BRAZING OF TITANIUM ALLOYS BY USING ALUMINIUM-BASE FILLER ALLOYS

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Investigations on brazing of titanium alloy samples by using different compositions of aluminium filler alloys were carried out. Silicon-free aluminium filler alloys were found to be acceptable for producing the brazed joints on titanium alloys. The 670–690 °C brazing temperature range is optimal for the selected filler alloys.

Keywords: *brazing, titanium alloys, aluminium alloys, commercial brazing filler alloys, wetting, microstructure, mechanical properties*

Since the 1960s, Al-base filler alloys have been widely used for brazing of titanium alloys. Pure aluminium or alloys of the Al–Si, Al–Si–Cu and Al–Mg systems are mainly applied as brazing filler alloys [7]. Compositions of some Al-base filler alloys are given in Table 1.

Key advantages of aluminium filler alloys are low melting temperature, low specific weight, good compatibility with titanium alloys base metal and, in particular, good wetting and flowing into the gap. Therefore, special consideration has been given to the aluminium filler alloys since the time when the Ti-base alloys have found application in aerospace engineering.

An important drawback of the Al-base filler alloys is their active reaction with the base metal. Even a relatively short time of contact of titanium with molten aluminium may lead to a deep erosion of the base metal. Silicon is added to the Al-base filler alloys to reduce reactivity of pure aluminium and decrease the brazing temperature (hence, decrease the probability of formation of intermetallics). But in this case silicides may form at the titanium alloy–filler alloy interface. However, the main problem is the Al_2O_3 film on the aluminium filler alloys, which prevents their spreading over the base metal.

Despite a large amount of the investigations conducted in Eastern Europe and particularly in Ukraine to study brazing of titanium by using aluminium filler alloys, brazing of titanium with this type of the filler alloys failed to receive acceptance. There are publications on development of new aluminium filler alloys for brazing of titanium alloys [7], this evidencing the industrial demand for commercial medium-melting point filler alloys for brazing of titanium and its alloys.

Wide application of aluminium filler alloys in this case is hindered by a low strength of the resulting brazed joints, which is much lower than that of the joints brazed with titanium filler alloys. One of the promising areas of using aluminium filler alloys is brazing of lamellar-ribbed thin-walled structures and thin-walled honey-

Table 1. List of standard aluminium-base brazing filler alloys

Grade of filler alloy	Manufacturing country	Composition of filler alloy	T_{br}, °C
AD1	USSR	Al–0.4Si–0.3Fe	665
AL2	Same	Al–13Si	560–700
AVCON 48	USA	Al–4.8Si–3.8Cu–0.2Fe–0.2Ni	610–680
AA3003	Same	Al–1Mn–0.6Si–0.7Fe	660–670
TiBrazeAl-600	»	Al–12Si–0.8Fe	590–610
TiBrazeAl-630	»	Al–1.5Mg–4Cu–2Ni	630–660
TiBrazeAl-640	»	Al–(4.4–5.2)Mg–(0.7-1)Mn–0.2Cr	640–660
TiBrazeAl-642	»	Al–5.3Si–0.8Fe–0.3Cu–0.2Ti	650–680
TiBrazeAl-645	»	Al–(4.3–5.5)Mg–0.25Si–0.4Fe–0.2Ti–0.2Cr	640–660
TiBrazeAl-655	»	Al–6.3Cu–0.3Mn–0.2Si–0.2Ti–0.2Zr	650–670
TiBrazeAl-665	»	Al–2.5Mg–0.2Si–0.4Fe–0.2Cr	660–680

comb panels for aerospace engineering, where a relatively low strength of the seams is acceptable, which is confirmed, in particular, in study [7]. The choice of the aluminium filler alloys is favoured by their good wetting and spreading over the titanium substrate at a comparatively low temperature, as well as the possibility of achieving a low level of erosion of the base metal in brazing. Therefore, all drawbacks in this case are surpassed by the advantages, such as a lower cost, higher affordability and better workability of the aluminium filler alloys compared to the titanium and silver ones.

The purpose of this study was to generate data on advantages and drawbacks of different compositions of aluminium filler alloys for brazing of titanium, as well to compare modern commercial and experimental filler alloys with widely used aluminium alloys AD1 and AMg6.

Low titanium alloy OT4 was used as a base metal. Two groups of aluminium filler alloys for brazing of titanium were investigated: in the first group silicon was used as a depressant, and in the second group the depressant was magnesium.

