# WELDING OF STEEL STUDS TO ALUMINUM SHEETS

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Technology for welding of steel studs to aluminum sheets and structure of stud being welded were developed considering economic and environmental appropriateness of replacement of steel structures by aluminum alloys in transport machine-building and construction and related with this necessity in steel fasteners providing required loading. It is shown that application for this of a heat barrier in a form of evaporated zinc coating at end face of the stud reduces possibility of formation of brittle intermetallic compounds in a transfer layer between steel stud and aluminum sheet, and increased surface of welding provides for uniform strength of joint with steel stud. 10 Ref., 6 Figures.

**Keywords:** *steel and aluminum welding, stud welding, heat barriers, coatings*

Replacement of steel by aluminum alloys, in particular in transport machine-building and during finishing works in construction of buildings and structures, finds wide application in recent years. It allows reducing mass and increasing corrosion resistance and related with this economic and environmental advantages of products. This, naturally, provokes a problem of fastening aluminum sheets to bearing structure or using surfaces of aluminum bodies for hanging devices and equipment, pipelines and wires on them. It is solved, as a rule, using drilling of the holes weakening aluminum body, or welding on of the fasteners without breaking structure integrity.

One of the widespread methods of fastener joining to parts of different designation is mechanized stud welding [1]. However, existing methods are mainly designed for joining of similar materials.

Studs for mass application, including from aluminum alloys, are manufactured using method of cold upsetting in accordance with ISO 13918. Selection of aluminum alloys is limited by aluminum Al 99.5 and alloy AlMg3 (AMg3) under the same standard. Considering material strength the practical application of studs from aluminum alloys suggests insignificant mass of element of the part being hanged.

Fastener loading can be increased applying steel studs instead of aluminum ones. However, application of standard steel studs and methods used for their welding to aluminum products is impossible due to known problem of welding zone embrittlement by insoluble iron and aluminum compounds.



Real methods of steel to aluminum joining using fusion appeared in recent years [2] which allow obtaining satisfactory result at reduction of heat input mainly into the steel part during the process.

Earlier work [3] showed that welding of steel and aluminum studs to the sheets from the same materials at their dissimilar combination using capacitor discharge provides the possibility of obtaining of satisfactory joining due to shot time of the process. Regardless specific quantity of intermetallic phase in the joint zone, it does not reduce joint quality since it is not uniform layer, but only inclusion into a soft aluminum matrix.

Regardless number of advantages caused by short time of the discharge in capacitor-discharge stud welding, the short time of the process requires relatively high accuracy in manufacture of studs and performance of works. In particular, high surface cleanness and preservation of normality of axis of manual tool–welding gun–joint plane of high accuracy (approximately ±2° for M6 stud) are necessary. Considering geometry, the latter requirement rises with increase of stud diameter and, respectively, diameter of shoulder on its end being welded. This condition played an important role in selection of method of stud welding based on reasons mentioned above.

Method of stud welding using short cycle direct-current arc is less demanding on welding procedure and is comparable on diameters of studs being welded by this method with capacitor-discharge welding. Welding of studs on oily or oxidized surface at allowable parallel misalignment of surfaces up to 10° is successfully performed due to significant increase of welding time (from units to tens of milliseconds). These peculiarities determined application of stud welding using short cycle, for example, in automobile industry. However, application of this method is limited by sheet thickness (more than 1/4 of stud diameter) or problems in welding of dissimilar materials, including during welding of steel studs to aluminum sheets.

Thus, necessity in development of technology for joining of these metals by method of short-cycle stud welding considering demands of industry and building has drawn. At that, the task is divided on two parts, i.e. propose a technology, allowing eliminating or making difficult formation of iron-aluminum intermetallics in the joint metal, and suggest a shape of steel stud, increasing strength of the joint up to the requirements of ISO 14555 standard (the joint should withstand stud bending for angle not less than 60°).

As it was mentioned above, formation of intermetallic compounds of iron and aluminum in fusion welding, to which stud welding is related, can be prevented by means of reduction of time of interaction of these metals and providing of allowable partial content of liquid phase before process finishing. The most favorable conditions are at minimum content of iron in the melt and high speed of cooling promoting very low mutual diffusion of the elements. The second condition can be well fulfilled in short-cycle stud welding since heat input into parts being welded does not exceed 1 kJ and it is rejected into the cold parts.

Stud with barrier coating which is used to slow down the melting of stud material (in the discussed process — steel) by means of absorption of arc energy heating the surfaces being welded was proposed for fulfillment of the first condition.

