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JOINT STRENGTH OF ALUMINUM ALLOYS STRUCTURES CONNECTED WITH CONTACT CAPACITOR WELDING

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Abstract. Currently, aluminum alloys are widely used in various industrial productions and constructions due to the unique properties, which allows creation of lightweight, durable, reliable, corrosion-resistant and aesthetic structures and products for different purposes. Nevertheless, aluminum alloys have a number of disadvantages, the main of which is a more complex and expensive process of manufacturing of welded structures. It requires the use of more advanced technologies such as argon arc welding and friction welding with mixing and qualified personnel in contrary with classical electric welding of steel structures. Such technologies also include the modern method of contact capacitor spot welding, the equipment for which is compact and mobile enough. And its usage does not require highly qualified personnel compared to other aluminum welding technologies. The existing regulatory documentation of the Russian Federation on contact capacitor spot welding does not provide sufficient recommendations for the design and calculation of the strength of joints of this type, which requires additional experimental studies of such joints. The purpose of this work is to determine experimentally the strength of two types of joints made using condenser welding technology and working on tension and shear units of ceiling suspension of sheets and profiles of aluminum alloy AMG2M to rod threaded rods made of aluminum alloy AMG3. For this purpose, 18 joints of these types were tested. Control calculations by standard methods for tension and for shear were performed in order to assess their applicability for analyses of these types of joints.

Keywords: aluminum alloy, spot capacitor welding, tension, shear, stress, strength, fracture

ПРОЧНОСТЬ СОЕДИНЕНИЙ ИЗ АЛЮМИНИЕВЫХ СПЛАВОВ, ВЫПОЛНЕННЫХ МЕТОДОМ КОНТАКТНОЙ КОНДЕНСАТОРНОЙ СВАРКИ

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Аннотация. В настоящее время алюминиевые сплавы находят широчайшее применение в самых разнообразных сферах промышленного производства и строительства за счет уникальных свойств физико-механических, позволяющих создавать легкие, прочные, надежные, коррозионностойкие и эстетичные конструкции и изделия самого разнообразного назначения. Тем не менее, алюминиевые сплавы обладают рядом недостатков, основным из которых является более сложный и дорогостоящий процесс изготовления сварных конструкций, требующий применения более совершенных технологий – аргонодуговой сварки и сварки трением с перемешиванием, а также квалифицированного персонала по сравнению с классической электросваркой конструкций из стали. К подобным технологиям также относятся современные методы лазерной сварки и контактной конденсаторной точечной сварки, оборудование для которой достаточно компактно и мобильно, а его использование не требует персонала высокой квалификации по сравнению с другими технологиями сварки алюминия. Существующая нормативная документация РФ по контактной конденсаторной точечной сварке не дает достаточных рекомендаций по проектированию и расчету прочности соединений данного типа, что требует дополнительных экспериментальных исследований таких соединений. Целью настоящей работы явилось экспериментальное определение прочности соединений двух типов, выполненных с помощью технологии конденсаторной сварки и работающих на растяжение и срез – узлов потолочной подвески листов и профилей алюминиевого сплава АМГ2М к стержневым резьбовым тягам, выполненным из алюминиевого сплава АМГ3. Для этого были испытаны 18 соединений указанных типов и выполнены контрольные расчеты нормативными методами на растяжение и срез с целью оценки их применимости для расчетов соединений данных типов.

Ключевые слова: алюминиевый сплав, точечная конденсаторная сварка, растяжение, срез, напряжение, прочность, разрушение

INTRODUCTION

At present, the use of various aluminum alloys is rapidly developing, finding the widest application in the most diverse areas of industrial production and construction due to their unique properties, allowing to create light, strong, reliable, corrosion-resistant and aesthetic structures and products of various purposes. Nevertheless, aluminum alloys have a number of disadvantages compared to steels, the main of which is a more complicated and costly process of producing welded structures, that requires the use of more advanced technologies such as argon arc welding, friction stir welding [1,2,3,4,5,6,7,8] and qualified personnel in contrast to the classical electric welding of steel structures. Such technologies also include various modern methods of laser welding and contact capacitor spot welding [9,10,11,12,13,14], the equipment for which is quite compact and mobile, and its use does not require highly qualified personnel compared to other aluminum welding technologies.

The existing regulatory documents of the Russian Federation on contact welding technologies, including condensation welding presented in GOST 15878-79 "Contact welding", do not give sufficient recommendations on the design and calculation of the strength of joints of this type, which requires additional experimental research of such joints.

The purpose of this work was to carry out tests and calculations of two types of joints consisting of sheet and T-type profiles of aluminum alloy AMG2M with threaded rods for mounting suspended rods of aluminum alloy AMG3 welded to them by the method of spot welding in order to determine the values of ultimate loads for these welded joints. Examples of similar studies in Russia and abroad are given in [15,16].

