ADVANCES IN THE FIELD OF TITANIUM WELDING TECHNOLOGY

V. N. Zamkov, V. P. Prilutskii , Yu. K. Novikov

E.O. Paton Electric Welding Institute
of the Ukrainian Academy of Sciences, Kiev, Ukraine

Due to their unique physico-chemical properties, titanium alloys in the volumes of application in weld structures are now inferior only to steel and aluminium, and the manufacturing process will lead to the further expansion of the volumes and fields of their application. In addition to traditional applications of titanium alloys in aerospace industry, shipbuilding and chemical engineering, titanium is likely to be used in transport engineering, medicine, construction, food and textile engineering, etc.

For these industries the titanium treatment and welding processes should provide the high quality of welded joints and, besides, should be simple, cheap and highly productive.

At the same time, there appear certain difficulties in welding of titanium which, even at the initial period of the commercial application of titanium, have preconditioned welding methods suitable for it: in inert gases (argon, helium) and in vacuum (Fig.1).

Many-year theoretical researches conducted at the E.O.Paton Electric Welding Institute and verified by experiments a1lowed to develop the new approaches to the problems of metallurgy and technology of titanium alloy welding.

Novelty of these approaches consists in the fact that titanium is welded in active environment comprising halogenides of alkali and alkali-earth metals. A new class of consumables for welding of titanium, i.e. fluxes and flux-cored filler wires. has been created On the base of fluorides of these metals. These consumables enabled not only to increase the efficiency of the existing welding methods, but to develop the new ones ensuring the high quality of welded joints.

These welding methods include: automatic submerged-arc welding, electroslag welding, argon tungsten-electrode semisubmerged arc welding and argon-arc tungsten-electrode flux-cored wire welding (Fig.1).

Automatic consumable-electrode submerged arc welding of titanium can be performed with the equipment used usually for welding of steel by this method. Depending on a thickness of members joined, fluxes AHT-1, AHT-3 and AHT-7, and welding titanium wire from 2.5 to 5 mm dia. can be used. This welding method is characterized by good formation of butt, fillet, T- and overlap jo1nts, high level of mechanical and corrosion properties or welded joints in commercial titanium, -and pseudo- -alloys. Reliability, simplicity, high speed of welding (up to 50 m/h), possibility to make welds in up to 12 mm thick metal without groove preparation by one-sided welding and up to 25 mm thick metal -by double-sided welding provide the high efficiency and economy of this technology (Fig.2,3).

Electroslag welding of titanium is one of the most important achievements in the field of titanium welding technology. Flux AHT-2 and argon shielding of slag pool used in welding allow to produce welded joints in commercial titanium- and pseudo- alloys of practically any thicknesses. Mechanical properties and gas impurity content of weld metal and the HAZ are at the level of base metal. Titanium alloys 30-350 mm thick at the weld length up to 600 mm aro welded with plate electrodes.

Electroslag consumable-nozzle welding is used for making both straight and curvilinear welds. There is an experience gained in the field of welding of above 1000 mm thick alloy ПТ-3В.

Electroslag wire electrode welding is designed to join titanium pieces 30-150 mm thick. Welding speed is 0.5-1.7 m/h, depending on the type of electrodes used.

Electroslag welding of titanium is the efficient and economic technology for fabrication of thick-walled titanium welded structures which in a number of cases has no alternative (Fig.4,5).

Application of halogenide fluxes in argon-arc tungsten-electrode welding of titanium causes contraction of the arc and, hence, increase in penetration depth, decrease in weld width and heat input. This welding method is used for making all types of welds in commercial titanium, α–, pseudo-α - and (α+β) titanium alloys 0.8-6 mm thick. Semisubmerged arc welding is performed in one pass without groove preparation. This technology features the possibility to make welds with different penetration shapes, e.g. weld width is larger than, equal to or less than the back bead width. The small sizes of welding pool allow to perform automatic argon tungsten-electrode semisubmerged arc welding on a vertical plane with horizontal and vertical welds.

Fluxes AHT-23A and ФAN-1 can be used, depending on a thickness of metal welded and a type of alloy, their consumption being insignificant and making-up not more than 10 g per 1 m of a weld (Fig.6,7).