Two variants of widely applied coatings, i.e. zinc and chromium having different heat properties were chosen for investigation. The temperature of zinc evaporation (906.2 °C) is lower than the steel melting temperature and that of chromium is higher (2672 °C), but the latter has

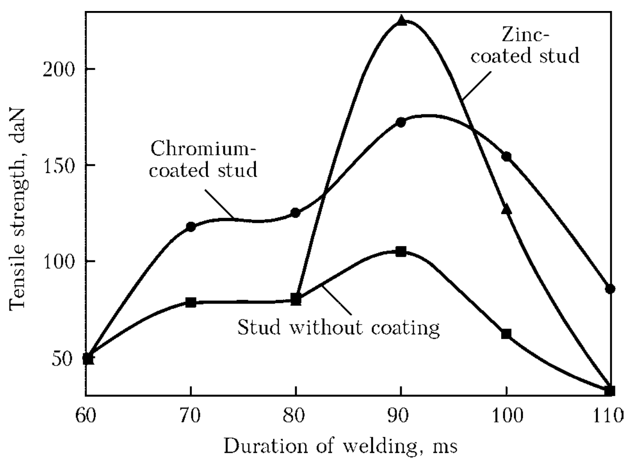


**Figure 1.** Dependence of strength of welded joints on coating composition and duration of welding

significantly higher evaporation temperature than zinc (~6.6 and ~1.7 kJ/g, respectively). Such a choice allowed comparing the role of thermo-physical parameters, i.e. temperature and heat of evaporation, in slowing down the melting of stud metal. The latter was evaluated on microstructures of welded joints.

The first series of experiments was carried out with standard (in accordance with ISO 13918) steel studs M6 without coating, with zinc and chromium coatings of 20 μm thickness. Short-cycle welding to A0 sheet of 3 mm thickness was performed on GLV 650 unit at current approximately 600 A (not regulated) and alternating values of welding time and arc length determining not only arc voltage, but speed of stud deepening into liquid metal pool on the surface of sheet in resistance arc welding with spring upsetting. Welding was carried out using argon shielding of joining zone at 15 l/min consumption of gas for all experiments.

Influence of stud coating on arc characteristics was studied using digital oscillograph C9-8. Analysis of oscillograms showed that application of zinc-coated studs provides some increase of arc voltage in comparison with welding of uncoated studs due to intensive evaporation of zinc coating and respective increase of pressure in a short arc gap.

As can be seen from Figure 1, joints with studs without coating have the lowest strength and zinc-coated studs have the highest one at optimum time of welding. Chromium coating does not provide such significant effect as zinc coating due to higher temperature of evaporation than of zinc. Therefore, the base metal of chromium-coated stud is melted before coating evaporation that causes increase of volume of liquid iron phase in the joint in comparison with welding of zinc-coated studs. At the same time, if welding duration is increased above the optimum, the strength of joints with chromium-coated studs is higher than in uncoated ones since part of the heat energy is consumed for chromium evaporation and lower in zinc-coated due to that the zinc coating completely evaporates during this time making bare steel core of the stud and resulting in balancing of strength of joints of zinc-coated and uncoated stud with aluminum sheet.

If duration of heating is less than the optimum one, the role of coating becomes insignificant due to insufficient evaporation and, respectively, reduction of cooling effect of steel base of the stud.

Figure 2, representing microstructures of joints obtained with steel stud M6 of standard shape and different coatings, shows well a heat-