The first group included standard alloy AL2, modern commercial filler alloy TiBrazeAl-642 and experimental alloys Al–12Si–1Mg, Al–12Si–0.3Li and Al–5Si–1.5V produced by the powder metallurgy method. The second group included alloy AMg6 and modern commercial filler alloy TiBrazeAl-665. Low alloy AD1 was investigated for comparison.

Experiments on selection of optimal parameters of heating for brazing were carried out in vacuum furnace SGV 2,4-2/15-I3 at a vacuum level of $5\cdot10^{-5}$ mm Hg. For additional cleaning of the brazing atmosphere, brazing was performed in vacuum in the titanium container with a getter.

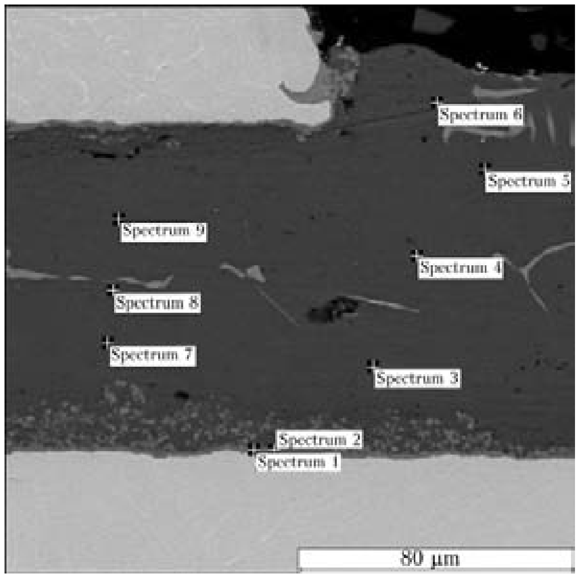

Figure 1. Microstructure of fillet region of the brazed joint on titanium alloy OT4 made by using filler alloy AMg6

Table 2 gives contact angles of the alloys on a substrate of titanium alloy OT4, which were measured by using software AutoCad 2002LT. Increase in the temperature of brazing of titanium alloys was accompanied by substantial improvement of wetting and spreading of the filler alloys over the substrate. However, it should be noted that Si-containing filler alloys TiBrazeAl-642, Al–13Si and Al–12Si–0.3Li featured a poor spreading over the surface of the titanium samples up to a temperature of 700 °C (at 740 °C, spreading of all the filler alloys was so high that it caused flowing out of a filler alloy from the gaps, the contact angle in this case being approximately 0°). At the same time, filler alloy AD1 and the Mg-containing filler alloys (AMg6 and TiBrazeAl-665) satisfactorily wetted titanium even at 670 °C.

Metallographic examinations of the brazed joints made by using the Mg-containing aluminium filler alloys showed the presence of a

Table 2. Dependence of contact angles on brazing temperature

Filler alloy	T_L, °C	Temperature of heating for brazing, °C			
		600	630	670	700
		Contact angles, deg			
AD1 (Al–0.4Si–0.3Fe)	660	–	–	60	~15
AMg6 (Al–6Mg–0.6Mn–0.4Si–0.4Fe–0.1Ti)	632	–	–	20	7–10
TiBrazeAl-642 (Al–5.3Si–0.8Fe–0.3Cu–0.2Ti)	630	–	–	40	~10
AL2 (Al–13Si)	578	90	90	55	~25
TiBrazeAl-665 (Al–2.5Mg–0.2Si–0.4Fe–0.2Cr)	650	–	–	25	8–10
Al–12Si–0.3Li	580	90	60	45	~10
Al–12Si–1Mg	575	–	85	40	~15
Al–5Si–1.5V	630	–	–	40	~10

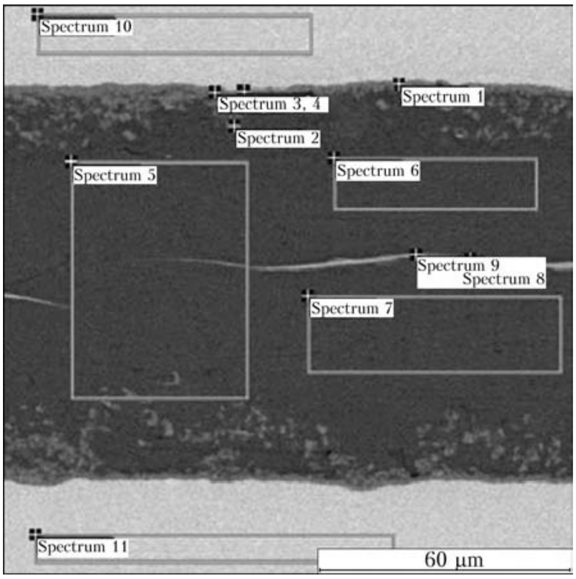

Figure 2. Microstructure of region of the brazed joint on titanium alloy OT4 made by using filler alloy AMg6

