Summary of Composite Material-Metal Connection Technology

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Abstract. As high-performance and lightweight materials, such as aluminum alloy and titanium alloy, metals are still used in aerospace and aircraft industry. Therefore, the bonding process of composite materials and metals is one of the key issues to be urgently solved and developed in the aerospace industry. Therefore, the connection technology of CFRP to metal is reviewed in this paper. The implementation process of laser welding, friction welding and resistance welding and the types of connection materials are summarized.

1. Introduction

The pursuit of high reliability, light weight, and high efficiency is the eternal direction of the aviation industry. Light materials, light structures, and advanced molding processes are effective ways to meet these requirements [1-3].

As high-performance and lightweight materials, metals such as aluminum alloys and titanium alloys are still used in the aerospace and aircraft industries. In structural applications, in order to ensure the best mechanical properties, while maintaining weight and cost-effective solutions [4], the composite material-metal connection process is one of the key issues to be solved and developed in the aerospace industry. However, the connection of different materials is usually difficult to achieve, especially when bonding and mechanical fastening are used. These two connection processes have some limitations, such as stress concentration, the need for large-area surface preparation, additional weight and harmful Environmental emissions.

The use of advanced welding technology to connect different materials has been developed as a way to solve the problems related to traditional connection technology. Advanced welding technologies include laser welding, friction stir welding, resistance welding, etc. The effective application of these technologies requires us to understand the mechanism of metals and polymers in the welding process. This article presents a comprehensive overview of the joining techniques of the different materials found in metal-polymer joints. This article is divided into three parts. The first part is the introduction. Next is the introduction of three different methods of metal-polymer welding. The last part of the paper summarizes this topic and summarizes the advantages and disadvantages of the methods and techniques discussed.
2. Laser welding
Laser welding is a technology that uses a laser beam as energy to make it impinge on the weldment joint to achieve the purpose of welding. The connection methods mainly include direct laser irradiation and laser transmission welding. In these two methods, the laser as the heat source corresponds to two process principles: heat conduction connection (HCJ) and transmission connection (TJ). Compared with HCJ, when using TJ, the laser beam is transmitted through the resin matrix composite material. TJ can only be used for resin-based composite materials with high transparency to electromagnetic radiation of the laser wavelength. However, glass fiber (GF), especially carbon fiber, reduces the transparency of the material. Therefore, only HCJ is suitable for fiber-reinforced resin matrix composite joints. In HCJ, the laser beam is irradiated on the metal connection block, as shown in Figure 1. The high-speed rotating laser beam scans and heats on the surface of the metal, and the heat generated is transferred to the connection interface through the metal, thereby melting the added thermoplastic resin and fiber-reinforced resin matrix. The molten resin flows into the microstructure of the aluminum alloy surface under the action of external clamping pressure, and then connects the metal and the fiber-reinforced resin-based composite material.

Fig 1. schematic diagram of laser welding

In 2010, Kawahito Y et al. proposed a new method for the direct connection of A5052 and PET (laser assisted metal and plastic connection method). Under ideal conditions, the tensile shear load of the joint under this method can reach 5000 N. The structural characteristics of the welded joint connection prove that the bonding mechanism of the joint connection in this method includes not only mechanical bonding, but also van der Waals force and chemical bonding. When receiving the paper, we assume that the corresponding authors grant us the copyright to use the paper for the book or journal in question. Should authors use tables or figures from other Publications, they must ask the corresponding publishers to grant them the right to publish this material in their paper [5]. In 2011, Katayama and others used high-brightness continuous wave lasers to connect carbon fiber reinforced composite materials (CFRP) with different types of stainless steel. The research results show that the oxide film of carbon fiber reinforced composite material (CFRP) and 304 stainless steel plate has strong chemical and physical adhesion, and can form a strong connection [6]. In 2013, Jung K W et al. used continuous wave (CW) linear laser diodes to study the feasibility, characteristics and mechanism of the connection of carbon fiber reinforced composite materials (CFRP) and galvanized steel dissimilar materials. A continuous wave (CW) linear laser diode is used to emit a linear beam on the steel side of the PAN-type carbon fiber reinforced composite (CFRP) and galvanized steel lap joint to realize the direct laser connection between PAN-type CFRP and galvanized steel. The tensile shear test shows that this method can produce high-strength joints of about 3300N [7]. In 2019, Tao W et al. successfully connected TC4 alloy and SCF/PPS directly through laser welding, and explored the best power suitable for the joint [8]. In 2012, Asier
Cenigaonaindia et al. studied a new method of connecting AISI 304 stainless steel and natural polyamide 5) by laser transmission, as shown in Figure 2. The laser beam passes through the transparent part (natural PA6 thermoplastic polymer) and is absorbed by the absorbent (deformed AISI 304 metal). The combination of high temperature and external pressure forces the molten polymer to flow into the previously processed metal surface texture. The entire metal surface is in contact with the thermoplastic polymer. Subsequently, the workpiece is cooled and the joint is strengthened under pressure so that the entire surface is evenly and firmly bonded[9].