The main stages of the study are as follows:

- manufacture and installation of loading devices of the tested joints;
- testing of specimen joints of two types;
- performing verification analysis of the strength of these joints in order to assess the possibility of using the standard calculation methods for the design of such joints to determine the values of the ultimate loads by calculation;
- conclusions and recommendations for manufacturing and operation of structures with the joints of this type.

METHODS

Two types of specimens were tested: a connection of plates with dimensions 100×100 mm made of sheet metal of 3 mm thickness and parts of a rolling Taurus with dimensions 100×70×70 mm made of aluminum alloy AMG2M, with studs having internal thread M4 made of aluminum alloy AMG3, connected by spot-condensation welding [18].

Welding was performed using a C99 welding machine [19].

Number of specimens of each type is 9 pieces, a total of 18 pieces (Fig. 1)

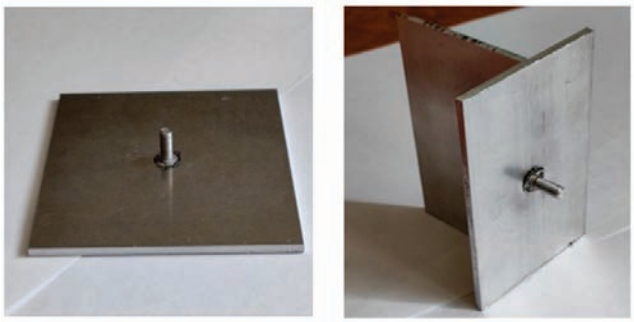


Figure 1. General view of tensile and shear test specimens

Joints were tested in tension under the action of a concentrated force perpendicular to the plane of the plates (type 1) and a concentrated force parallel to the plane of the taurus flange (type 2).

Tests were performed on an Instron 3382 universal testing machine in static loading mode [20].

For the tests, joint elements were fastened in specially designed equipment consisting of steel plates, high-strength bolts and rods, installed in the grips of the testing machine (Fig. 2).

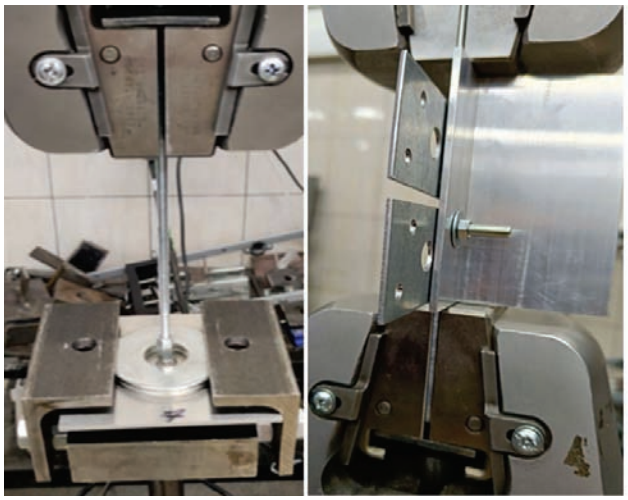


Figure 2. General view of the tensile and shear test of specimens installed in the testing machine

RESULTS AND DISCUSSION

Tensile tests

The tensile tests used a tensile force with control of the rate and magnitude of loading. In these tests, specimen fracture occurs solely by welding (Fig.3-4).

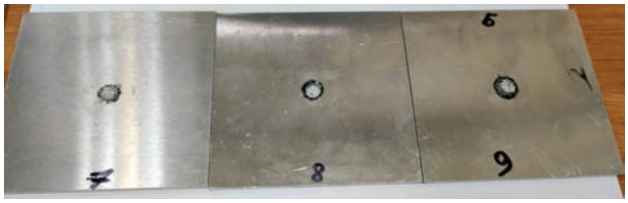


Figure 3. General view of specimens Type 1 after tensile test

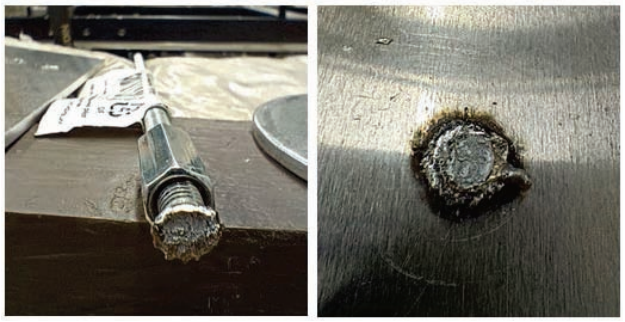


Figure 4. Type of destruction in the welded zone during tensile tests

In the course of loading, the axial load - longitudinal displacement relation was fixed by the recording unit of the Instron 3382 testing machine in the form of corresponding graphical diagrams (Fig. 5).

