Study on microstructure and properties of dissimilar welded joints of steel and aluminum by CMT welding process

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Abstract. This paper summarizes the characteristics of CMT welding technology, introduces the main application of CMT welding and analyses the influence of welding parameters on the microstructure and properties of welded joints of steel and aluminum. In the dissimilar welding of steel and aluminum by CMT, the suitable welding speed, wire feeding speed and preset clearance should be selected to obtain the welded joints with good microstructure and performance.

1. Introduction

21st century, the establishment of green ecological environment, low-carbon environmental protection, energy saving and emission reduction become an inevitable way of life. Automobile, as an important means of transportation in life, plays an important role in the future society. The research and development of intelligent environmental protection and energy-saving new car is the common goal of the global automotive manufacturing industry. Because of its small density, high strength and good thermal conductivity, aluminum alloy is used in the future automobile body structure manufacture, but the cost of pure aluminum manufacturing is higher. The composite materials of aluminum and steel have their respective advantages, high strength, good corrosion resistance, light quality and lower production cost, so they can get better applications in the future of automobiles, ships and other fields.

The welding of aluminum and steel has been a hot spot of scientific research, aluminum and steel have great differences in thermal physical properties, and it is difficult to make them mutually soluble by using the general welding methods. Cold metal transition (CMT) welding as a new welding technology, through the welding wire back to reach the droplet transfer which minimizes the welding heat input, can be well applied to the dissimilar welding of aluminum and steel.

Many studies have shown that the main problems in the welding of aluminum and steel are still the formation of brittle metal compounds and residual stresses in welded joints. Although there are many researches on the properties of welded joints of aluminum and steel, they are limited to the study on the single aspect of the specific influencing factors. In this paper, the advantages and applications of CMT welding are summarized, and the influence of welding parameters on the microstructure and properties of welded joints is analyzed comprehensively, which can accumulate valuable experience for welding joints with excellent properties of aluminum and steel by CMT dissimilar welding in the future.
2. CMT welding technology advantages

CMT welding is a new type technology of low heat input welding developed by Fronius company. Compared with the traditional gas shielded welding, CMT welding has three main advantages. First is digital coordination control. CMT welding adopts digital control droplet transfer and wire feeding movement. Second is low welding heat input. When the melt droplet is transferred in CMT welding, the voltage is almost zero and the heat input is almost zero. Third is no splash transition. CMT welding droplet transition is through the wire back, which separates the melt drop and the wire, and the droplet transition is in the short circuit process. In this process, the current of short circuit can be controlled to achieve no spatter [1,2,3].

3. CMT welding application

In CMT welding process, through the combination of wire feeding movement and droplet transfer, the low heat input and no spatter welding are achieved [4,5]. Compared with the ordinary welding technology, CMT welding seam forming is beautiful, its application is more extensive. At present, CMT welding is mainly used in the following three aspects.

3.1. Sheet welding

CMT welding can control the amount of heat input, so as to reduce the deformation degree of welding. The welding process is basically free of spatter, which is suitable for the welding of thin plates. Ordinary metal inert-gas (MIG) welding of thin aluminum plate is easy to cause aluminum plate burning. Using CMT welding, the droplet transition is stable, the weld forming is beautiful, the welding process has no splash and there is no need to worry about burning.

3.2. Welding of dissimilar metals

CMT welding is also suitable for dissimilar metal welding. It is mainly used for welding of aluminum and steel, aluminum and magnesium, copper and nickel base alloys. At present, the most study is the welding between steel and aluminum, copper and aluminum, magnesium and aluminum, and the difficulty of welding is how to control the formation of intermetallic compounds. Compared with ordinary gas shielded welding, CMT welding can reduce the formation of brittle metal compounds by reducing the heat input to control the welding temperature with using the automatic back-pumping droplet transfer form.

Z P Cai et al. [6] adopted CMT welding to connect aluminum alloy AA6061-T6 and pure copper T2. The results show that the good lap between aluminum alloy AA6061-T6 and pure copper T2 can be achieved by using CMT technology. J C Feng et al. [7] conducted CMT welding of aluminum and galvanized steel plates and studied the Zn distribution of joints and the microstructure of the interface. The results show that there is little Zn in other regions except for the presence of a small amount of Zn in the air gap. In the lens, the content of zinc is higher than that between grains. FeAl₃ metal compound and Al-Fe-Zn three phase solid solution are formed on the interface.

3.3. Surface deposition of steel

In some special fields, the surface properties of steel are more demanding, which often requires a layer of metal deposited on the surface of steel. Many scholars at home and abroad have studied different deposition technology, such as surfacing technology, arc deposition, induction melting and so on, but the technical operation of the deposition is more complicated and less efficient. In recent years, CMT has been widely used in the surface deposition of steel due to its advantages of low dilution rate, high deposition efficiency and simple operation.

X F Jiang et al. [8] used CuSi3 as a deposition material and CMT deposition welding was performed on the surface of 30CrMnSi steel plate. The microstructure and composition were observed by means of the back scattering, energy spectrum analysis and X-ray diffraction. The results show that the application of CMT technology can make the deposited layer and the matrix metallurgy get a good
combination, and the change of wire feeding speed will result in the obvious change of the microstructure of the deposited zone.

