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STRUCTURE AND MECHANICAL PROPERTIES OF TITANIUM ALLOY-CARBON STEEL BIMETAL OBTAINED BY EXPLOSION WELDING

P.S. Shlonskyi, Feng Gao

Liaoning Xin Huayang Weiye Equipment Manufacturing Company Ltd No. 1 Road, Tieling high-tech industrial development zone, Liaoning province, China

ABSTRACT

The quality of the bimetal produced by explosion welding is affected by the mechanical characteristics of flying plate material. For development of explosion welding modes, a study of the structure and mechanical properties of titanium alloy Grade 12 (TA10, flying plate) + carbon steel 16 Mn (09G2S) bimetal was conducted. The thickness of the titanium alloy plates was 5 and 6 mm, the mechanical properties, namely the relative elongation in as-delivered condition for these plates differed by 15 %. The results on tear and shear strength of titanium alloy-carbon steel bimetal are given. In the case of titanium alloy TA10 it is demonstrated that for plates with a lower relative elongation, the strength of the joint produced by explosion welding is lower. Bending test showed no delamination for two thicknesses of the titanium alloy. Also, for the two thicknesses of the titanium alloy, the joint zone has a microstructure characteristic for explosion welding.

KEYWORDS: explosion welding, titanium-steel bimetal, mechanical properties

INTRODUCTION

Different branches of modern mechanical engineering feel an urgent need for titanium-steel bimetal. Production of this bimetal runs into difficulties, which are primarily related to the specific properties of titanium, namely formation of brittle intermetallic compounds in the joint zone.

Explosion welding is one of the methods, allowing production of titanium-steel bimetal, owing to a short duration of the process of the joint formation and absence of heating [1–3]. However, the task of producing sound titanium-steel bimetal has not been solved completely, as there exists a very narrow range for producing a sound joint, and also brittle intermetallic compounds form in the joint zone.

In the case of [4, 5], we can see that at present investigations on producing bimetal plates by explosion welding in the People's Republic of China and in the world are concentrated, predominantly, on pure titanium. It should be noted that pure titanium strength drops with temperature rise, and after achievement of 250 °C it decreases two times. Therefore, titanium alloys should be used for equipment operating at higher temperatures. So, in [6] investigation of the properties of bimetal of TA10 titanium alloy and Q345 carbon steel was conducted.

EXPERIMENTAL MATERIALS AND METHODS

TA10 titanium is a low alloy of titanium of Ti–Mo–Ni system, containing 0.3 % Mo and 0.8 % Ni (Table 1), which not only improves its high-temperature mechanical properties, but also provides its good corrosion resistance to chlorides with a low pH or to weakly-reducing acids, and its corrosion resistance is much better than that of pure titanium [7].

TA10 titanium alloy 5 and 6 mm thick was used as the flying plate. Mechanical properties of the material of the plates of different thickness are given in Tables 2 and 3. Relative elongation in as-delivered condition differed by 15 % for plates of different thickness. Plate size was 450×300 mm.

The objective of this work was investigation of the influence of relative elongation of TA10 titanium alloy on the mechanical properties and microstructure

Table 1. TA10 chemical composition according to GB/T 3620.1–2007 (PRC standard)

Ti, balance, %	Admixtures, not more than, %						
	Mo	Ni	Fe	C	N	H	O
	0.2–0.4	0.6–0.9	0.30	0.08	0.03	0.015	0.25

Table 2. Mechanical properties of 6 mm sheet of titanium alloy TA10

Material condition	σ_y, MPa	σ_t, MPa	δ, %
M	275	345	30

Table 3. Mechanical properties of 5 mm sheet of titanium alloy TA10

Material condition	σ_y, MPa	σ_t, MPa	δ, %
M	227	362	26

Figure 1. Appearance of plates of titanium alloy Grade 12 and carbon steel 09G2S before explosion welding (*a*) and after it (*b*)

of the joint of TA10 + 09G2S bimetal produced by explosion welding.

During optimization of the mode of explosion welding of TA10 titanium alloy to 09G2S steel experiments were conducted on full-scale samples.

Used as the base was an 80 mm plate of 09G2S carbon steel.

The height of the explosive was 50 and 45 mm for 6 and 5 mm plates of the titanium alloy, respectively. The detonation rate was measured by wire sensors; it was 2100 and 2040 $m \cdot s^{-1}$ for 6 and 5 mm plates, respectively. Plate appearance before (*a*) explosion welding and after welding (*b*) is shown in Figure 1.

Explosion welding was followed by heat treatment to relieve internal stresses at temperature not higher than 540 °C, and checking the joint quality by ultrasonic testing. Samples for mechanical tests were cut out by the scheme shown in Figure 2.