Elimination of pores in welds, decrease in consumption of welding consumables, power, reduction of deformations - these are the characteristic advantages of argon-arc welding using the above fluxes.

It should be emphasized, that no pores are detected in welds made with all welding methods considered in the present paper. It results from metallurgical interaction between fluoride slags and welding pool metal.

Argon-arc tungsten-electrode flux-cored filler wire welding is efficient for joining the 5-16 mm thick metal. Here, two types of wires have been developed: ППТ-1 and ППТ-3 grades with flux and flux-metal cores. They can be used for welding of titanium within the said range of thicknesses without groove preparation in one pass (Fig.8,9).

Consumption of the flux-cored wire is 1.2-1.4 m per 1 m of a weld.

It should be noted, that semisubmerged-arc and flux-cored filler wire welding is performed with the standard commercial equipment designed for argon-arc tungsten-electrode welding.

Fig.10 shows the results of technico-economic analysis of the welding methods considered against argon-arc tungsten-electrode welding.

The follow1ng basic indices calculated per weld meter were compared:

1) welding time; 2) argon flow rate;

3) welding wire consumption; 4) power consumption.

Values or these indices for argon-arc tungsten-electrode welding wire assumed as equal to 100 %.

It can be seen from Fig.10a that the application of the AHT-23A type flux for argon-arc tungsten-electrode welding of titanium up to 3 mm thick reduces argon flow rate by more than 50 % decreases welding wire consumption by 30 % and saves up to 25 % of power. Total cost of one meter of a weld decreases by 15-20 %.

In semisubmerged arc welding of 3-6 mm thick titanium by using the ΦAN-1 grade flux the time of welding and the consumption of welding consumables (argon and welding wire) are reduced by more than 60 % (Fig.10b). Allowing for the extra costs of the flux, the cost of one meter of a weld is almost twice as low.

Application of flux-cored filler wire in argon-arc tungsten-electrode welding of 4-16 mm thick titanium reduces the time of welding and the consumption of argon by 70 %, the consumption of welding wire - by almost 90 % and the consumption of power - by 60 % (Fig.10c). All this outs down the costs of one meter of a weld approximately by 35-40 %.

Automatic consumable-electrode submerge-arc welding reduces the welding time and the power consumption by 75 %, the welding wire consumption - by 25 % (Fig.10d). In this welding method argon is not used. The total cost of a weld, as in the previous case, is reduced by 35-40 %.

Thus, the new approaches to the problems of metallurgy and technology of titanium welding led to creation of the new efficient and economic methods for fabrication of titanium welded structures.

