

CFRP-ALUMINUM ALLOY COMPOSITE STRUCTURES: A NEW TYPE OF COMPOSITE STRUCTURES IN FUTURE

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ABSTRACT

High-strength, light-weight and durable materials are always desired by structure engineer. Although CFRP (carbon fiber reinforced-polymer) meets the demands, but its anisotropy makes the connection of structural elements considerably weak which is the main cause that make its high strength not be utilized fully. However, Al (aluminum alloy) is now becoming the structural material in civil engineering in recent years also due to its light-weight and anti-corrosion properties. Although it has reasonable strength as normal steel, but its low modulus makes it deformation control difficult that results in limiting its application in large span structures. The combination of CFRP and Al, which can make the high-strength being fully developed and make the connection being easy between elements, will be expected as a new type in composite structures in future. The state of the art of CFRP-Al composite in aero and space structures, and aluminum structures in civil engineering are firstly reviewed in this paper. CFRP-Al composite pipes, which can be used as elements in long-span space truss structures, under axial compressive and flexural loading were studied by tests. It is shown that CFRP can significantly increase the load capacity and the stiffness of pure Al members. The results of the experimental study have showed that this new composite will have potential benefits for the structures in future.

KEYWORDS

CFRP, Al (aluminum alloy), composite structures, light weight, anti-corrosion.

1. INTRODUCTION

The larger breathing space is always the dream of people all the while. There are two basic ways to obtain it by structural engineer: one is to use the appropriate structure styles, another is to use the light weight materials. These may be considered the main motives behind the introduction of CFRP (carbon fiber reinforced polymer) and Al (aluminum alloy) to be used as structural material in civil engineering. As compared with the Al, CFRP yields more high performance and offers more specific strength, stiffness and resistance (Hollaway, 2001). However CFRP is an anisotropic material, which has high strength and elastic module along the fiber direction and low strength in the transverse direction (Feng and Ye, 2002). So in the design of the CFRP and the CFRP composite structures, two directions have to be considered. Besides adding to the complications and difficulties in the design process of CFRP structures due to the anisotropic, the connections between elements are always the weak position in the structural and can not be easy solved with proper design. Al is a light weight, corrosion resistant material, which is widely applied in the aviation, railway and automobile (Mazzoloni, 1985). Since 1940s, Al was introduced in the construction of bridges in North America and Europe, including footbridges, highway bridges, railway bridges and float bridges. At the same time, Al building structures, such as the long-span dome, springs up and becomes widely used all over the world for its light weight, easy manufacture, and anti-corrosion properties. Besides that, Al is also used in the construction of frames, water channels, roof boardings, walls, and communication towers, and so on. However, comparing with steel, the elastic module of Al, for example type of T6061 T6, is about 1/3 of it. The

deflection and the buckling often restrict the use of Al in structures. Therefore, FRP-Al composite structures are suggested here to use their common strong points and can overcome their individual weakness, weak connection for CFRP and lower modulus for Al. By combination of FRP and aluminum, FRP high strength can be made useful in the longitudinal direction to improve the stiffness and stable bearing capacity of Al components; and using aluminum in connections instead of FRP further ensures the reliability and strength at the junction between components. Moreover, the combination can make full use of the advantages of two materials that is the light-weight and anti-corrosion. In this paper, the state of the art of the CFRP-Al composite is firstly reviewed. Then, the experimental researches on CFRP-Al composite elements in compressive and bending are stated. The results show that FRP-Al composite elements have potential benefits for structures in future.

2. CFRP-AL COMPOSITE STRUCTURES

Al structures have the advantages of light weight and corrosion resistant, which were firstly used in the construction of bridges. The first pure Al bridge, which is a 29.72m long railway bridge, was built across the Glass River near New York in 1946. It was also used in the retrofit for existing bridges that Al bridge decks replace steel or concrete decks (Napier et al, 1998; Hag-Elsafi and Alampalli, 2002). For building structures, Al can reduce the structures self weight, which will improve the structures ultimate span and make the construction easy and fast. In addition, Al structures are glossy without painting, anti-corrosion, and non-magnetic. Due to these advantages, Al long-span space structures have been used in some special environments. In China, the applications of Al structures have gained attention in recent years, such as the dome structure of Shanghai international gymnastic center (Figure 1), glass ellipsoid Al of Shanghai science and technology museum, and a non-magnetic latticed structure roof (Figure 2).



