using arc welding, have, as a rule, unsatisfactory values of mechanical properties, especially those of ductility in the as-welded state as compared to the base metal. Therefore, it is often recommended to produce such joints applying filler metal for improvement of mechanical properties of the weld metal. However, due to the limited choice of filler materials for welding of high-strength two-phase titanium alloys, there is urgent problem of selecting the type of filler material, when developing the technology for welding of new high-strength titanium alloys.

In welding of titanium alloys with high tensile strength it is rational to change either the degree, or the system of weld metal alloying [1, 2]. It is the easiest to make this during fusion arc welding applying the filler wires, differing by chemical composition from the base metal. The thermal cycle of arc welding of high-alloyed titanium alloys leads to the substantial change in the structure of both the near-weld zone as well as weld metal, and, as a consequence, in deterioration of mechanical characteristics of the welded joint. Therefore, when developing the technology for welding of high-strength titanium alloys, and selecting or developing the filler material, it is necessary to pay attention to the possibility of producing welded joints with high impact toughness, moreover, the strength of the joints should be at least 0.9 of the strength of base material. Furthermore, to improve the properties of welded joints in the area of HAZ and to relieve welding stresses it is rational to use the postweld heat treatment (PWHT).

The aim of the work is the evaluation of effect of thermal welding cycle, type of filler metal and PWHT on the structure and properties of welded joints of two-phase high-alloyed titanium alloys having σ_t > > 1000 MPa. The properties of high-strength titanium alloys VT23, T110 and experimental alloy Ti–6.5A1–3Mo–2.5V–4Nb–1Cr–1Fe–2.5Zr welded joints [3], produced using argon arc welding applying tungsten electrode (TIG) with application of filler metal to the groove and without the edge preparation, were compared.

The joints of alloys VT23 [4] and T110 were produced using TIG welding of plates of 8 mm thickness, welding was carried out to the edge groove applying filler wire SP15sv (Ti–4.5A1–2.5Mo–2.5V–3.5Nb–1.5Zr) designed for welding of high-strength titanium alloys VT23 and VT22 (Figure 1, *a*).

The high-strength alloy of grade T110 of system Ti–5.5A1–1.2Mo–1.2V–4Nb–2Fe–0.5Zr was developed at the PWI together with the O.K. Antonov ASTC [5].

The welded joints of experimental high-alloyed 8-component system Ti–6.5A1–3Mo–2.5V–4Nb–

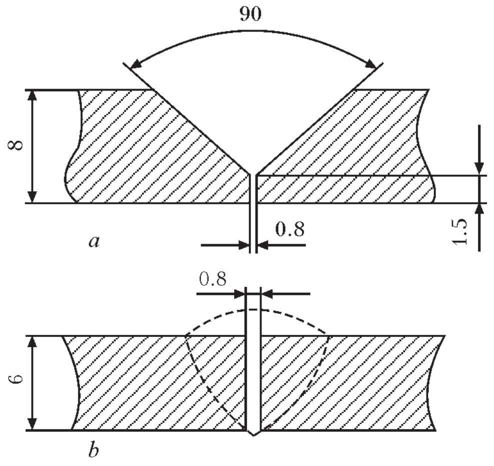

Figure 1. Scheme of edge preparation for TIG welding: *a* — one-sided welding with edge preparation and feeding of filler wire SP15sv; *b* — one-sided welding without edge preparation with feeding of filler wire VT1-00sv

1Cr–1Fe–2.5Zr were produced with thickness of 6 and 8 mm. Moreover, the joints of 8 mm thickness were produced using multilayer TIG welding to the edge groove applying filler wire SP15sv (see Figure 1, *a*) and the joints of 6 mm thickness were made with through penetration applying filler wire VT1-00sv (Figure 1, *b*). Alloy Ti–6.5A1–3Mo–2.5V–4Nb–1Cr–1Fe–2.5Zr contains more alloying elements as compared to T110 alloy and in the as-annealed state it has tensile strength exceeding 1200 MPa.