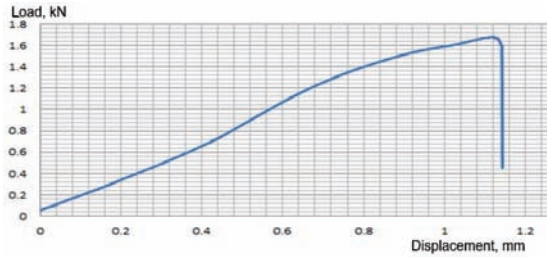


Figure 5. Diagram of displacements during the tensile test of the Type 1 sample

The results of the tensile tests are presented in Table 1. The estimation of the average obtained values of the ultimate load was made both without rejection and with rejection of the value for specimen No. 9 based on the condition of deviation from the average value by more than 50%.

Table 1. Destructive forces during tensile tests

Sample№	Maximal force, kN	Deviation from average value %	
		Before rejection	After rejection
1	1,68	-19	-17
2	2,32	13	14
3	1,75	-15	-14
4	1,63	-21	-20
*5	2,90	41	42
6	2,41	17	18
7	1,74	-16	-15
8	1,86	-10	-9
***9**	**0,74**	**-64**	**-**
Average value before rejection			**2,06**
Standard deviation			0.608
Coefficient of variation			32%
Average value after rejection			**2.04**
Standard deviation			0.457
Coefficient of variation			22%

* – samples subjected to rejection.

Shear tests

During shear testing of a batch of specimens, the failure of this type of connection occurred solely by welding (Fig. 6). In the course of specimen preparation for the test, the welded joint of specimen No. 8 failed before the test while manually tightening the tie rod fastening nut.



Figure 6. General view of Type 2 specimens after the shear tests

During loading, the relationship between the shear force and linear displacement in the shear plane was recorded in the form of appropriate graphical diagrams (Fig. 7).

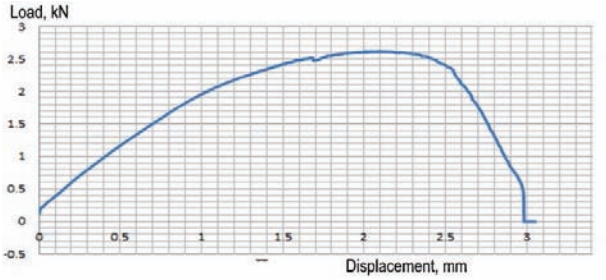


Figure 7. Displacement diagram when testing a type 2 sample on a shear

The results of the shear test are shown in Table 2.

Table 2. Destructive forces during shear tests

Sam-ple№	Maximal force, kN	Deviation from average value %	
		Before rejection	After rejection
1	14	26	14
2	-6	4	-6
3	-21	-12	-21
4	0,5	11	0,5
*5	5	15	5
6	-	-72	-
7	0,9	18	0,9
***8**	-	-	-
9	7	18	7
Average value before rejection			**2,08**
Standard deviation			0,608
Coefficient of variation			32%
Average value after rejection			**2,29**
Standard deviation			0,25
Coefficient of variation			11%

* – samples subjected to rejection.

Verification calculations

Tensile and shear calculations of two types of joints were performed in accordance with the provisions of normative document SP 128.13330.2016 "Aluminum structures".

Dimensions of the threaded rod M4 RT according to DIN EN ISO 13918 (Fig.8):

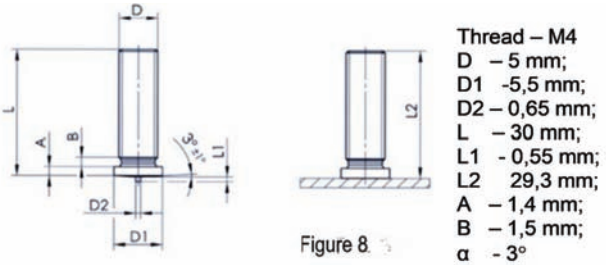


Figure 8

Diameter of welding zone (D_1+0,5 mm) D_w=6 mm.

Welding area:

$$A = \frac{\pi \cdot D_w^2}{4} = \frac{3{,}14 \cdot 6^2}{4} = 28{,}3\ mm^2.$$

The strength parameters of the aluminum alloys used in the tested assemblies are given in accordance with the current regulatory documents GOST 21631-2019 "Sheets of aluminium and aluminium alloys. Specifications", SP 128 and materials [17] with rounding to 5 MPa (Table 3).

Table 3. Strength parameters of aluminum alloys

Node element	Растяжение [МПа]		Сдвиг (срез) [МПа]	
	Yield strength $\sigma_{0,2}$	Maximum resistance $\sigma_в$	Yield strength $\tau_{0,2}$	Maximum resistance $\tau_в$
Plate АМГ2М	70	125	55	90
Threaded stud АМГ3	100	165	70	115

Tensile Calculation

Experimental values of normal tensile stresses (Table 4).