Figure 1: International Gymnastic Center

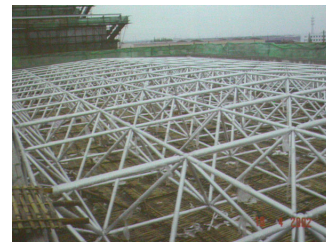


Figure 2: Non-Magnetic Latticed Structure Roof

Comparing with the pure Al structures, CFRP-Al composite structures can be used to get more light and handy building structures. This kind of composite structures has been widely used in aviation industry, like the construction of commercial airplanes, military airplanes and spaceships (Harris et al, 2002). F-22 fighter, manufactured by Lockheed Martin, is a typical composite structure which is composed of 39% titanium alloy, 24% aluminum alloy and 39% FRP. Its tail fin manufactured by Al honeycomb core and CFRP stressed-skin structures. In the plane wing, the main skeleton structure is made up of Al and FRP is used as stressed skin. CFRP-Al composite structures have been used in manufacturing transportation and communication. Many automobile actuating arms made of CFRP-Al composite, can not only reduce the weight, but also improve the strength and stiffness of the rods (Lee et al, 2004).

FRP repairing the cracked Al structures was studied by Pantelides et al (2003). But the idea of the combination of CFRP and Al for civil engineering structures is different. CFRP and Al are used in a reasonable configuration to realize the longer span structures. So many feasible combination styles of CFRP and Al can be designed. Honeycomb panels made of FRP skins and Al honeycomb shown in Figure 3 can be used as lightweight walls and roof structures. CFRP-Al composite beams show in Figure 4, made by sticking CFRP sheets on the tensile and compressive wings of Al profiles, can make full utilization of CFRP high longitudinal strength. They are lighter than pure Al beams but heavier than pure CFRP beams, while the composite beams become cheaper, easier to manufacture, and have good ductility and fatigue resistance. The connection style of metal can be used to avoid the complexity of CFRP connection. CFRP-Al composite pipes and tubes, which are used to construct long-span space structures, were developed and studied in this paper. The CFRP sheets are wrapped and adhered with epoxy resin on the Al pipe's surface. The manufacture process is listed in Figure 5. By the combination, FRP high strength can be fully utilized in longitudinal direction to improve the stiffness and stable bearing capacity of aluminum pipes, and the aluminum connections can be employed instead of the CFRP ensures the reliability and strength at junction

between components. Moreover, aluminum can also supply enough bearing capacity in transverse direction to overcome the low strength of CFRP in this direction. With the development of science and technology, the establish of outer space structures are becoming more and more. Besides same requirements as the ordinary structures, some special requirements in outer space are demanded As all the building materials have to be sent from the earth, the whole structure must be light, handy, and modular. CFRP-Al c composite structures can meet all the requirements.