LIST OF FIGURES

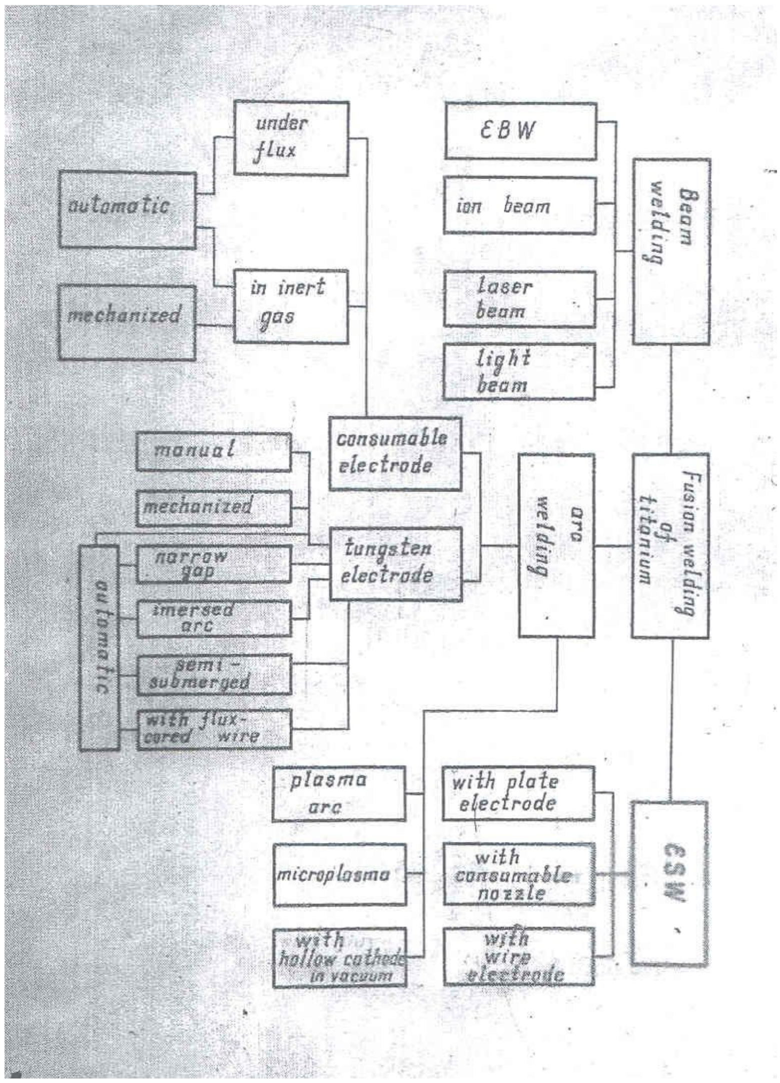

under flux
automatic
in inert gas
mechanized
EBW
ion beam
laser beam
light beam
Beam welding
consumable electrode
manual
mechanized
tungsten electrode
narrow gap
imersed arc
semi-submerged
with flux-cored wire
automatic
arc welding
Fusion welding of titanium
plasma arc
microplasma
with hollow cathode in vacuum
with plate electrode
with consumable nozzle
with wire electrode
ESW

Fig.1

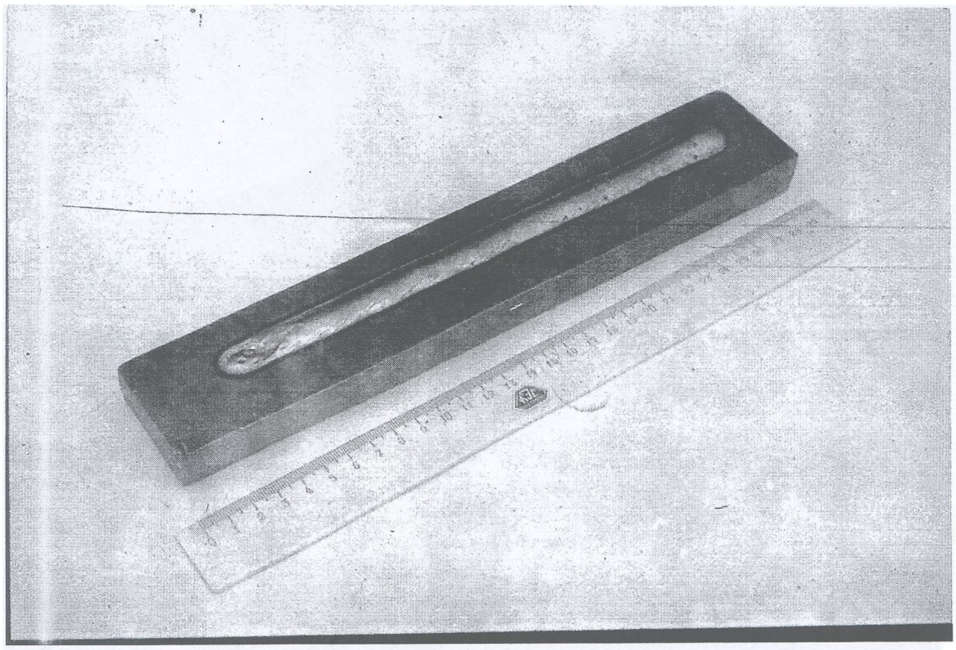


Fig.2

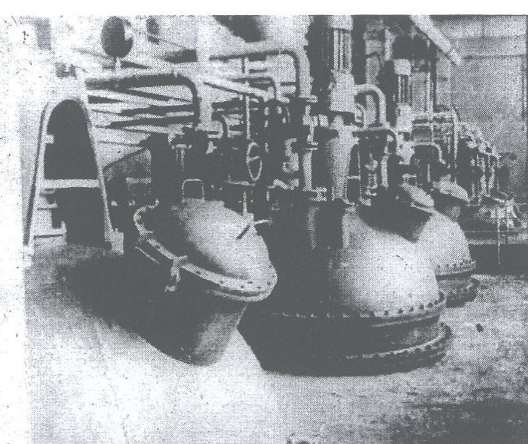


Fig.13. Battery of candle pressure filters of commercial BTI-0 welded by the automatic submerged-arc welding (AHT-7 flux).

