Research status of CMT welding between Aluminum and Galvanized Steel

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Abstract. In recent years, many scholars have done a lot of research on the CMT welding of aluminum and steel. The welded joints are divided into melting zone, interface zone, heat affected zone and zinc rich zone. In a certain range, the Si element in welding wire is favorable for welding. During the welding process, the choice of welding parameters has a significant effect on the weld appearance and microstructure, the zinc layer is conducive to the wetting and spreading of aluminum and is conducive to welding.

1. Introduction
Aluminum alloy and steel are excellent metals which are widely used in production and life. In many areas, the two advantages are combined to optimize and upgrade products. Particularly, the automotive industry has greatly increased the use of aluminum alloys in order to reduce self weight while ensuring safety. In recent years, many scholars have done a lot of research on the welding of aluminum and steel, and almost all the welding methods have been tried in the field of welding. However, these welding methods generally restrict the shape and structure of the welding parts. The new CMT (Cold Metal Transfer) technology has the advantages of low heat input, little spatter, small deformation, good bridge ability, uniform welding seam, low operation cost and high welding efficiency, and it has been used in aluminum and galvanized steel plate welding more and more. Yu Gang[1] and others carried out cold metal transition welding experiments on aluminum alloy and galvanized steel sheet, and analyzed the microstructure and mechanical properties of the joint. The experimental results show that the CMT welded aluminum / galvanized steel can obtain beautiful welded joints with good appearance and good performance. Li Yulong[2] and others used the Fronius cold metal transition welding machine to weld the wrought aluminum 6061 and SPCC galvanized steel plates together, and analyzed the joints. The welded joints are well formed, with defects such as stomata and shrinkage holes. The defects are mainly located in the upper part of the aluminum melting zone, and the influence on the mechanical properties can be neglected. At present, scholars who use CMT welding method to weld aluminum / galvanized steel obtain good welding joints[3-5].

2. Microstructure and composition analysis of the Welding-brazed Joint
The melting point of aluminum / steel is very different (the melting point of aluminum is about 660°C, the melting point of galvanized steel is about 1500°C). The molten aluminum has been melted while the galvanized steel is still solid. It is a melting brazing process. The welded joints are divided into melting zone, interface zone, heat affected zone and zinc rich zone.
Shi Changliang[6] and others welded the forged aluminum 6061 with the size 120×50×1(mm) to galvanized steel DX52-ZE75/75 with the same size and analyzed the microstructure of the joint. It is found that a dense compound layer with an average thickness of 7−8 μm is formed in the center interface area of the welded joint, and the composition is FeAl₃ intermetallic compound layer. The thickness of the reaction layer in the transition interface is about 4−5μm, and there is a gray floe on one side of the melting zone. The composition is an α solid solution, and a dense FeAl₃ intermetallic compound layer is on the side of the steel, and the color is gray. It is also found that the zinc rich area is a reticular structure composed of solid dendritic crystals and residual aluminum between dendrites. The solid dendrite is composed of Al - rich alpha phase solid solution. Through the mechanical experiment of the joint, it is found that fracture occurs easily in the heat affected zone of the aluminum base material, and the maximum tensile strength of the joint is 72.09MPa.

Zhao Boyan[7] and others selected Al-12Si welding wire and welded 7075 aluminum alloy and galvanized steel plate with CMT welding brazing. It was observed that the steel side interface area was composed of welded Al₇.₂Fe₂Si ternary compound with thickness of about 2−3 μm. The composition of the weld center consists of a -Al based solid solution and a Al-Si second phase.

Lai Huaqing[8] carried out CMT welding tests on 5052 aluminum alloy sheets and Q235 galvanized steel sheets with thickness of 1mm. It was found that an intermetallic compound with Fe₂Al₅ and FeAl was formed at the Aluminum / Steel interface. The intermetallic compound with high hardness and low toughness is formed at the interface. The hardness of the fusion zone is also higher due to the strengthening of the second phase particles. The hardness of the heat affected zone is the lowest, which is lower than that of the aluminum alloy base metal. The grain of the melting zone near the interface is refined. It is possible to form a zinc rich zone at low temperature when welded joints are welded. The zinc rich zone is not conducive to the mechanical properties of joints. Improving the proper heat input of welding can eliminate the zinc rich zone.