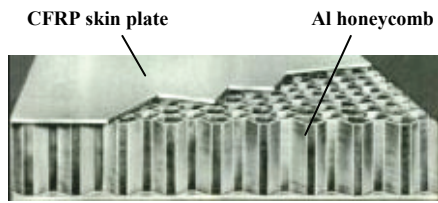


Figure 3: CFRP-Al Sandwich Panel

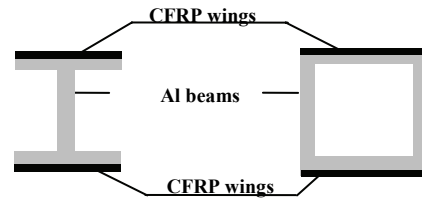


Figure 4: CFRP-Al Composite Beams

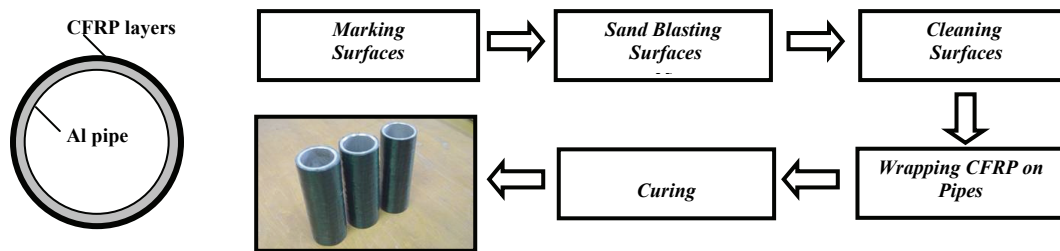


Figure 5: Manufacture Process of FRP-Al Composite Pipes

3. EXPERIMENTAL STUDY ON CFRP-AL MEMBERS

3.1 Axial Compressive Tests

Two sets of composite pipes were tested under axial loading. Twelve specimens in Set 1 are short pipes. Their bearing strength enhanced obviously with CFRP layer numbers increasing which can be seen from in Figure 6. And ten specimens in Set 2 with large slenderness and different CFRP layer numbers were tested to investigate their buckling load-capacity. Their buckling strength were enhanced significantly to the pure Al pipes, the flexural stiffness and deformation capacity were enhanced both. Figure 7 shows the curves of the transverse deflection to the vertical load for the long pipes with the slenderness ratio about 120. Based on the tests and a series of finite element analysis, the buckling behaviors of composite pipes were studied, a formula of stability factor was presented (Qian, 2006).

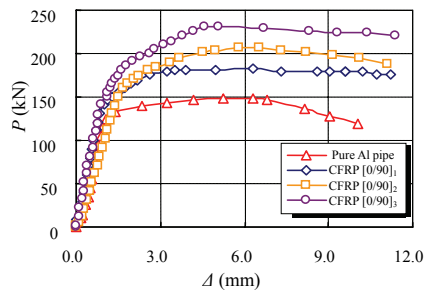


Figure 6: Load-Axial Deflection Curves of Set 1

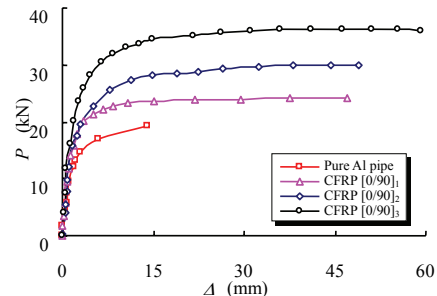


Figure 7: Load-Lateral Deflection Curves of Set 2

3.2 Bending Tests

Two sets of the square tube specimens with different width-thickness ratio were tested under bending. Their load-deflection curves are shown in Figure 8. It can be seen that the strength and stiffness of the composite members are

higher than those of pure Al members while the ductile failure mode is remained. Based on the tests, it was found the initial stiffness of the composite member can be determined by the sum of the Al and CFRP.

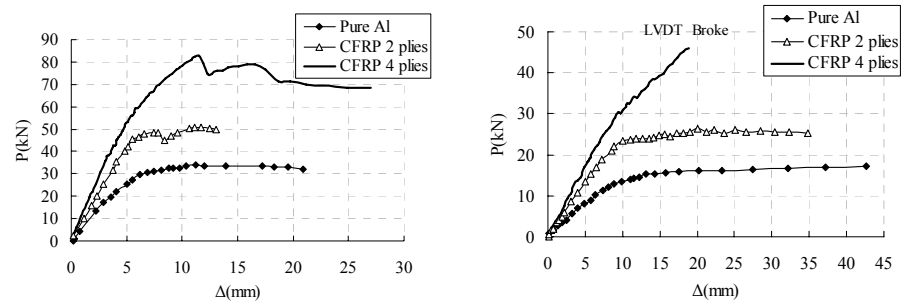


Figure 8: Load-Deflection Curves of the Flexural Specimens

4. SUMMARY

Since 1940s, Al has been applied and developed and had found its application in civil engineering, especially in the construction of bridges and space structures. It has potential benefits because of its high specific strength, high specific stiffness, corrosion resistant and easy processing properties. But Al has its own inherited faults. Its elastic module is only 1/3 of steel and the distortion of aluminum structures is usually large, so the aluminum structures are scarcely used. In order to avoid Al inherited faults and get the more light and handy structures, CFRP-Al composite components and structures are suggested in this paper. The experiment study shows that the combination not only improves components stiffness but also bearing capacity.

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