Fig.3

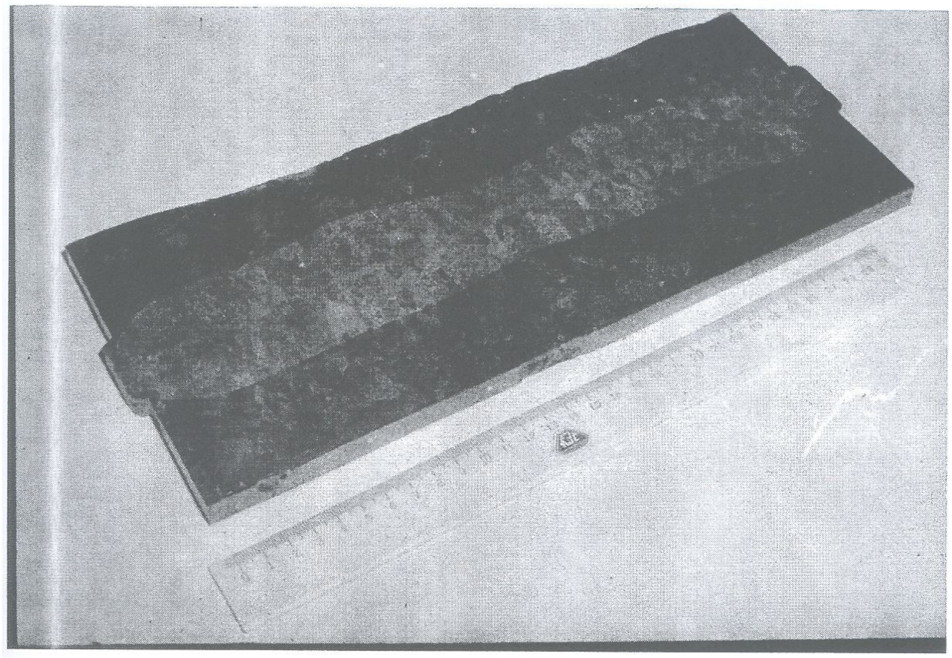


Fig.4

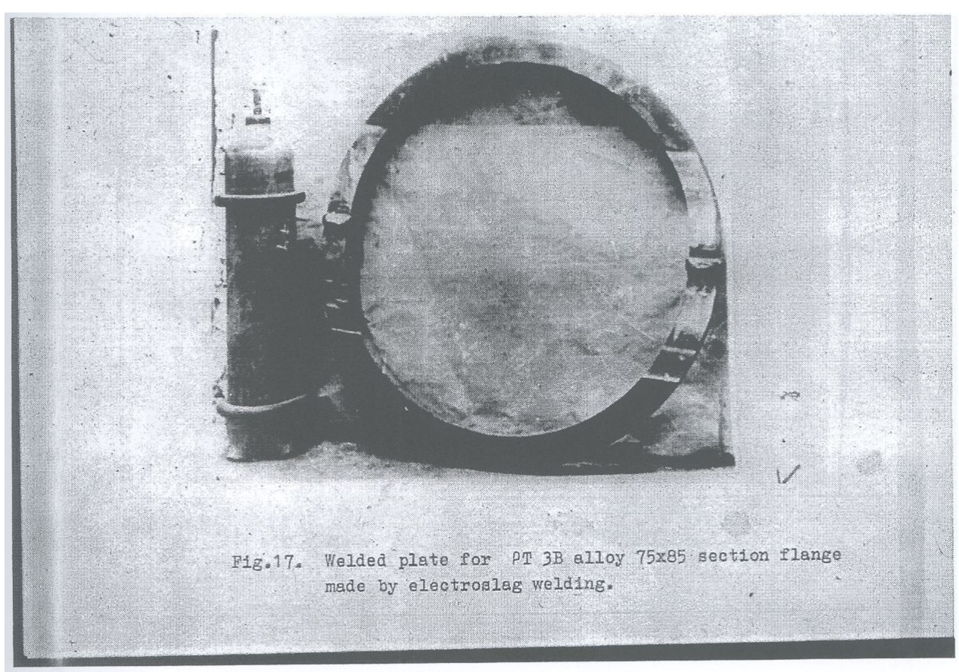


Fig.17. Welded plate for PT 3B alloy 75x85 section flange made by electroslag welding.