continuous intermetallic interlayer at the filler alloy–base metal interface (T_{br} = 685 °C, vacuum — $5\cdot10^{-5}$ mm Hg, t = 3 min). Composition of the interlayer varied from (wt.%) 48.67Al–47.95Ti–1.05Si–0.57Mn in the fillet region (see spectrum 1 in Figure 1; Table 3) to 72.68Al–20.75Ti–1.33Mg–0.74Si–0.36Mn (spectrum 2 in Figure 2; Table 4). In the first case it corresponded approximately to a composition of intermetallic compound $TiAl_2$, and in the second case — to $TiAl_3$.

Also, one should note a low content of magnesium in the brazed seams, i.e. maximum 1.5 wt.% (see Tables 3 and 4). This can be explained by evaporation of magnesium from the seam metal during heating and melting of a filler alloy in vacuum. Very likely that it is this fact that caused destruction of the aluminium oxide film on the surface of the filler alloy, which made wetting of the base metal with the filler alloy melt much easier. The destructed oxide film was distributed over the entire seam (see oxygen content in spectra 1–9 in Figure 1 and Table 3;

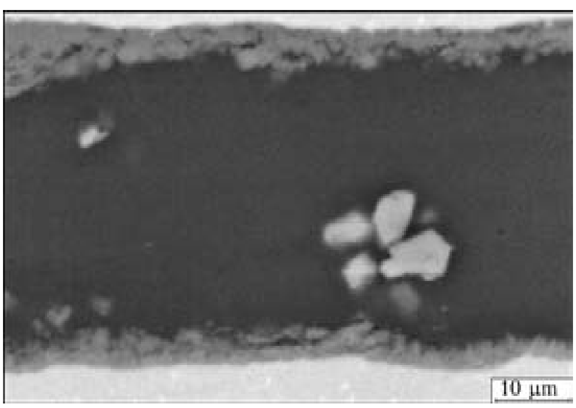

Figure 3. Microstructure of region of the brazed joint on titanium alloy OT4 made by using filler alloy Al–5Si–1.5V

Table 3. Chemical heterogeneity of fillet region of the brazed joint on titanium alloy OT4 made by using filler alloy AMg6, wt.%

Spectrum number	O	Mg	Al	Si	Ti	Mn	Fe
1	1.76	–	48.67	1.05	47.95	0.57	–
2	1.62	–	50.89	1.06	45.83	0.60	–
3	1.13	0.43	97.01	–	0.79	0.64	–
4	0.77	0.49	97.84	–	0.25	0.65	–
5	1.24	0.28	97.78	–	0.13	0.57	–
6	3.01	0.15	95.68	–	0.15	0.69	0.32
7	1.07	0.53	97.01	–	0.77	0.62	–
8	1.78	0.71	96.59	–	0.28	0.63	–
9	1.31	0.71	96.71	–	0.64	0.63	–

spectra 5–9 in Figure 2 and Table 4), except for the intermetallic interlayer at the filler alloy–base metal interface.

Light phase inclusions along the seam axis were compounds of aluminium with iron and silicon, which were present in alloy AMg6 in small quantities.

Metallographic examinations of the joints brazed by using the Si-containing aluminium filler alloys showed that the brazed joints were characterised by a poor quality and the presence of cracks in the seams and fillet regions. Solidification of silicide in the form of a continuous strip was observed along the seam on both interfaces with the base metal. Such peculiarities of formation of the brazed seams did not allow providing of sound brazed joints and avoiding formation of silicides and cracks (Figure 3).

Strength tests of the overlap joints on alloy OT4 brazed by using commercial filler alloys TiBrazeAl-665 and TiBrazeAl-642, as well as alloys AD1 and AMg6 were carried out to evaluate the level of strength of the brazed joints. Thickness of the filler alloy foils was 100 μm for TiBrazeAl-665 and TiBrazeAl-642, and 60 μm for AD1 and

Table 4. Chemical heterogeneity of region of the brazed joint on titanium alloy OT4 made by using filler alloy AMg6, wt.%

Spectrum number	O	Mg	Al	Si	Ti	Mn	Fe
1	–	0.46	64.12	1.32	33.55	0.30	0.25
2	4.14	1.33	72.68	0.74	20.75	0.36	–
3	–	–	54.42	1.34	43.83	0.41	–
4	–	0.75	68.94	1.10	28.78	0.43	–
5	1.16	1.43	96.22	–	0.60	0.59	–
6	1.12	1.25	96.35	–	0.74	0.54	–
7	1.23	1.46	96.47	–	0.30	0.54	–
8	1.64	0.96	81.16	0.48	0.30	1.99	10.13
9	1.15	1.05	85.72	0.46	0.30	1.66	9.66
10	–	–	4.49	–	94.95	0.56	–
11	–	–	3.59	–	95.90	0.51	–

AMg6. A filler alloy in the form of a foil was placed in the gap between the samples brazed. The time of holding at a brazing temperature was 3 min, and the brazing temperature was 685 °C. Additionally, brazing of the samples by using the AMg6 filler alloy was carried out at a temperature of 720 °C. The mechanical test results are shown in Figure 4.