One-side TIG welding was performed using electrode of 5 mm diameter. Welding current amounted to 250–350 A, welding speed was 10 m/h. After welding, all the welded joints were subjected to annealing. The temperature of annealing for experimental alloy Ti–6.5A1–3Mo–2.5V–4Nb–1Cr–1Fe–2.5Zr was selected in order to provide the highest impact toughness of weld metal and, according to the results of work [3], it amounted to 900 ^{o}C (1 h) in combination with the subsequent furnace cooling. The examples of produced welded joints are given in Figure 2.

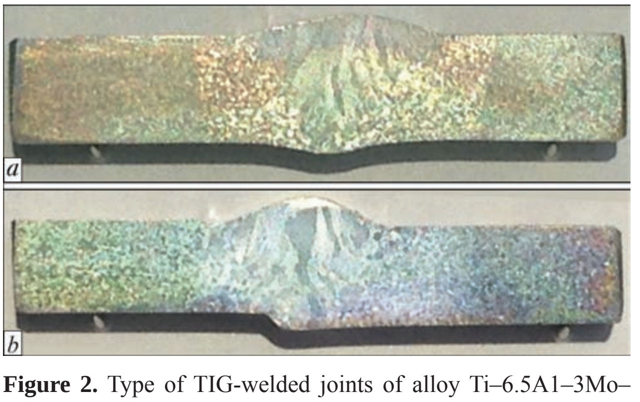

Figure 2. Type of TIG-welded joints of alloy Ti–6.5A1–3Mo–2.5V–4Nb–1Cr–1Fe–2.5Zr: *a* — to edge groove; *b* — without edge preparation with feeding of filler wire VT1-00sv

The investigations showed that the TIG-welded joint of alloy Ti–6.5A1–3Mo–2.5V–4Nb–1Cr–1Fe–2.5Zr with through penetration applying filler wire VT1-00sv, which was fed in the welding process at rate of 60 m/h, has content of filler metal in weld at level of 20 %, and the joint, produced using VT1-00sv wire, fed at rate of 30 m/h, has content of filler in weld metal at level of 10 %. The joint, welded to V-shaped groove applying wire SP15sv, was performed in 3 passes and the weld consists mainly of filler metal.

The properties of produced welded joints in the state after welding and annealing are given in the Table. The application of filler wire in TIG welding of alloys VT23 and T110 to the edge groove provides the strength of welded joints at level of 90 % of strength of the alloy itself. This condition is not fulfilled in case of TIG welding to the edge groove of the joints of alloy Ti–6.5A1–3Mo–2.5V–4Nb–1Cr–1Fe–2.5Zr applying wire SP15sv.

The width of welds in the upper part amounts to about 14 mm and in the root part it is about 3 mm. The macrostructure of metal of welds, produced both to the groove as well as without the groove, is composed of non-equiaxial grains elongated in the direction of heat dissipation. The coarsest grains are located in the weld upper part. The angle between the grain axis and the weld axis amounts from 0 to 30°. The

