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Manufacturing Technology and Application Trends of Titanium Clad Steel Plates

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Abstract: Some of the major manufacturing processes and corresponding mechanical properties of titanium clad steel plates were analyzed, and the consequences of research, manufacturing, and application of titanium clad steel plates in both markets of China and overseas were also summarized. As an economical and environmentally friendly technology, the roll bonding process is expected to become the next-generation mainstream process for the manufacturing of titanium clad steel plate. Some of the crucial and most important technical problems of this particular process, including vacuum sealing technology, surface treatment process technology, application of a transition layer, and rolling process, were discussed along with the advantageous mechanical properties and life-cycle economy of these plates processed by this technology. Finally, the market needs, application trends, and requirements of titanium clad steel plate were also considered from industries of petrochemical, shipbuilding, marine, and electric power.
Key words: titanium clad steel plate; manufacturing technology; application trend; petrochemical; rolling; marine

In these years, industries have increasingly focused on sustainable development, i.e., minimizing costs and maximizing the efficiency of metallic materials derived from limited resources. The excellent property of corrosion resistance of titanium, especially in marine environments, is very well known. However, pure titanium has a very limited application due to several reasons such as exorbitant costs and lack of other desirable properties; thus, it is impractical in most applications. A solution is offered by titanium-steel composite materials; these kinds of materials combine the advantages of steel such as high strength, high toughness, and low cost with the corrosion resistance of titanium. These new materials minimize the use of pure titanium while exhibiting excellent overall properties. Therefore, the titanium-steel composite materials are anticipated to be embraced by the petrochemical, shipbuilding, marine, and other industries[1,2]. Titanium clad steel plates have been manufactured over the past 50 years, and manufacturing processes have advanced with growing market needs[3]. Referring to the related literature, this study summarizes the manufacturing technology and application trends of titanium clad steel plates.

1 Manufacturing Processes of Titanium Clad Steel Plates

Currently, there are four manufacturing processes of titanium clad steel plates: explosive bonding process, roll bonding process, explosive roll bonding process, and diffusion bonding process. Each of these processes has distinctive advantages and disadvantages.

1.1 Explosive bonding process

In this process, an explosion provides an instantaneous blast of energy that deforms, melts, and diffuses a metal surface, achieving a welding clad of heterogeneous metals[4,5] (Fig. 1). This process is applicable to a wide range of metal combinations and has flexible equipment requirements. Explosive bonding is especially useful for steel-titanium combinations because it easily generates intermetallic compounds[4,6]. However, existing explosive bonding processes are limited by poor productive continuity, high costs, low yield rate, and uneven interfacial bonding strength. Moreover, explosions can easily generate severe environmental and noise pollution.

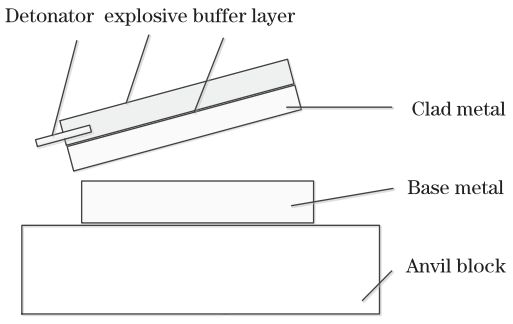

Fig. 1 Schematic of manufacturing by the explosive bonding process

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1.2 Roll bonding process

Under sufficient pressure from the rolling mill, two metal layers pass through a pair of flat rollers, thereby generating plastic deformation at the layer interface; eventually, the two layers become metallurgically bonded[7,8] (Fig. 2). This manufacturing process delivers good plate shapes with high manufacturing efficiency, low pollution, and low energy consumption[8,9]. It is particularly suitable for manufacturing wide clad plates, sheets, single and double side titanium clad steel pipes, and similar items and is currently the primary trend in titanium clad steel plate manufacturing. However, this process is often required to solve the brittle problem of metal compounds by several processes such as surface treatment before rolling and heat treatment process after rolling.