The collision velocity of the plates was calculated by the formula where: D is the detonation rate; r is the load coefficient during explosion welding, ratio of explosive weight to that of the flying plate [1].

Explosive density is equal to 1 $g \cdot cm^{-3}$.

$$Vc = D\frac{\left(\sqrt{1+\frac{32}{27}r}-1\right)}{\left(\sqrt{1+\frac{32}{27}r}+1\right)}.$$

After performing a simple calculation, we get the collision velocity of 592 and 598 $m \cdot s^{-1}$ for 6 and 5 mm plates, respectively. Thus, plate energies at collision will have close values, and the energy of 5 mm plate will be even lower.

Microstructural studies were performed in a metallographic microscope MS600. Microstructure of titanium alloy TA10 + 09G2S joint is shown in Figure 3.

EXPERIMENTAL RESULTS AND THEIR DISCUSSION

As one can see from Figure 3, the joint zone has a wavy interface characteristic for explosion welding. The wave shape, their amplitude and frequency are almost the same for different cladding thicknesses. Here, intermetallic compounds in the form of dispersed inclusions in the regions on the wave back side are observed on the interface of TA10 + 09G2S joint with 5 mm cladding (Figure 3, *b*). It fully correlates

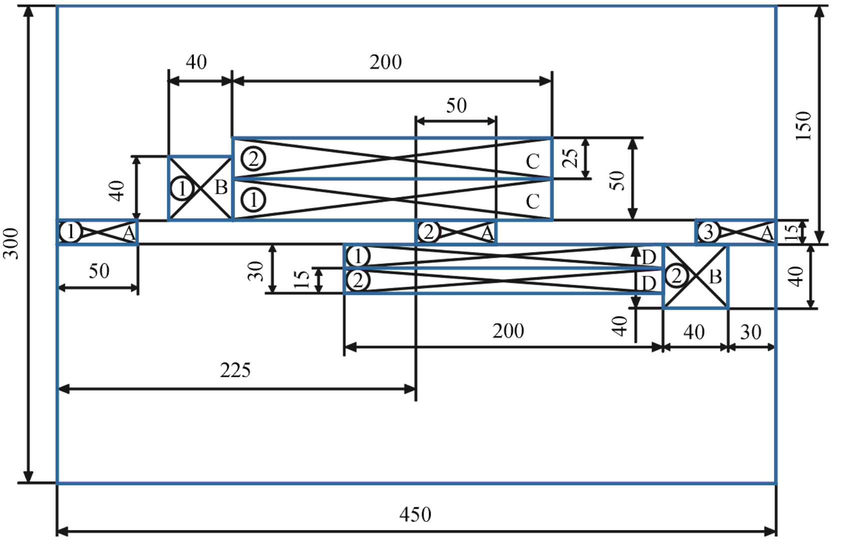

Figure 2. Scheme of cutting out samples for mechanical tests: 1A, 2A, 3A are samples for microstructural studies: 1B, 2B are samples for investigation of cladding tear strength; 1C, 2C are samples for studying the cladding shear strength; 1D, 2D are samples for studying the bending strength

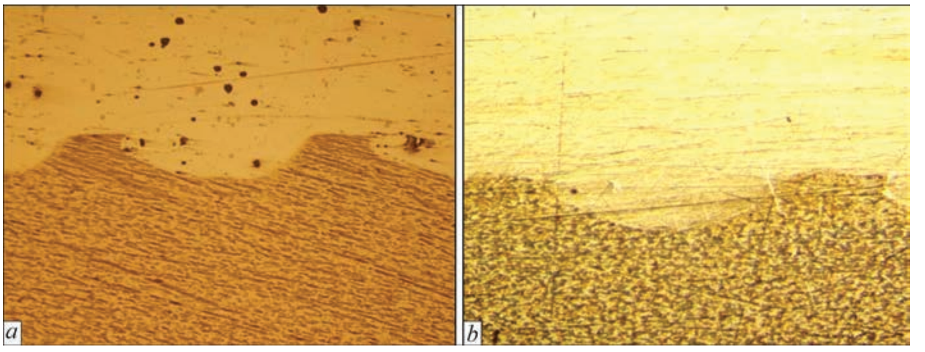

Figure 3. Microstructure of the zone of the joint of titanium TA10 (top) + steel 09G2S (bottom), cladding thickness of 6 mm (*a*) (×100) and 5 mm (*b*) (×200)

with the results of work [8], where the features of phase formation in pressure welding were studied.

Evaluation of mechanical properties of TA10 + 09G2S bimetal produced by explosion welding was performed by testing the cladding for tear, shear and bending.

Tear tests were conducted by pulling off around a circular contour. A test sample is placed into a tubular-shaped support, and on top a die is inserted into the blind hole on the sample, to which the rupture machine pressure is applied (Figure 4, *a*).