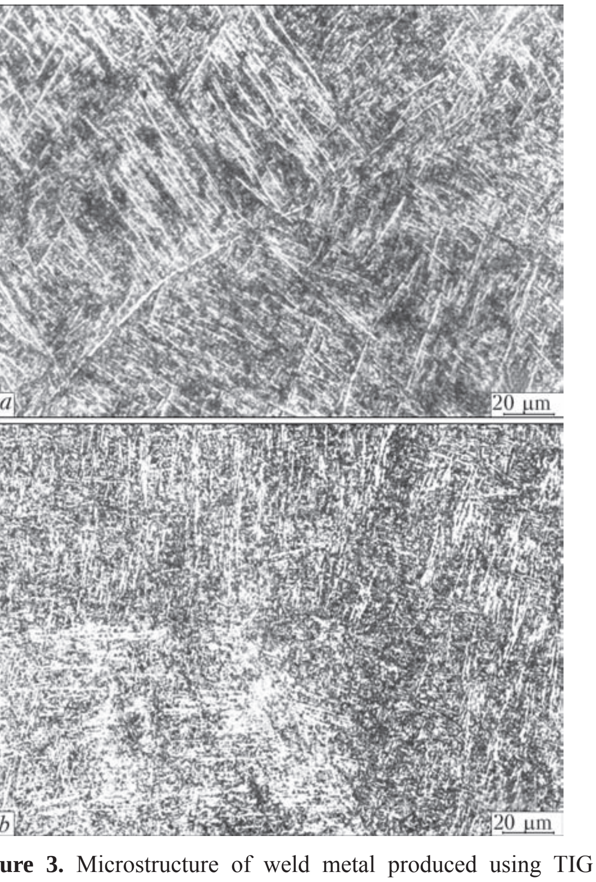

Figure 3. Microstructure of weld metal produced using TIG welding with filler wire SP15sv in the state after annealing at 750 °C for 1 h: *a* — alloy VT23; *b* — T110

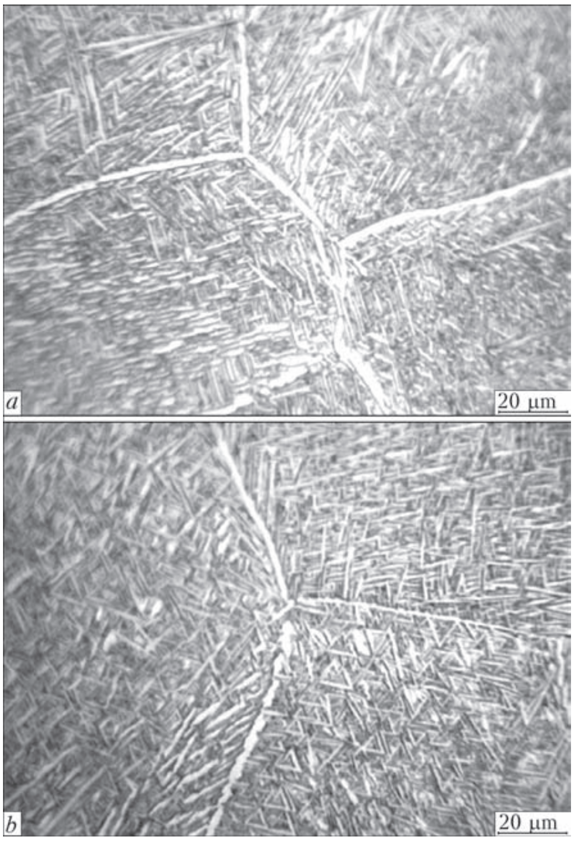

Figure 4. Microstructure of base metal (*a*) and HAZ (*b*) of TIG-welded joints of alloy Ti–6.5A1–3Mo–2.5V–4Nb–1Cr–1Fe–2.5Zr, produced applying filler wire VT1-00sv, in the state after annealing at 900 °C for 1 h

base and HAZ metals consist of the equiaxial grains corresponding to No. 3–4 at the comparison with the reference scales.

The investigations of the structure of produced welded joints showed that in TIG welding of alloy VT23 applying wire SP15sv a negligible decrease in alloying level of weld metal occurs. In the as-welded state the structure is formed in the weld, consisting mainly of metastable α'-(α'') phase. As a result of annealing the stable laminar α-phase and the dispersed mixture of α- and β-phases are formed (Figure 3, *a*). Also in the weld of alloy T110 as a result of annealing at 750 °C the decomposition of metastable phases with formation of laminar α-phase and fine-dispersed mixture of α- and β-phases occur (Figure 3, *b*).