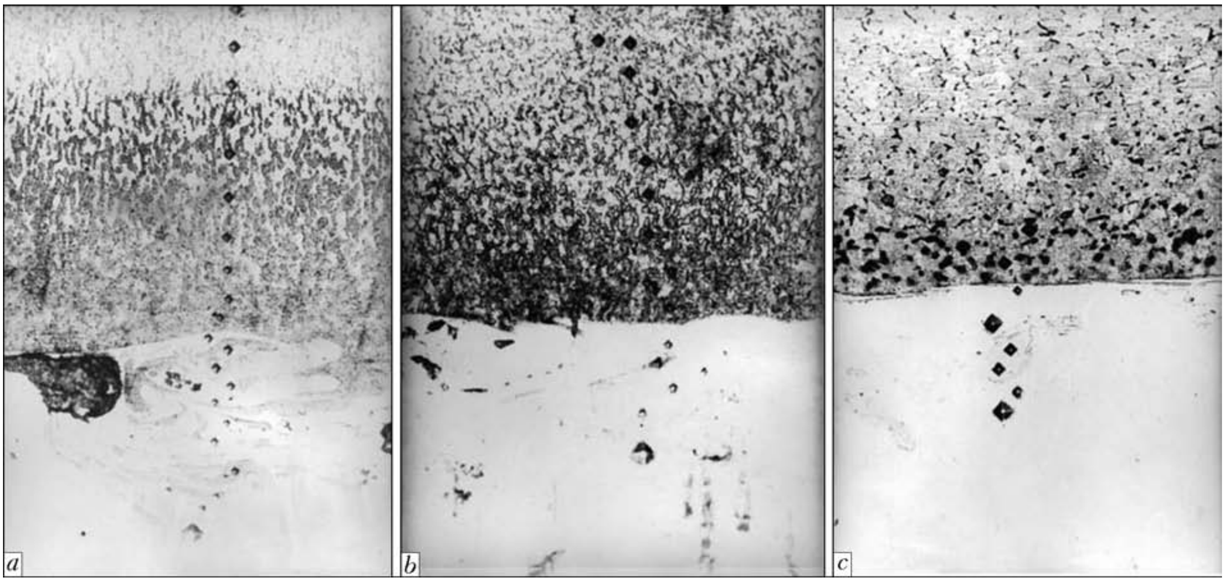


**Figure 2.** Microstructures (×200) of joining zone of steel studs M6 to aluminum sheet of 3 mm thickness with different coatings before welding: *a* — without coating; *b* — chromium coating; *c* — zinc coating

affected zone (HAZ) of the arc reducing at transfer from uncoated stud to chromium-coated and further to zinc-coated one.

Microhardness measured at 50 g loading along the line normal to joint surface (Figure 3) shows that maximum registered hardness is two times lower the hardness of $FeAl_3$ intermetallic (9600 MPa [5]) in all cases.

Thus, coating on surface of stud being welded allows controlling heat emission in the stud material and obtaining joint of steel stud to aluminum sheet having no brittle interface. However, strength of such a joint does not exceed strength of aluminum alloy (failure stress achieved 800 MPa in our experiments).

It should be noted that heat regulating coatings were used earlier as well, for example, aluminum coatings in niobium to zirconium welding [6]. However, at that the coating plays a role of heat sink cooling HAZ. While fusible electroplated coatings (zinc, silver) in steel to aluminum fusion welding were used for improvement of steel wetting by aluminum [7].

Since, as it is known, strength of the joint depends on its area (at other things being equal) then providing of uniform strength of the joint in steel stud requires increase in diameter of surface being welded proportionally to relation of tensile strength limits of steel and aluminum. Assuming that strength of steel 08, from which studs are mainly manufactured, is 325 MPa [8] and strength of aluminum alloy AD-60 being 60 MPa [9], a coefficient of increase in diameter of standard shoulder will be 2.3. Considering that a bead increasing area of the joint is formed on sheet around the shoulder as a result of stud upsetting into the molten metal pool, the calculated coefficient of shoulder diameter was reduced up to 2.1. Thus, diameter of the shoulder should be increased from 7.5 to 16 mm for obtaining of the joint not inferior to strength to steel stud M6, which is welded to aluminum sheet.

Welding of increased diameter studs to fusible aluminum is reasonable at arc rotation in magnetic field [10] that reduces density of heat emission on the sheet and, respectively, danger of its burning through. For this, the studs with different shape of surface being welded were manufactured (Figure 4).

Thickness of zinc coating meeting the requirement of minimum but necessary for melting (for elimination of inevitable deviations of technological conditions from ideal ones which were mentioned at the beginning of work) steel bas of the stud was calculated with the help of spe-

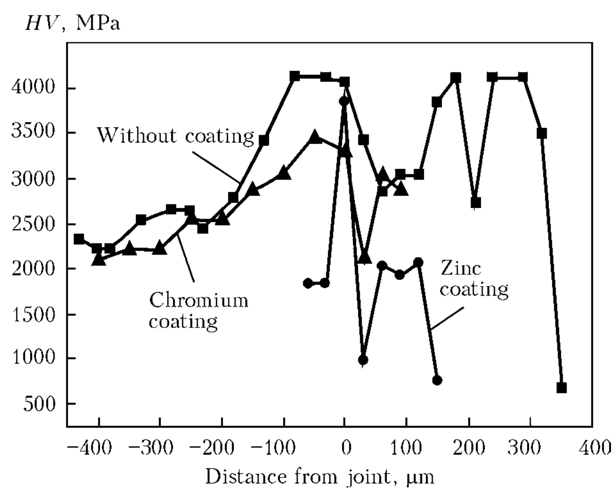


**Figure 3.** Distribution of microhardness normal to plane of joining of steel stud to aluminum sheet

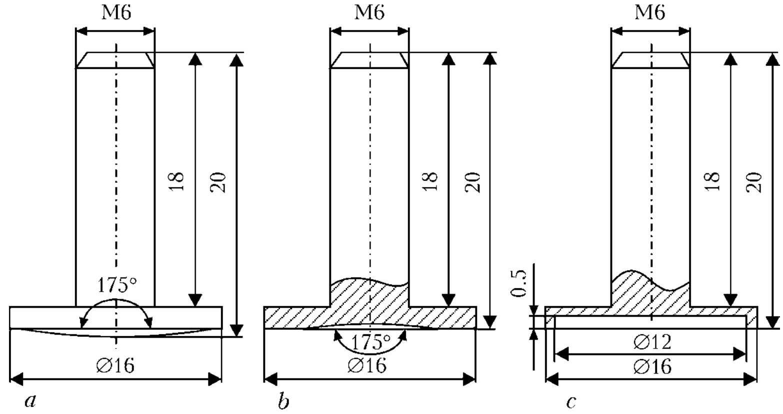


**Figure 4.** Sketches (*a*–*c*) of steel studs for welding to aluminum sheet using short-cycle welding with rotating arc