L. A. Jácome[9] and others used CMT to weld aluminum alloy and galvanized steel, and the welding wires were Al99.5, AlSi5, AlSi3Mn1 and AlMn1 respectively. It is found that when the thickness of the intermetallic compound is less than 5 μm, the welded joints with the same tensile strength of the parent material are obtained, and the plastic deformation is greater than 9%. The Mn element can effectively enhance the performance of the joint. Si can prevent the formation of intermetallic compounds, but also affect the mechanical properties of the joints.

3. Influence of welding stick composition on welding joint
In CMT welding, the selection of wire will have a great influence on the performance of the welded joint. When the welding parameters are the same, the performance of the joint obtained with different welding wires is different. In a certain range, the Si element in welding wire is favorable for welding. The welding joint with silicon containing wire is better, and the metal compound layer is thinner.

Cao Rui[10] and others selected the welding wires of 4043, 4047 and 5356 respectively. The orthogonal experimental method of CMT welding for aluminum and galvanized steel plate has been carried out and it has been proved that the welding wire is an important factor affecting the performance of the welded joint. The welding joint performance of the aluminum alloy welding wire with a small amount of silicon is superior to that of the aluminum and magnesium welding wire and the high silicon welding wire.

Guo Xin[11] and others used CMT welding aluminum alloy and galvanized steel plate. ER4043 aluminum and silicon welding wire and ER5183 aluminum magnesium welding wire would get artistic welds. The wetting angle of the weld seam with ER4043 is smaller, the welding joint strength is higher, the reaction layer is only 6 μm, and the reaction layer produced by ER5183 is 45 um.

Pang Eryuan[12] and others studied the effect of different wire on the welded joint of 5083 aluminum alloy and Q235 galvanized steel sheet CMT. It was found that two kinds of welding wires using ER4043 and ER5083 respectively would get good weld seam. The mechanical properties of the joint obtained by ER4043 aluminum silicon welding wire are better than those of ER5083, and the metal compound layer formed is thinner.
Zhao Jingqi[13] made CMT brazing between 6061 aluminum alloy and DP780 galvanized steel sheet and he analyzed the mechanical properties and microstructure of welded joints with different filler materials. A good welded joint can be obtained by using AlSi5 wire and AlSi12 cored wire, and there is a layer of intermediate compound layer with a dense side structure and a sawtooth shape at the interface. The mechanical properties of the joint obtained by AlSi5 wire as filler are better than that obtained by using AlSi12 cored wire.

Wang Niwen[14] used CMT arc melting brazing technology and selected AlSi5 welding wire and AlSi12 wire to weld three kinds of aluminum alloy (1060/5052/5A05) and Q235 galvanized steel plate with a thickness of 2mm respectively. When AlSi12 welding wire is used as filling material, three kinds of material would get good joint, and the joint weld fracture is mixed fracture. When using AlSi5, the joint forming of 1060 has a bad result, the other two joints are well formed, but with brittle fracture at the interface of joint. When using AlSi12 welding wire, the mechanical properties of welded joint of 5052 and galvanized steel are better.

### 4. Influence of process parameters on welding joint

During the welding process, the choice of welding parameters has a significant effect on the weld appearance and microstructure. The welding speed, wire feeding speed and clearance amount have a significant effect on wettability of solder, and heat input has great influence on the melting area of solder joint.