The tear strength of TA10 + 09G2S bimetal joint was determined by dividing the force applied to pull off the cladding, by the ring area. One can see from Figure 4, *b* that rupture occurred in the joint zone, that is characteristic for titanium alloy — carbon steel bimetal, and the joint line is of a clearly defined wavy shape.

Results of tear and shear tests are shown in Table 4. As one can see from the results in Table 4, the tear strength for the titanium alloy with smaller relative elongation is lower by 73 and 112 % for samples from regions 1 and 2, respectively. The tear strength decreases by 92.5 % on average.

Shear strength tests of the bimetal were conducted by stretching flat samples with transverse cuts of the layers (Figure 5). The results of shear strength tests completely correlate with those of tear strength tests.

As one can see from Table 4, the shear strength for the titanium alloy with smaller relative elongation is 117 and 68 % lower for samples from regions 1 and 2, respectively. Shear strength at the beginning

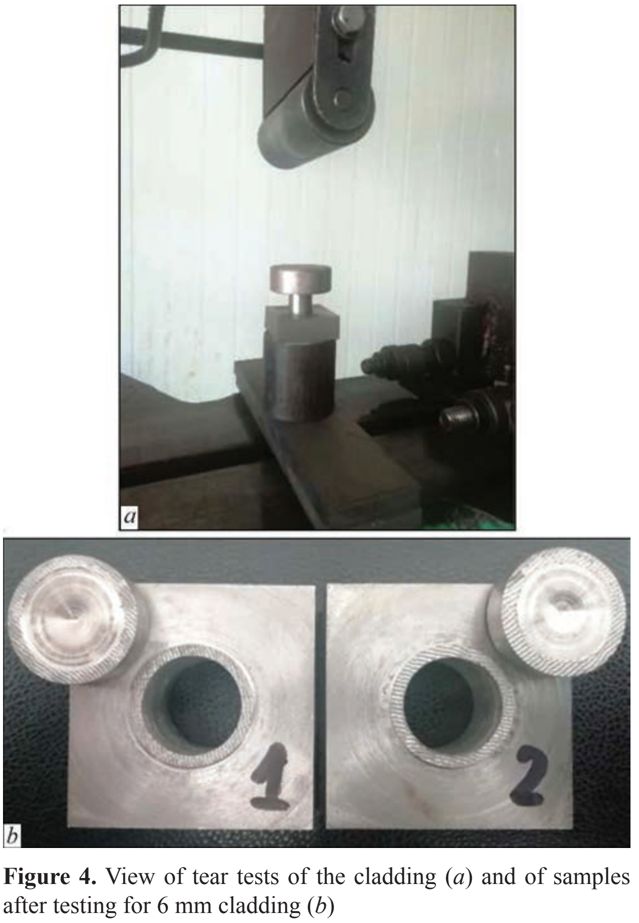

Figure 4. View of tear tests of the cladding (*a*) and of samples after testing for 6 mm cladding (*b*)

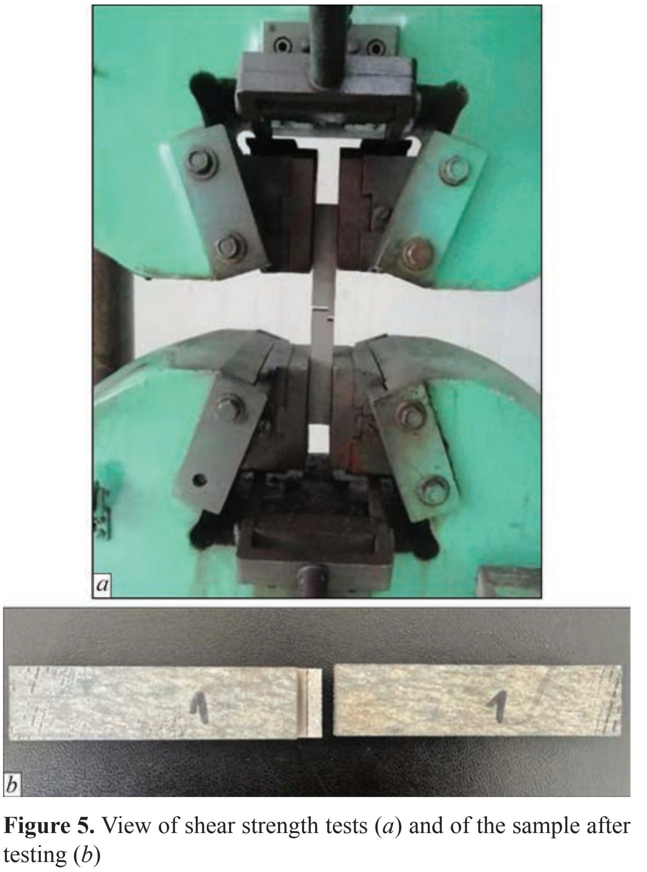

Figure 5. View of shear strength tests (*a*) and of the sample after testing (*b*)