Fig 2. Steps of the new joining process

3. Friction welding
Friction stir welding (FSW) is a solid-state welding technique that uses plastic deformation (Figure 3). In recent years, it has been successfully applied to the interconnection of PA6 and aluminum alloy, magnesium alloy, carbon steel and other materials.

Fig 3. Schematic diagram of friction stir welding

In 2015, Nagatsuka K and others successfully realized the overlap of CF/PA6 and aluminum alloy (A5052) by friction welding. As shown in Figure 4, the tool has a 15 mm diameter shoulder (without probe) and is tilted 3° forward from the vertical. The CF/PA6 weldment was cut parallel to the longitudinal direction (FD) and the transverse direction (TD) and spliced with the ground aluminum alloy (A5052) along the longitudinal direction [10].
In 2016, Khodabakhshi F and others successfully welded AA5059 aluminum alloy and high-density polyethylene sheet (HDPE) through optimized friction stir welding joint design for dissimilar material welding, as shown in Figure 5. The tool is made of H13 steel, with a shoulder diameter of 16 mm, a pin diameter of 5 mm, and a height of 3.7 mm. During the machining process, the depth of the knife is kept at about 0.2 mm, and the angle of the knife is kept at about 2.5° [11].

Friction stir spot welding is based on another variation of standard friction stir welding (FSW). Amancio-Filho ST and others successfully used friction spot welding to join magnesium and
thermoplastic composite materials. As shown in Figure 6(A), this tool system consists of a clamping ring, a sleeve, and a pin. The tool components are installed coaxially and can be rotated and moved independently of each other. As shown in Figure 6(B), the sleeve and the pin begin to rotate in the same direction. Then the sleeve contacts the upper surface of the metal sheet downward, generating frictional heat. The main advantages of this method are: short connection period, no emissions, simple operation, commercial equipment available, and good mechanical performance. However, this technology also has some shortcomings, for example, it cannot be directly applied to thermosetting composite materials, and it is also not suitable for very thick metal materials (the thickness currently tested is within 1-2 mm) [12].

![Fig 6.](image)

**Fig 6.** (A) Illustration of the FSpW tools used in this work (dimensions in mm). (B) Schematic description of the “Sleeve Plunge” FSpJ-variant.

### 4. Resistance welding

Resistance welding is a welding method that uses the Joule heat generated by the energized resistance element to melt, flow, cool and solidify the material, and finally realize the connection, as shown in Figure 7. Resistance welding is usually used for the connection of metals or thermoplastic composite materials. In recent years, with the development of the assembly process of dissimilar lightweight materials, resistance welding has also been used in the interconnection of metals and thermoplastic composite materials.

![Fig.7.](image)

**Fig.7.** Resistance welding diagram

In 2000, Ye et al. of the University of Sydney first used resistance welding for the connection of carbon fiber reinforced polyetherimide composite (CF/PEI) and aluminum alloy, in order to prevent the aluminum alloy and carbon fiber from contacting the conductive implant during the welding process To cause power loss, they designed a composite heating element. The heating element structure is shown in Figure 14. The innermost layer is conductive CF/PEI prepreg, and then insulation GF/PEI prepreg is
added on both sides of the CF/PEI prepreg, and finally consists of two layers of PEI. The film provides resin for connection on the outermost side. Using the composite heating element as a heat source, under the conditions of a power density of 110kw/m² and a welding time of 6min, good welding of CF/PEI composite materials can be achieved, with a welding strength of more than 20MPa [13].

In 2017, Nagatsuka and others of Osaka University developed a resistance point on the same side for metal-polymer connection in order to overcome the shortcomings of current transmission during resistance spot welding of metal-polymer joints due to the insulation of polymers. As shown in Figure 8, the electrodes are only arranged at different positions on the conductive metal side to realize the serial connection of the spot welding heads. After power on, the current can only flow through the metal side, and the metal near the electrode can be locally heated by the Joule effect. Heat conduction is used to melt the resin matrix of the thermoplastic composite material near the joint interface, and then cool to achieve an effective metal-polymer connection. Nagatsuka used this method to connect stainless steel plates (SUS304) with CF/PA6, CF/PP and CF/PPS composite materials. This method is based on the interaction between the heat conduction on the metal surface and the molten polymer, which completely avoids the adverse effect of the heating element introduced in the traditional composite resistance welding process on the joint, and has great application potential in the metal-composite connection [14].

![Fig.8. Schematic illustration of (a) joining mechanism and (b) experimental layout of the series-RSW process for dissimilar materials joining of metal/plastic and CFRP (All dimensions in mm).](image)

5. Conclusion
1. The connection of different materials is usually difficult to achieve, especially when bonding and mechanical fastening are used. These two connection processes have some limitations, such as stress concentration, the need for large-area surface preparation, additional weight and harmful environmental emissions.

2. Without the need for adhesives and mechanical fasteners (bolts, rivets, etc.), both the laser direct connection process and the laser transmission welding process can achieve high-strength connection of metal and composite materials; friction stir welding is used in metal and thermoplastic composites.
been used in the interconnection of materials; and resistance welding is also very promising in the connection of metal-composite materials.

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