8-component alloy Ti–6.5A1–3Mo–2.5V–4Nb–1Cr–1Fe–2.5Zr in the initial state had fine-dispersed structure in the ranges of primary β-grains [3]. The morphology of α-phase in the base metal after annealing at 900 °C during 1 h and furnace cooling is laminar, and the plate width amounts to 1–1.5 mm (Figure 4, *a*). Along the boundaries of the primary β-grains the α-fringe is present. In HAZ after the same annealing the metal structure has also laminar character (Figure 4, *b*), but the plates are finer than in the metal of weld produced applying wire VT1-00sv

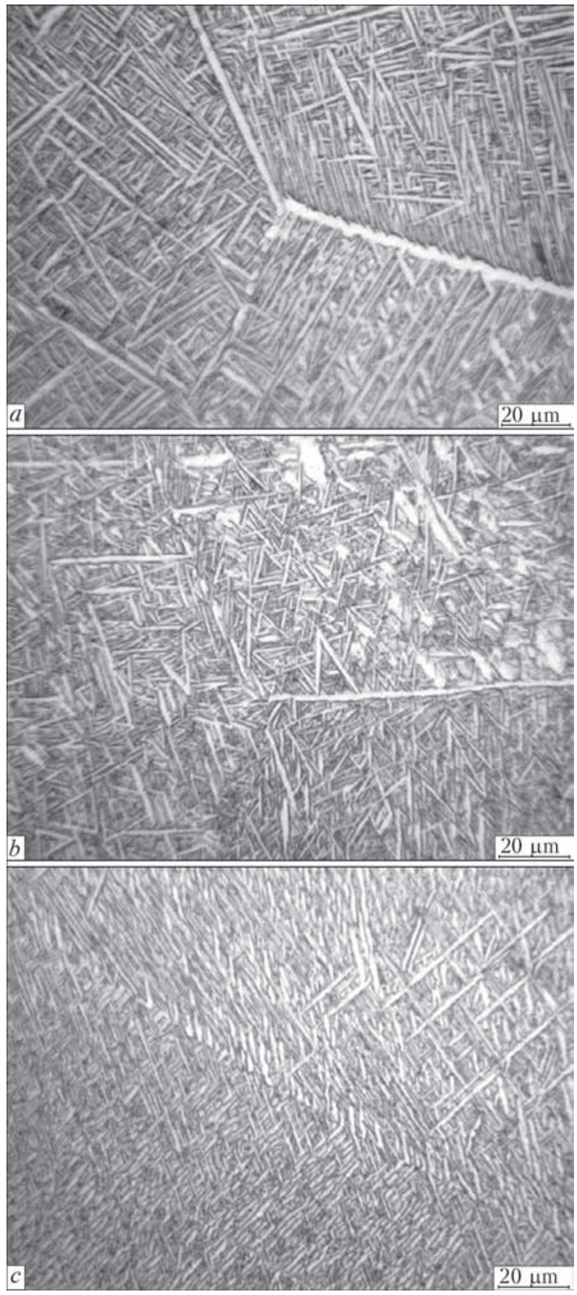

Figure 5. Microstructure of weld metal of TIG-welded joint of alloy Ti–6.5A1–3Mo–2.5V–4Nb–1Cr–1Fe–2.5Zr after annealing at 900 °C for 1 h: *a* — wire VT1-00sv content of 20 % in weld metal; *b* — of 10 %; *c* — welding to groove with wire SP15sv

(20 %), that is connected with higher alloying of HAZ metal than that of weld metal. The delayed furnace cooling from 900 °C was performed to prevent fixing of the metastable phases.

The weld metal of alloy Ti–6.5A1–3Mo–2.5V–4Nb–1Cr–1Fe–2.5Zr produced applying wire VT1-00sv at the presence of 20 % of filler in the weld is characterized by a larger laminar structure (Figure 5, *a*). In the weld metal the plates have a greater length and thickness of 1.5–2 μm, and in the gaps between the plates the (α + β) structure is dispersed. As compared to annealing at 750 °C, when the metal structure of all the zones of welded joints remained