Cui Qingqing[15] chose magnesium aluminum welding wire to conduct cold metal transition welding on 1 mm thick 5052 aluminum alloy and galvanized sheet. Through a large number of experiments, the best process parameters are obtained as follows: when the welding gun is in the middle position, the welding speed is 750mm/min, the speed of wire feeding is 4.1m/min, the welding current is 65A, the voltage is 12.5V, and the synergetic pulse parameter is \(F=\text{OFF}\). When aluminum silicon welding wire is used for CMT welding of 1mm thick 5052 aluminum alloy and galvanized steel, the larger the welding current is, the greater the welding heat input will be. And with the increase of welding speed, the heat input of welding decreases. The best process parameters are as follows: welding current is 66A and welding speed is 750mm/min. The heat input has a great influence on the melting zone of the joint.

Shi Zhongxing[16] et al. used AlSi5 welding wire to weld 2mm thick Q235 galvanized steel by CMT welding. It is concluded that when the wire feeding speed is constant, the wettability of solder becomes worse with the increase of welding speed. Then the interface layer tends to flat, and the number of flower like structure decreases. When the welding speed is constant, if the wire feeding speed is increased, the wettability of solder is getting better. Then the interface layer tends to be spherical, and the number of flower like structure increases.

Cui Dianzhong[17] et al. adopted the CMT welding method and chose ER4043 welding wire to weld Q235 galvanized steel and 5052 aluminum. The experimental results show that with the increase of heat input, the weld width, the softening degree of the heat affected zone of the weld joint, the hardness of the interface layer of the brazed joint and the thickness of the interface layer are all increased.

Wang Fengjiang[18] et al. carried out CMT lap welding experiments on galvanized steel and 6061 aluminum alloy. It is concluded that with the increase of welding speed, the radius of nugget increases significantly, and the fusion zone is formed better and the spreading height decreases. With the increase of welding clearance, wetting ability of liquid wire is increased in certain interval, and the morphology of brazing interface is improved obviously.

Mu Gang[19] et al. chose 1.5mm thick galvanized steel sheet and CuSi3 welding wire to carry out CMT Cu brazing test. The experiment adopts the unified welding method. The relationship between the speed, current and voltage is changed with the change of the welding characteristic curve of the welding wire. The wire feeding speed is constant, and the current and voltage are fixed. The welding speed is 75cm/min, the lap number is 10mm, and the lap gap is 0mm, 0.5mm and 1.0mm. The sensitivity of welding defects is determined by wetting, splashing, weld formation and zinc burning.
is concluded that the larger the current is, the smaller the wetting angle is. When the fixed current is maintained, the larger the lap gap is, the smaller the wetting angle is. Welding defects are less when the gap is between 0 and 1mm and the current is 125 to 152A. At high temperatures, the weld is oxidized to form cupric oxide and the surface of the weld is blackened.

H.T. Zhang[20] et al. used Al-Si welding wire and argon protection gas to conduct CMT welding experiment on hot dip galvanized steel and pure aluminum 1060. They analyzed the microstructure and mechanical properties of the joint, and found that the composition of the intermetallic compound was closely related to the heat input. When the heat input is low, the intermetallic compound of the joint is entirely made up of Fe2Al5. When the heat input increases, the intermetallic compound layer is composed of two-phase which are FeAl3 and FeAl2. The hardness of the interface layer is higher than that of the base metal, and the hardness of the weld increases with the increase of heat input. Through joint tensile test, it is found that when the heat input is increased, the inherent strength of the joint will decrease and the fracture will occur at HAZ of Al.

Shi Zhongxing[21] chose AlSi5 solder to conduct surface wetting and spreading test on Q235 steel plate and galvanized steel sheet by CMT arc brazing. And he used a metallographic microscope to analyze the microstructure of the joint cross section. It is found that the greater the wire feeding speed and the greater the heat input in the CMT arc brazing process, the better the wetting and spreading of the AlSi5 solder. And the wettability and wettability of AlSi5 solder on Q235 surface are better with the increase of welding time.

Zhao Yue[22] carried out CMT welding experiments on 5052 aluminum alloy and non galvanized EH36 steel plate. It is concluded that the groove angle has a certain effect on the heating condition of the joint and the wetting and spreading properties of the solder. When the angle of the steel side groove is 50 degrees and the angle of the aluminum side groove is 50 degrees, the joint is heated uniformly, and the wetting and spreading performance of the brazing filler metal on both sides of the base metal is increased. When the heating area of the arc increases, the arc stability is the strongest.