Based on the data presented, it can be noted that strength of the joints made by using Mg-containing filler alloys TiBrazeAl-642 and AMg6 was almost identical and equal to 82–83 MPa, whereas strength of the joints made by using Si-containing filler alloy TiBrazeAl-665 was low, which could be due to solidification of silicide in the form of a continuous strip at the filler alloy–base metal interface.

It should be noted that the evaluated strength value (83 MPa) of the joints brazed by using commercial filler alloys TiBrazeAl-665 (Al–2.5Mg–0.3Cr) turned out to be lower than that claimed by the manufacturer (about 98 MPa) [7]. The attempts to achieve the claimed values failed, and after changing the configuration of the samples brazed, which was aimed at decreasing the bending component of stresses in shear tests, the determined strength value of the brazed joints was the same 83 MPa. Probably, in our experiments we omitted some know-how of the authors.

Increase in the brazing temperature had an extremely negative effect on strength of the joints brazed with aluminium filler alloys. For example, a twofold decrease in strength was revealed in brazing with alloy AMg6 at a temperature of 720 °C (see pos. 3 in Figure 4). In this case the decrease can be explained by growth of the Ti_3Al interlayer because of intensification of the reactivity of aluminium with respect to titanium with increase in the temperature and extension of the time of contact of the molten filler alloy with the titanium substrate.

The obtained strength value (about 83 MPa) of the brazed joints made by using aluminium filler alloys is sufficient for brazing of lamellar-ribbed structures and sheet parts with a large contact area. The main advantage of the aluminium filler alloys in this case will be, as mentioned above, the workability, low cost and affordability.

Analysis of the results obtained shows that the 680–690 °C brazing temperature is acceptable for producing the brazed joints on titanium alloys by using the Si-free aluminium filler alloys, such as alloys AD1, AMg6 and TiBrazeAl-642. The time of holding in brazing of titanium by using the above filler alloys should be as short as possible to prevent formation of brittle intermetallic interlayers.

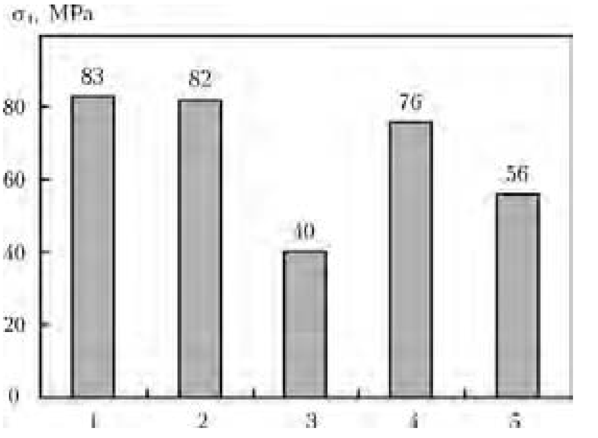

Figure 4. Strength of the overlap joints on alloy OT4 (holding time — 3 min) made by using the following filler alloys: 1 — TiBrazeAl-642; 2, 3 — AMg6; 4 — AD1; 5 — TiBrazeAl-665 (1, 2, 4, 5 — T_{br} = 685; 3 — 720 °C)

CONCLUSIONS

1. Si-free brazing filler alloys, e.g. AD1, AMg6, TiBrazeAl-642, were found to be acceptable for producing the brazed joints on titanium alloys. The best results were obtained with the Al–Mg system based filler alloys (AMg6, TiBrazeAl-642).

2. The 680–700 °C brazing temperature range is optimal for the chosen filler materials. The holding time in brazing of titanium with the given filler alloys should be as short as possible to prevent formation of brittle intermetallic interlayers.

3. When using filler alloys based on the Al–Si system, formation of silicides, in addition to the Al- and Ti-base intermetallic interlayers, occurs in the brazed seams. They have the form of a continuous strip propagating along the seam on the side of the base metal, this leading to origination of defects in the form of cracks.

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