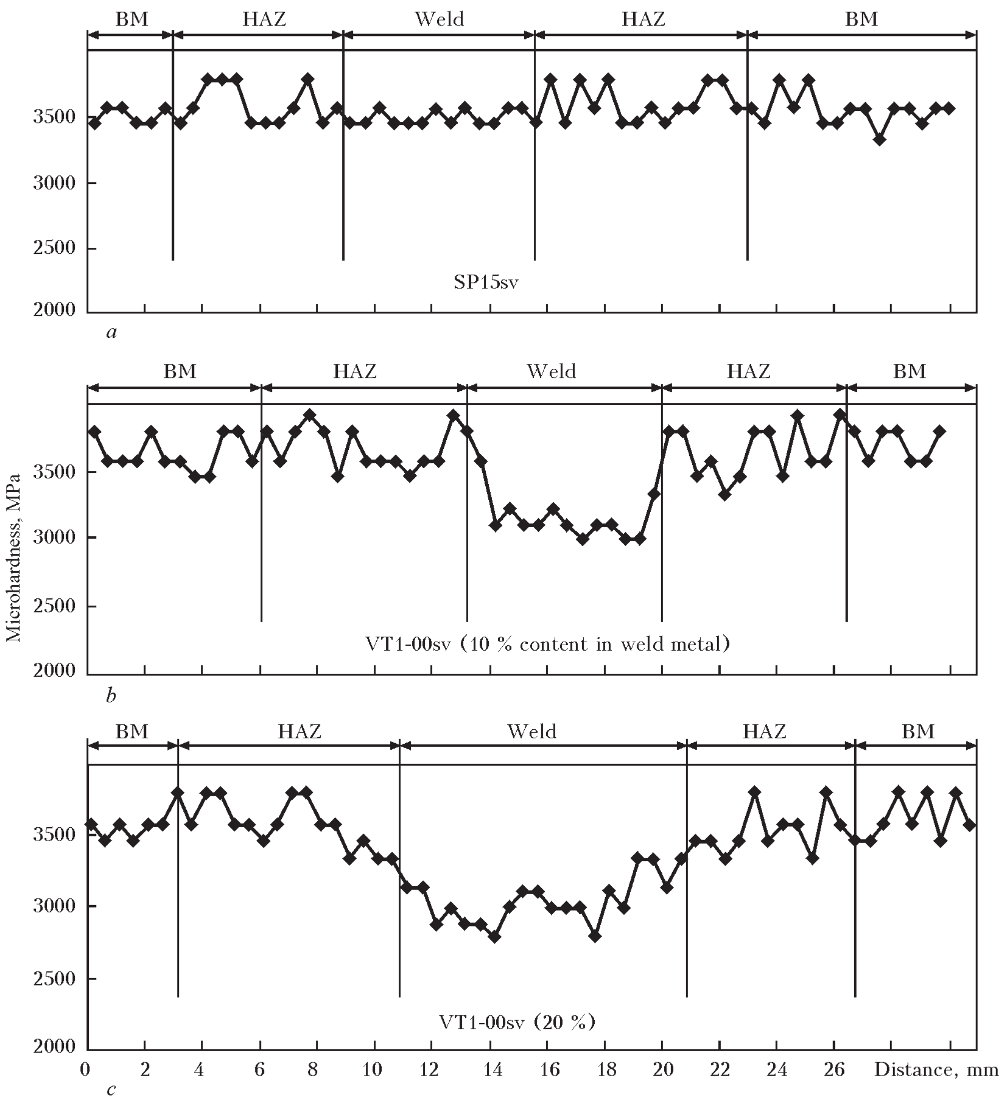

Figure 6. Microhardness of TIG-welded joint of experimental alloy Ti–6.5A1–3Mo–2.5V–4Nb–1Cr–1Fe–2.5Zr, produced applying different filler wires in the state after annealing at 900 °C for 1 h

fine-dispersed [3], the coagulation of α-phase after annealing at 900 °C can provide some increase in the ductile properties.

When introducing 10 % of wire VT1-00sv to the weld, the dilution degree of weld metal will be lower than in the previous case, therefore the microstructure of weld metal is finer, the plates of α-phase are shorter and have thickness of 1.0–1.5 μm (Figure 5, *b*).