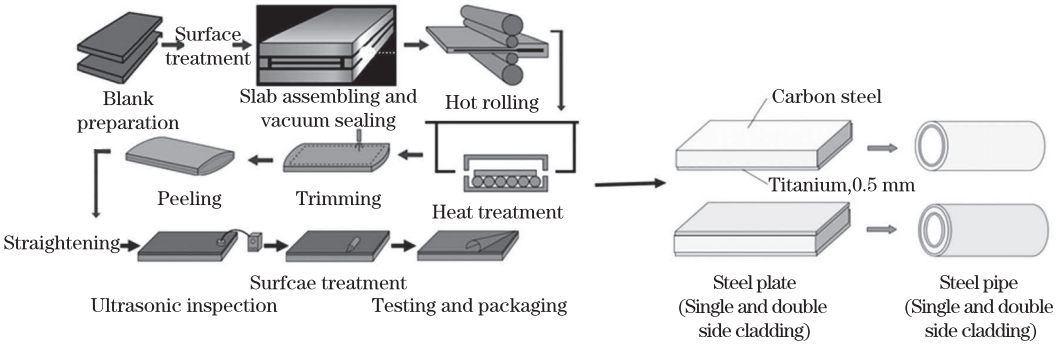

Fig. 2 Schematic of manufacturing by roll bonding process

1.3 Explosive roll bonding process

In this process, a thick clad plate slab is first manufactured by the explosive bonding process, and the finished product (subjected to requirements) is obtained through a second process such as hot or cold rolling[10,11]. This process combines advantages of the explosive bonding and roll bonding processes and enables flexible production[12]. Although explosive roll bonding is extendible to a wide range of manufactured products, problems of the explosive bonding process remain.

1.4 Diffusion bonding process

This process compresses the metal plates without deforming the base metals while heating these metals to below their melting points. The two metals were combinef by atomic diffusion across the interface[13]. However, the diffusion process is time consuming, and the manufactured products are limited to small size and low bonding strength[14-16]. Therefore, the diffusion bonding process is inapplicable to industrial-scale production of titanium clad steel plates.

2 Global Research Status of Titanium Clad Steel Plates

The variety and throughput of composite boards are the highest in Japan. Japan′s annual output of composite boards has reached one million tons, 1% of which is made into clad plates.

Remarkable advances have been made by many enterprises such as Nippon Steel, Kobe Steel, Kawasaki Steel, and Sumitomo Metal Industries, which have been performing researches and production of titanium clad steel plates for years. In Japan, titanium clad steel plates were typically manufactured by the explosive bonding process until 1986, when the roll bonding process was developed. With roll bonding process, the JFE Steel Corporation now produces titanium clad steel plates with excellent mechanical properties (maximum shear strength higher than 250 MPa, maximum thickness of 72 mm, and maximum width of 3.9 m)[17].

In the 1930s, the Soviet Union began actively performing research on the technology of metal clad plate processing. Metal clad plates of aluminum, titanium, steel, and other metals and alloys were manufactured by the explosive bonding, roll bonding, and diffusion bonding processes. In addition, the Soviet Union significantly advanced the cold roll bonding process. Moreover, Britain, France, Germany, and many other countries significantly contributed to research on titanium-steel composite materials.

China has abundant titanium resources, but the development and application of titanium clad steel plate in China have not kept up with the rest of the world, and not even mentioned the manufacturing until 1980s. For now, there are several domestic steel works and groups that produce titanium clad steel plates in China, including Baoji Titanium Industry Co., Ltd., Northwest Institute for Nonferrous Metal Research, Ansteel Group Corporation, Sichuan Jinglei Science and Technology Co., Ltd., Jinan Steel Group, Kunming Iron & Steel Corporation, Nanjing Iron & Steel Corporation, etc. The typical manufacturing processes are the explosive bonding and explosive roll bonding processes, which collectively comprise over 70% of China′s market share.

However, in terms of manufacturing technologies, manufacturing quality, and application ranges, China′s