Fig.5

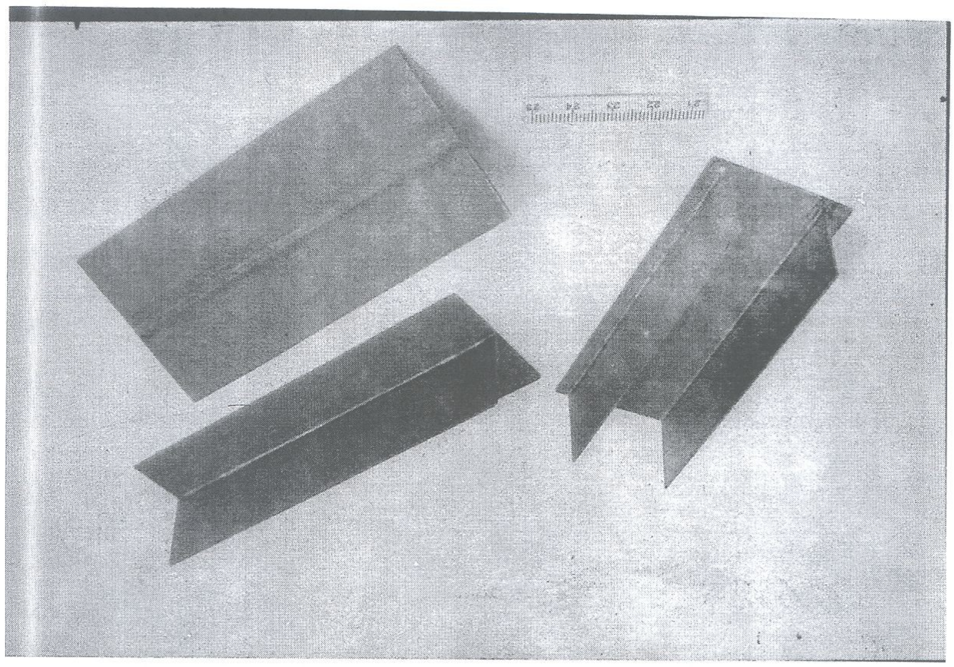


Fig.6

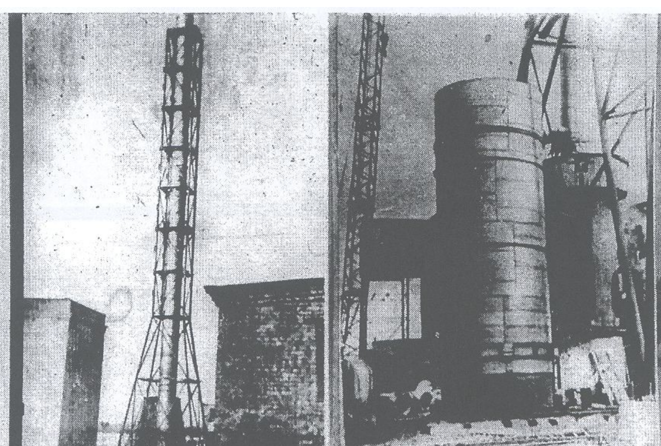


Fig.14. Purification structure (a) of commercial titanium BTI-0 (tower diameter is 4 m, height - 120 m); welded course of tower shaft (b) of 10 m height (4 mm wall thickness). Semi-submerged arc welding.