In TIG welding to the edge groove a significant amount of filler gets to the weld metal, in case with wire SP15sv, alloying system of which differs from the alloying system of base metal, the weld metal has a structure differing from the structures produced in the case with applying of wire VT1-00sv. The microstructure of weld metal of alloy Ti–6.5A1–3Mo–2.5V–4Nb–1Cr–1Fe–2.5Zr, produced to the edge groove using wire SP15sv, after annealing at 900 °C, is presented in Figure 5, *c*. The microstructure of metal of the considered weld as compared to the microstructure of welds produced with wire VT1-00sv is characterized by a higher dispersity of the α-phase particles. The plates of α-phase have a smaller length and their thickness amounts to 0.5–1.5 μm.

The distribution of microhardness in weld metal of alloy Ti–6.5A1–3Mo–2.5V–4Nb–1Cr–1Fe–2.5Zr in the as-annealed state (Figure 6) showed a great heterogeneity in the joints with 20 % of VT1-00sv filler.

Thus, it is rational to produce the joints using TIG welding for complex-alloyed titanium alloy Ti–6.5A1–3Mo–2.5V–4Nb–1Cr–1Fe–2.5Zr with filler wire VT1-00sv on the modes, providing the through penetration and content of wire in the weld metal at level of 10 %. As a result of subsequent annealing at 900 °C a finer-dispersed structure is formed than that at 20 % content of the filler , that provides good values of strength and impact toughness of welded joints.

Conclusions

1. Use of high-alloy filler wire SP15sv in TIG welding to the edge groove of alloys VT23 and T110 with the

Mechanical properties of TIG-welded joints of titanium alloys produced applying different filler wires

Titanium alloy	Filler wire (content in weld metal)	Plate thickness, mm	State of welded joints	σ_t, MPa	Impact toughness of weld metal *KCV*, J/cm^2
VT23	SP15sv	8	As-welded	1010	21
VT23	SP15sv	8	Annealing at 750 °C, 1 h, air cooling	1090	22
T110	SP15sv	8	As-welded	1030	20
T110	SP15sv	8	Annealing at 750 °C, 1 h, air cooling	1020	35
Ti–6.5Al–3Mo–2.5V–4Nb–1Cr–1Fe–2.5Zr	VT1-00sv (20 %)	6	As-welded	1226	15
Ti–6.5Al–3Mo–2.5V–4Nb–1Cr–1Fe–2.5Zr	VT1-00sv (20 %)	6	Annealing at 900 °C, 1 h, furnace cooling	1048	27
Ti–6.5Al–3Mo–2.5V–4Nb–1Cr–1Fe–2.5Zr	VT1-00sv (10 %)	6	As-welded	1287	11
Ti–6.5Al–3Mo–2.5V–4Nb–1Cr–1Fe–2.5Zr	VT1-00sv (10 %)	6	Annealing at 900 °C, 1 h, furnace cooling	1110	24
Ti–6.5Al–3Mo–2.5V–4Nb–1Cr–1Fe–2.5Zr	SP15sv	8	As-welded	1208	18
Ti–6.5Al–3Mo–2.5V–4Nb–1Cr–1Fe–2.5Zr	SP15sv	8	Annealing at 900 °C, 1 h, furnace cooling	1047	25

subsequent annealing at 750 °C provides the required level of mechanical properties of welded joints.

2. Use of high-alloy filler wire SP15sv for producing the joints using TIG welding to the edge groove of high strength 8-component alloy Ti–6.5A1–3Mo–2.5V–4Nb–1Cr–1Fe–2.5Zr does not provide the required level of strength of welded joints.

3. Application of postweld annealing at 900 °C of high-strength alloy of system Ti–6.5A1–3Mo–2.5V–4Nb–1Cr–1Fe–2.5Zr provides a complete decomposition of metastable phases, as a result of annealing the equilibrium finer-dispersed structure is formed, providing satisfactory values of impact toughness of the joints.

4. High values of strength (σ_t = 1110 MPa) at good impact toughness (*KCV* = 24 J/cm^2) of welded joints of alloy Ti–6.5A1–3Mo–2.5V–4Nb–1Cr–1Fe–2.5Zr were obtained applying filler wire VT1-00sv at welding modes providing the through penetration and 10 % content of filler in the weld metal.

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