4. Influence of CMT welding parameters on microstructure and properties of welded joints

Many scholars at home and abroad have conducted extensive researches on the performance of CMT welded joints, including the joint microstructure characteristics [9], mechanical properties, corrosion resistance and so on. However, the research on the welding parameters affecting the performance is not very deep, so the research on the influencing factors of CMT welded joints is still important.

4.1. Influence of welding speed on the forming of welded joints

The change of welding speed will result in the change of welding heat input, and then affect the performance of welded joints. D Wu et al. [10] conducted CMT lap welding of aluminum and dipped aluminum plates and studied the influence of process parameters on the forming of welded joints. When the welding current is 85A, the resulting morphology of welded joints with different welding speed is shown in Figure 1. It is found that the welding speed has great influence on the forming of welded joints. With the increase of welding speed, the welding heat input will be reduced, the weld width becomes narrower and the arc stability will become poorer, which result in the discontinuous welding seam. When the welding speed decreases, the heat input increases and the weld depth increases.

![Figure 1. Morphology of welded joints with different welding speed.](image)

4.2. Influence of welding heat input on the microstructure of welded joints

In the welding of steel and aluminum, welding heat input can not be too large. Otherwise, the performance of the heat-affected zone (HAZ) will decrease. The control of welding heat input can reduce the formation and growth of inter metallic compounds, the amount of welding heat input during welding is affected by the wire feeding speed and welding speed [11].

R Cao et al. [12] used CMT welding technology, 1mm thick aluminum alloy and 1mm thick carbon steel (Q235) were connected together. The results show that the joint strength between aluminum and steel is mainly determined by the softening of inter metallic reaction layer and the HAZ of the aluminum. By properly controlling the heat input, the softening of the HAZ property and the thickness of inter metallic reaction layer can be reduced to a minimum to obtain the welding joints with good performance.

D Z Cui et al. [13] conducted CMT fusion brazing welding of 5052 aluminum and Q235 galvanized steel using ER4043 welding wire as the filler metal and studied the effect of the welding heat input on the structure and performance of welded joints. The experimental results show that the performance of welded joints is greatly influenced by the heat input, and the degree of grain coarsening in HAZ increases with the increase of heat input. The HAZ microstructure of each specimen is shown in Figure 2.

Compared with Figure 2, it is found that there is little difference in the HAZ of (a) (b) (c) three samples, and the microstructure of the HAZ of the specimen (d) is obviously larger. This is due to the large heat input, the grains grow significantly, which leads to the softening of HAZ and the decline in
the performance of welded joints. In order to obtain the welded joints with good performance, it is necessary to control the heat input quantity in the actual welding so as to avoid the overheating in the HAZ.

![Figure 2. Microstructure of heat-affected zone in welded joints of steel and aluminum.](image)

4.3. Influence of preset clearance on the strength of welded joints

S Yang et al. [14] conducted a CMT fusion brazing of the automobile galvanized low carbon steel plate and 6061 aluminum alloy and studied the performance of welded joints using different sizes of feeler to control the preset clearance. The results show that the preset gap can increase the length of fuse line effectively, and improve the tensile shear strength of welded joints.

S Yang and other people [15] used CMT welding, aluminum alloy 6061-T6 and galvanized low carbon steel were welded together. The influence of pre-setting gap of aluminum alloy and steel on the quality of welded joints was studied. The tensile and shear test of the weld seam were carried out. In addition, the weld microstructure was analyzed by optical microscope, scanning electron microscope (SEM) and energy dispersive spectrometer (EDS). The experimental results show that the preset gap can improve the welding strength and affect the morphology of welded joints.

Therefore, the use of preset clearance in CMT welding has a certain effect on the performance of welded joints. The suitable preset clearance should be selected for different material welding, and the welding joints with good performance can be obtained.

4.4. Influence of welding direction on the forming of welded joints

Different welding direction has great influence on weld forming and protection. In the steel and aluminum welding, the weld forming and protection effect of the left welding direction is better than that of the right welding direction. The main reason for this phenomenon is that the weld formed during right welding will be heated by the arc, which will prolong the cooling time of the weld and lead to the oxidation and other defects. Therefore, the welding of steel and aluminum generally uses the left welding method, welding arc can first heat the molten pool of the parent material area, which can preheat the material, so that the melted wire can be better spread out.

5. Conclusions

As a new low heat input welding method, CMT is widely used in dissimilar welding of steel and aluminum. With the improvement of welding quality requirements, the research on CMT welding technology needs continuous improvement. In this paper, the advantages and applications of CMT welding were summarized, the influence of welding parameters on the microstructure and properties of welded joints was analyzed comprehensively, and the following conclusions were obtained.
(1) As the welding speed increases, the weld width becomes narrower and the arc stability becomes worse, resulting in the discontinuous weld seam. When the welding speed decreases, the heat input increases and the weld depth increases. Too large or too small welding speed will have an impact on the weld forming. In actual welding, the appropriate welding speed should be selected according to the welding materials.

(2) The welding heat input has certain influence on the HAZ. When the heat input is large, the grains will grow significantly and the HAZ is softened, which leads to the decrease in the performance of welded joints. In the actual welding, the heat input of welding should be controlled to avoid the overheating in the HAZ so as to obtain the welded joints with good performance.

(3) In the dissimilar welding of aluminum and steel, the left welding method is generally used and the suitable preset clearance should be selected to improve the strength of welded joints. When the gap is too large, the strength of the joints will be decreased.

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