Fig.7

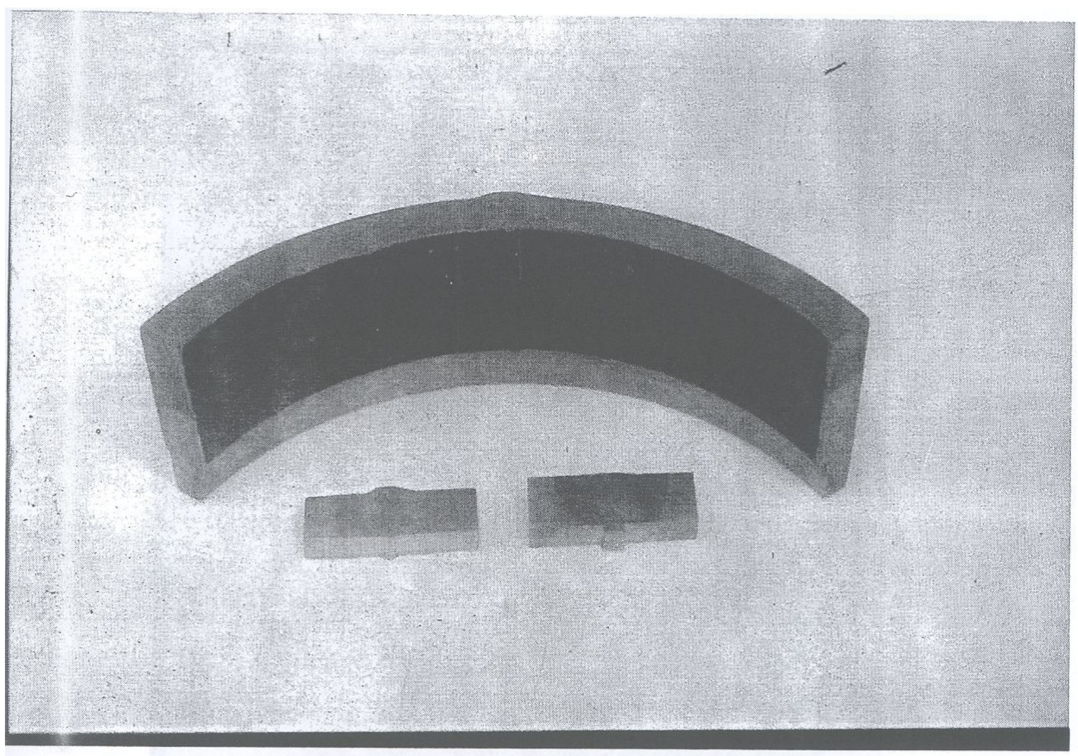


Fig.8

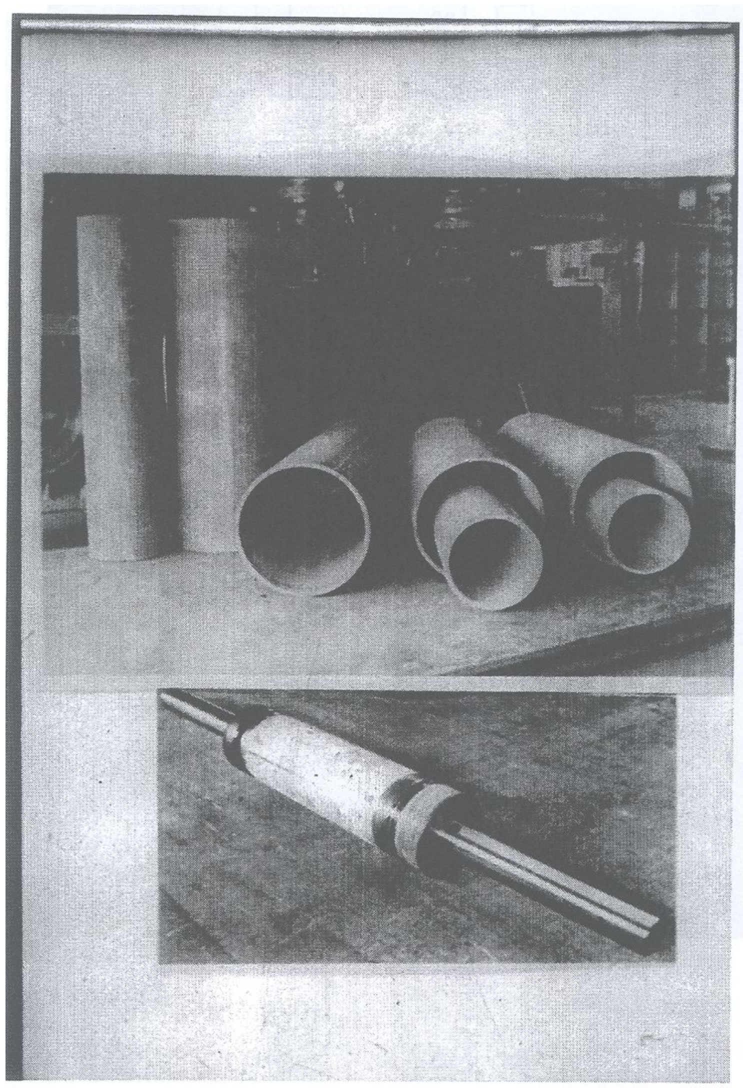
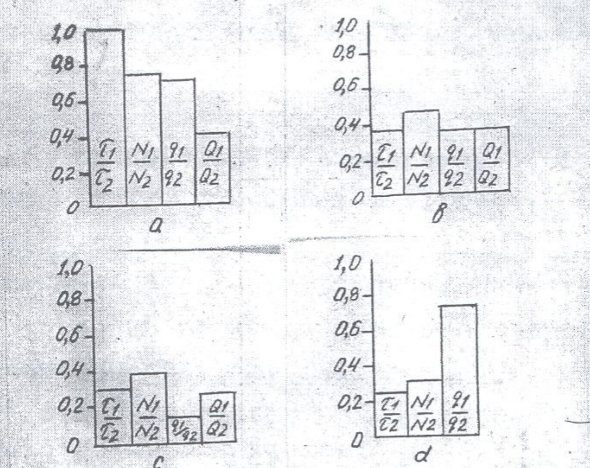


Fig.9



Time of welding of 1 m of a weld:

τ_1 - semisubmerged arc;
τ_2 - without flux.

Power consumed per 1 m of a weld in welding:

N_1 - semisubmered arc;
N_2 - without flux.

Filler wire consumed per 1 m of a weld in welding:

q_1 - with flux-cored filler wire;
q_2 - without.

Argon flow rate per 1 m of a weld in welding:

Q_1 - semisubmerged-arc;
Q_2 - without flux.

Fig.10

METALLURGICAL AND TECHNOLOGICAL PECULIARITIES OF ARC WELDING OF THERMALLY STRENGTHENED TITANIUM ALLOYS

V. N. Zamkov, V. F. Topolskii , I. K. Tyapko

E.O. Paton Electric Welding Institute
of the Ukrainian Academy of Sciences, Kiev, Ukraine

As compared to welding of commercial titanium, welding of thermally-strengthened ($\alpha+\beta$) titanium alloys is characterized with additional difficulties.

They are caused by peculiarities of phase transformations and structural changes of metal under the effect of welding thermal cycle and, consequently, by differences in thermal stability and kinetics of dissociation of metastable phases in the cast weld metol, the HAZ and the base metal in subsequent thermal strengthening.

The present paper will not dwell on physical implication and mechanisms of these processes, because the results of their detailed studies are published by many researchers. However, despite this fact, the problem of making welded joints in ($\alpha+\beta$) alloys with the properties close to these of the alloys after strengthening heat-treatment remains actual.

Studies of weldability of medium- and high-al1oy ($\alpha+\beta$) titanium alloys conducted recently at the E.O.Paton Electric Welding Institute allow to formulate two basic statements without the consideration of which it is impossible to salve the above problem:

- optimum chemical composition of a weld does not usually correspond to chemical composition of base metal;
- heat-treatment conditions recommended for strengthening of ($\alpha+\beta$) alloys are not suitable for welded joints in these alloys.

Concrete definition of these statements in welding of alloys Ti-6Al-4V, Ti-4.54Al-3Mo-1V, Ti-4.5Al-2Mo-4.5V-0.6Fe-0.6Cr, Ti-5Al-5Mo-5V-1Fe-1Cr allowed to create a versatile multi-alloyed welding titanium wire based on Ti-Al-Mo-V-Nb-Zr-Re system a1loy. The wire has the SP15 grade. This wire used for welding of the above and some other titanium alloys provides the high performance of welded joints both after annealing and after strengthening heat-treatment.