R. Cao[23] et al. used CMT welding technology to connect 1 mm thick aluminum alloy to 1 mm thick mild steel (Q235). It is found that by proper control of heat input (100~200 Joule/mm), the degradation of the performance of the heat affected zone and the thickness of the intermetallic compound will be reduced, and the aluminum steel joint with the same strength of pure aluminum joint is formed.

5. The effect of galvanizing layer in welding

The zinc coating effectively improves the corrosion resistance of the material. During the welding process, the zinc layer is conducive to the wetting and spreading of aluminum and is conducive to welding. During welding, too much volatile zinc is accumulated to form a zinc rich area. And because of the presence of zinc vapor, the weld is prone to porosity.

Shi Chang Liang[24] carried out CMT welding experiments on wrought aluminum 6061 and galvanized steel. It is found that most of the zinc contained in the welded joint was located in the zinc rich zone. During the arc heating process, the zinc content in the center part of the joint basically evaporated. During the CMT welding process, the zinc coating was damaged by the arc, but the zinc coating with a certain thickness was retained, which had good corrosion resistance. Shi Liang also carries out CMT welding of 1 mm thick pure galvanized steel and the galvanized steel with different thickness of zinc layer. It is found that during the welding process, the zinc layer is conducive to wetting and spreading the molten aluminum on the steel sheet, forming a continuous welded joint. The thinner the zinc layer is, the greater the heat input required to get a good shaped joint. When the zinc coating is thin or not, it is difficult to obtain a continuous good shaped joint.

Zhang Hongtao[25] used argon as protective gas and bead welded on Q235 and galvanized steel respectively to analyze the effect of zinc coating on the welding process. It is found that the galvanized layer is closely related to the morphological characteristics of the arc. When the welding current is small, the arc is burning under the welding wire and the fluctuation of the current and voltage signals is small. The problem of selective formation of spots can be eliminated with the zinc layer as the
plasma cathode. The stability of the welding current is improved, and the galvanizing layer plays the role of stabilizing the arc. When the welding current is greater than 20A, the zinc vapor will lift the edge of the arc, which will affect the arc shape, reduce the arc heating diameter and reduce the heat input.

Yu Gang[26] used orthogonal experimental design to explore the CMT weldability of aluminum alloy and galvanized steel sheet dissimilar metal. It is found that the galvanizing layer has the following effects on the welding process: 1. The zinc layer evaporates and changes the arc shape to stabilize the arc and reduce heat input. 2. After melting, the galvanized layer which is too late to evaporate forms a homeopathic liquid film on the surface of the steel plate. It is favorable for wetting and spreading of the liquid wire on the surface of the steel plate. Through experiments, it is concluded that the thicker the zinc layer is, the better the welding will be.

J.C.Feng[27] et al. studied the interface microstructure and zinc distribution of galvanized steel and aluminum cold metal transition welded joints. During welding, because of the high temperature of the bath, zinc always exists in the steam state and cannot fuse with aluminum. Zinc vapor, which is too late to dissipate, eventually becomes a blowhole, and there is few zinc in the rest of the fusion zone. The zinc layer near the joint is almost completely evaporated. The zinc coating on the back of the joint is about 1/10 of the zinc content of the base metal, and the zinc coating in the heat affected zone is seriously damaged, and the corrosion resistance of the joint decreases.

6. Conclusion
CMT welding technology has its unique advantages in the field of dissimilar welding. Aluminum steel welding is of great significance in aerospace, vehicle, ship, railway and other industrial fields. During welding, the composition of welding wire, process parameters and galvanized layer thickness of galvanized steel are closely related to the obtained welded joints. According to the actual situation, selecting suitable welding wire and process parameters will help to obtain good weld shape. At present, there are few studies on CMT welding of Al / high strength galvanized steel, and the defects such as blowhole and slag still need to be further studied on.

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