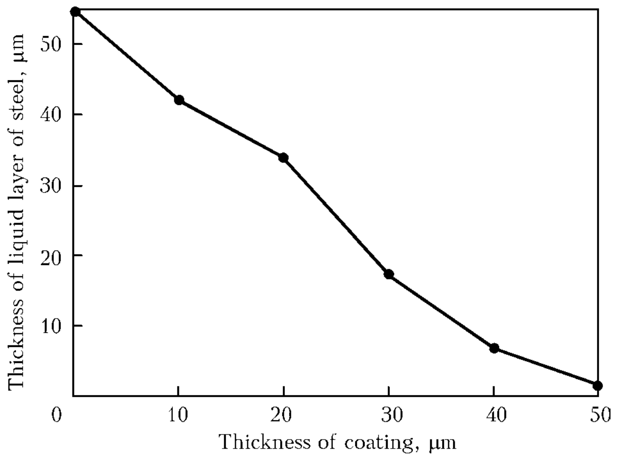


**Figure 5.** Calculated dependence of thickness of steel molten layer at the end of M6 stud of standard shape on thickness of deposited zinc coating (duration of welding 40 ms, welding current 600 A)

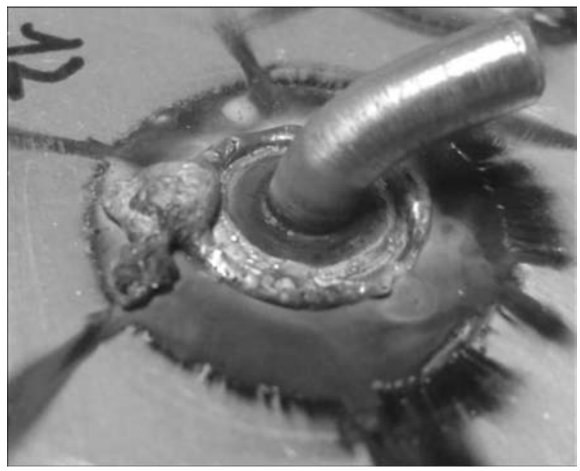

**Figure 6.** Joining of steel stud of 6 mm diameter to aluminum sheet of 3 mm thickness after impact bending testing on ISO 14555

cially developed Fortran-program. Calculation was carried out only for the zinc coating since no data about dependence of thermal-physical characteristics in liquid state on temperature were found for other metals except for zinc.

Figure 5 shows the effect of thickness of the zinc coating on thickness of molten metal of the stud body. It is obvious that increase of welding duration related to application of the studs with increased diameter of surface being joined should promote rise of coating thickness.

Experiments on welding of the studs, shown on Figure 4, were carried out on VKM-16i apparatus of «Soyer» company, thickness of zinc coating of the studs made 20, 30, and 50 μm.

Insufficient filling of gap under the shoulder was observed in the joints with electroplated studs which have strip button that resulted in weak strength of the joint. The joint of satisfactory quality (Figure 6) was obtained at 970 A current, 22 V arc voltage, 0.2 s pulse duration, 1 A current of magnetic coil and 1.5 mm arc length (height of stud lifting).

**Conclusions**

1. Minimization of formation of brittle transfer layer, consisting of intermetallic iron and aluminum compounds, is the main condition for obtaining of strong joint of steel stud with aluminum sheet necessary for automotive and shipbuilding as well as construction industries. Methods used at present time for joining of aluminum and steel parts are based on limitation of energy of heating of steel part and, respectively, reduction of iron content in liquid aluminum pool.

2. The method was developed for regulation of welding heating of the parts by means of deposition of metal layer having evaporation temperature lower than the melting temperature of base metal over surface being heated. Such materials for the steel stud can be magnesium, zinc, cadmium, tellurium as well as some alloys of these metals. Zinc has an advantage from economical point of view.

3. Obtaining of equal on strength joint with steel stud requires increase of diameter of stud surface being welded up to the size not less than 2.5 of diameter of main body of the stud. Such

studs should be welded using short-cycle welding method with magnetic rotation of the arc that allows reducing depth of penetration of aluminum sheet.

4. New shape of the stud was developed due to which joints corresponding to the indexes of satisfactory strength on ISO 14555 were obtained.

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