Table 4. Normal tensile stresses during tensile

Sample №	P (kN)	δP (%)	σ (Pa)	δσ (%)	$\delta\sigma_B$ (%)
1	1,68	-17	5,94E+07	-17	-26
2	2,32	14	8,20E+07	14	2
3	1,75	-14	6,18E+07	-14	-23
4	1,63	-20	5,76E+07	-20	-28
5	2,90	42	1,02E+08	42	28
6	2,41	18	8,52E+07	18	6
7	1,74	-15	6,15E+07	-15	-23
8	1,86	-9	6,57E+07	-9	-18
Average	**2,04**	**0**	**7,20E+07**	**0**	**-10**

Tension in the welding zone for the average value of the fracturing force *P*=2.04 kN:

$$\sigma = \frac{P}{A} = \frac{2{,}04 \cdot 10^3}{28{,}3 \cdot 10^{-6}} = 72 \cdot 10^6 = 72\ MPa \leq \sigma_B = 80\ MPa\ (\delta = -10\%).$$

Stress range at failure of 8 specimens:

σ=68,5÷122 MPa (deviation from σ_B –±28%)

Shear calculation

The experimental values of shear tangential stresses are presented in Table 5.

Table 5. Shear stresses during cutting

Sample №	P (kN)	δP (%)	τ (Pa)	δτ (%)	$\delta\tau_B$ (%)
1	2,61	14	9,22E+07	28	54
2	2,16	-6	7,63E+07	6	27
3	1,82	-21	6,43E+07	-11	7
4	2,3	0	8,13E+07	13	35
5	2,39	4	8,45E+07	17	41
6	2,31	1	8,16E+07	13	36
7	2,44	7	8,62E+07	20	44
Average	**2,29**	**0**	**8,09E+07**	**12**	**35**

Tangential stress in the welding area for the average value of the destructive force *P*=2.29 kN:

$$\tau = \frac{P}{A} = \frac{2{,}29 \cdot 10^3}{28{,}3 \cdot 10^{-6}} = 80{,}9 \cdot 10^6 = 80{,}9\ MPa > \tau_B = 55\ \text{МПа}\ MPa(35\%).$$

Stress range at failure of 7 specimens:

τ=64.3÷92.2 MPa (deviation from τ_B 7÷54%).

Conclusions on the results of tests and verification calculations

1. According to the test results, the failure of all specimens of types 1 and 2 occurred in the welded area.
2. Tensile fracture force of type 1 junction is within 1.68÷2.9 kN, the average value is 2.04 kN (Table 1).
3. The divergence of calculation results in tension with the experiment is satisfactory, lies in the range of -28÷+28%, from 59.4 MPa to 102 MPa, the average value is 72 MPa. The average deviation from the value of tensile strength of 80 MPa is -10% (Table 4).
4. Fracture force at shear for the joint of type 2 is in the range of 1,68÷2,9 kN, average value 2,29 kN. (table 2). During the preparation of type 2 specimens for shear tests, the effect of the tightening force on the strength of the welded joint was recorded. At the applied insignificant force the considerable decrease of fracturing load down to 0,57 kN (specimen No.6) and complete fracture of the weld (specimen No.8) took place.
5. The divergence of calculation results on a shear with experiment is more essential, than at a tension, and lies in the limits of 7÷54%, from 64,3 MPa to 92,2 MPa, average value of 80,9 MPa. The average deviation from the value of shear time resistance of 55 MPa is 35% (Table 5).
6. Significantly greater difference of the results of calculations for shear with the data of

experiments than for tensile is a consequence of more complex actual stress state when loading the joint with shear force, created by the construction of the joint, than in pure shear (shear). As a consequence, the values of fracturing tangential stresses for all the tested specimens noticeably exceed the calculated value for pure shear (shear), which goes into the joint strength reserve in the calculations of connections of this type by the normative method.

7. Reducing the dispersion of values of destructive loads and ensuring operational reliability of joints can be achieved in the process of their production when performing the following preparatory actions:

- stripping followed by de-greasing of the welded surfaces of the stud head and the plate area [22];
- control of the amount of preliminary pressing of the stud to the plate surface before the weld pulse [23,24].
- control loading of the manufactured assemblies with the force that exceeds the value of the planned operational load by 50%.

8. To ensure the strength of the nodes during installation and operation, it is necessary to provide a hinged connection of the stud with the loading rod to avoid the appearance of additional bending stresses that may occur at a rigid connection.

9. In order to guarantee compliance with the regulatory requirements of SP 128 to ensure the strength of aluminum alloy structures, the value of maximum load for both types of assemblies investigated should not exceed 1 kN (100 kg) per assembly. In this case, the requirements for preparation and quality control of manufacturing and installation of the assemblies shall be observed (clauses 6-7).

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