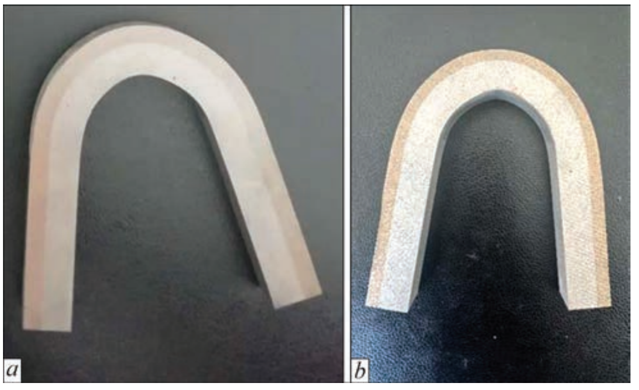

Figure 6. Bending tests of TA10 + 09G2S bimetal, cladding thickness of 6 mm (*a*), cladding thickness of 5 mm (*b*)

Figure 7. Appearance of TA10-09G2S bimetal tubesheet of 3340 mm diameter after heat treatment

of the sample is higher than that at the end for both the thicknesses. Shear strength decreases by 92.5 % on average. The discrepancy of mechanical testing results in regions 1 + 2 is attributable to dispersity of intermetallic formation.

At investigation of mechanical properties of the bimetal produced by explosion welding, bending test is quite revealing, as delamination in the joint zone takes place in case of poor quality welding. Samples for both the cladding thicknesses of 6 and 5 mm (Figure 6) withstood bending through 180° without delamination, which is indicative of a high welding quality.

Ultrasonic testing of the joint continuity showed absence of delaminations over the entire plane of the bimetal plate.

Based on the conducted investigations recommendations were provided on producing by explosion welding bimetal tubesheets of 3340 mm diameter for heat exchanger (Figure 7).

CONCLUSIONS

1. It was found that lowering of relative elongation by 15 % for titanium alloy TA10 leads to lowering of tear and shear strength by 92.5 % on average at close values of explosion welding energy.

2. As a result of the conducted work, recommendations were issued for correction of the mode of explosion welding of titanium alloy TA10 to carbon steel 09G2S with 5 mm cladding to improve the joint quality.

Table 4. Results of the cladding tear and shear tests for TA10 + 09G2S bimetal produced by explosion welding

Cladding thickness/ sample number	Tear strength, MPa	Shear strength, MPa
5 mm/No. 1	289.1	163.2
5 mm/No. 2	167.1	146.9
6 mm/No. 1	502.4	354.4
6 mm/No. 2	354.8	247

REFERENCES

1. Kudinov, V.M., Koroteev, A.Ya. (1978) *Explosion welding in metallurgy*. Moscow, Metallurgy [in Russian].
2. Lysak, V.I., Kuz'min, S.V. (2005) *Explosion welding*. Moscow, Mechanical Eng. [in Russian].
3. Deribas, A.A. (1980) *Phisics of hardening and explosion-welding*. Novosibirsk, Science [in Russian].
4. Zheng Yuanmou (2002) *Explosive welding and metal cladded materials as well as the engineering applications*. Central South University Press, Changsha.
5. Wang Yaohua (2007) *Researches and practices on explosive welding of metal sheets*. National Defense Industry Press, Beijing.
6. HAN Xiao-min, WANG Shao-gang, HUANG Yan et al. (2015) Interfacial microstructure and mechanical properties of TA10-Q345R composite plate with explosive welding. *Titanium Academics J., Nanjing*, 32(**6**), 24–29. DOI: https://doi.org/10.3969/j.issn.1001–4837.
7. Findik, F. (2011) Recent developments in explosive welding. *Materials and Design*, 32(**3**), 1081–1093.
8. Markashova, L.I., Arsenyuk, V.V., Grigorenko, G.M. (2002) Features of phase formation during pressure welding of dissimilar metals under high-speed deformation conditions. *Automatic Welding*, **9**, 12–17 [in Russian].

ORCID

P.S. Shlonskyi: 0000-0002-3566-1752

CONFLICT OF INTEREST

The Authors declare no conflict of interest

CORRESPONDING AUTHOR

P.S. Shlonskyi
Liaoning Xin Huayang Weiye Equipment Manufacturing Company Ltd No. 1 Road, Tieling high-tech industrial development zone, Liaoning province, China.
E-mail: shlensk@ukr.net

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