The results of mechanical tests of welded joints subjected to annealing after welding prove tho fact that tho SP15 wire used for welding provides wolds equally strong to base metal and high impact toughness of cast weld meta1.

It is a known fact that ductility and strength of (α+β) alloys depend on the quantitative ratio and properties of α- and β-pases. The higher the difference in strength of the phases, the lower the ductility of an alloy. The soft enough base (α-phase) and the high-alloy β- or α"-phase form in hardened (α+β) titanium alloys in ageing in the 420-500 °C temperature range.

After ageing at lower temperatures (290-380 °C) the extent of alloying β- and α"-phase is much lower. It decreases the difference in the phase strengths and provides th more favourable (...) characteristics of metal.

On the basis of these data, the E.O.Paton Electric Welding Institute has developed diagrams and conditions for strengthening heat-treatment of (α+β) titanium alloy welded structures. Mechanical characteristics (in static and dynamic testing) of welded joints made by using the SP15 wire are given in Table 2.

The results given evidence that at present the strength level (at satisfactory ductility and impact toughness) of welded joints in (α+β) titanium alloys after strengthening heat-treatment is not less than 1100 MPa, i.e. 90 % of strength of the alloys proper. It is provided by the SP15 wire used in welding and by low-temperature ageing in thermal strengthening of welded structures.

Table 1.

MECHANICAL PROPERTIES OF AS-ANNEALED ($\alpha+\beta$) TITANIUM ALLOYS WELDED JOINTS MADE BY USING THE SP15 WIRE

Alloy grade	Metal thick-ness, mm	Tensile strength of welded joint, MPa	Place of fracture of tensile specimens	Impact toughness of weld metal, J/cm^2
BT6 Ti-6Al-4V	5.0	925-935	base metal	50-55
BT14 Ti-4.5Al-3Mo-1V	5.0	950-960	base metal	50-60
	24.0	960-970	base metal	45-55
BT23 Ti-4.5Al-2Mo-4.5V-0.6Fe-0.6Cr	6.0	1000-1020	base metal	55-65
	10.0	980-1000	base metal	50-60
	30.0	950-970	weld metal	50-55
BT22 Ti-5Al-5Mo-5V-1Fe-1Cr	20.0	1000-1010	weld metal	80-90

Table 2.

MECHANICAL PROPERTIES OF WELDED JOINTS IN ($\alpha+\beta$) TITANIUM ALLOYS AFTER STRENGTHENING HEAT TREATMENT

Alloy grade	Welded joint thermal strengthening conditions	Metal thick-ness, mm	Tensile strength, MPa	Weld metal impact tough-ness, J/cm^2	Low-cycle fati-gue, MPa	Frac-ture tough-ness, MPa/mm
BT6 Ti-6Al-4V	Water quenching from polymorphous transformation temperature (Tpt)-(20-40) °C, ageing at 370 °C for 4h, air cooling	5	1150-1200	40-45	-	-
BT14 Ti-4.5Al-3Mo-1V	Water quenching from (Tpt)-(20-40)°C, ageing: at 370 °C for 8h, air cooling: at 620°C for 2.5h, air cooling	5 24	1150-1180 1120-1150	40-45 35-40	- -	- -
BT23 Ti-4.5Al-2Mo-4.5V-0.6Fe-0.6Cr	Air quenching from (Tpt)-(20-40)°C, ageing: at 380 °C for 8h, at 550°C for 2h, air cooling	6 10 30	1150-1180 1150-1170 1100-1120	40-45 45-50 40-45	- - =570 N>0.35E6 =735 N>1.5E6	- - 2800
BT22 Ti-5Al-5Mo-5V-1Fe-1Cr	Annealing at 830 °C for 2h. Cooling in furnace down to 600 °C for 1h, air cooling: ageing: at 380°C for 8h, at 550°C for 2h, air cooling	20	1100-1150	55-60	=600 N>0.4E6 =400 N>1.5E6	-