ISSN: 2664-9640

Research on Tight Connection of FRP Flange

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Abstract

The most commonly used connection form in the production process of the petrochemical industry and in the use of equipment is bolted flange connection. It has a wide range of applications in pressure vessels and pipelines produced in petrochemical, pressure vessels, nuclear energy, and other industries. specialty. Therefore, in large petroleum and petrochemical enterprises, a large number of equipment piping systems use bolt flange joints as connectors. Therefore, once these flange joints leak suddenly, it will reduce output, waste energy, and pollute the environment, and at the worst, they will explode when exposed to static electricity or open flames, which will cause huge losses to the lives of employees and the benefits of the enterprise. Therefore, to ensure the long-term and safe operation of petroleum and petrochemical production, bolt flange joints, an important component in pipelines and equipment systems, are the most important for sealing and safety performance.

Keywords

Composite material, glass fiber reinforced plastic, tight connection, petrochemical industry.

1. Introduction

With the rapid and diversified development of aerospace and military materials, traditional metal materials are no longer unique. Due to the high specific strength of composite materials, strong shock absorption performance, better ductility, corrosion resistance, and design It has the advantages of strong performance and lighter weight than ordinary metal materials[1]. Composite materials have seen explosive development and are widely used in various fields, making the application of composite materials more perfect[2]. The most prominent phenomenon in oil production is that glass fiber reinforced plastic (GFRP, commonly known as glass fiber reinforced plastic) pipelines and their accessories have been used on a large scale in the gathering and transportation production of various oil fields at home and abroad.

my country's oilfields have been vigorously developing FRP pipelines in oilfield production since the 1990s, and have received good economic benefits from existing projects. According to literature surveys, Daqing Oilfield[3] and Xinjiang Oilfield[4] have been used since 1990. In the production of oil collection, water injection, and supply operations, four types of non-metallic pipes, namely, glass steel pipe, steel frame plastic composite pipe, flexible composite pipe, and plastic alloy pipe, have been applied respectively. According to incomplete statistics, the application of FRP pipelines invested in my country's oil and gas fields during the "Eighth Five-Year Plan" period is shown in Table 1.

Table 1 Oilfield planned procurement table

oilfield	Type of pipe	number	use	Construction time (years)
Daqing	Low pressure	31	Water delivery	1991

		18	powered by	
		4	Thermoelectric	
		21.5	polymer	1994
		14		1996
	high pressure	0.43	Water injection	1994
		6	polymer	
Jilin	Low pressure	1.56	Oil	1996
	high pressure	9.2		
Liaohe	Low pressure	0.5	Water pumping	1996
	high pressure	1		
Shengli	Low pressure	3.09	Sewage reinjection system	1989
		2.66		1991
		2.78		1992
		19.4886		1993
		46.4886		1994
		52.821		1995
	high pressure	5	Water injection	1995
		1.7	Water injection tubing	1995
Zhongyaun	Low pressure	2.7	Sewage treatment	1984
		21	Off-site gathering and transportation	1994
Qinghai	Low pressure	20	Pure water	1990
Jiangsu	Low pressure	1	Acidic water	1991
Sichuan	high pressure	1.5	Tubing	1995
Changqing	Low pressure	14.41		1996

As of 2012, the total length of non-metallic pipelines used in Xinjiang oilfields was 3774.68 km, of which glass steel pipes used 228km, and they were all used in water injection, water supply pipeline network, crude oil gathering, and transportation in oil fields[5]. Through the analysis of statistical data in the past five years, the damage and replacement rate of non-metallic pipelines in gathering and transportation operations, water injection, and water supply are significantly better than that of metal pipelines. It can be seen from the following table 1-2 that the application of non-metallic pipelines in oil fields has great advantages[6].

Therefore, numerous composite material pipes and composite material fittings have been produced, and the connection of FRP pipes with steel pipes, pressure-bearing equipment, and containers has also appeared. In the above three kinds of connection processes[7], what follows is that the connection of FRP flanges and steel flanges is widely used in the production sites of petroleum and petrochemical enterprises.

ISSN: 2664-9640

2. Bolt flange connection member

2.1. Bolt flange connection structure

A typical flange connection is mainly composed of upper and lower flanges, intermediate gaskets, bolts, and nuts. During normal use, the flange connection mainly bears the pressure and temperature of the working medium. There are three main types of flange sealing[8]:

(1) Self-tightening seal: the medium pressure in the pipeline or container can make the compressive stress on the gasket be proportional to the medium pressure, to achieve the purpose of compaction, so the required bolt pre-tightening force is small;

(2) Compulsory sealing: The compulsory sealing is achieved through the joint action of bolts and nuts to compress the gasket strongly, so the bolt pre-tightening force is relatively large;

(3) Semi-self-tightening seal: The semi-self-tightening type is a combination of self-tightening and forced, bolts and medium pressure simultaneously seal the gasket.

The FRP flange-gasket-steel flange structure studied in this paper is a typically forced seal, which is mainly composed of three parts: connected parts-upper and lower flanges, seals-non-metallic gaskets and connecting parts-bolts, Nut. These three parts constitute the entire bolted flange joint system, as shown in Figure 1 below:

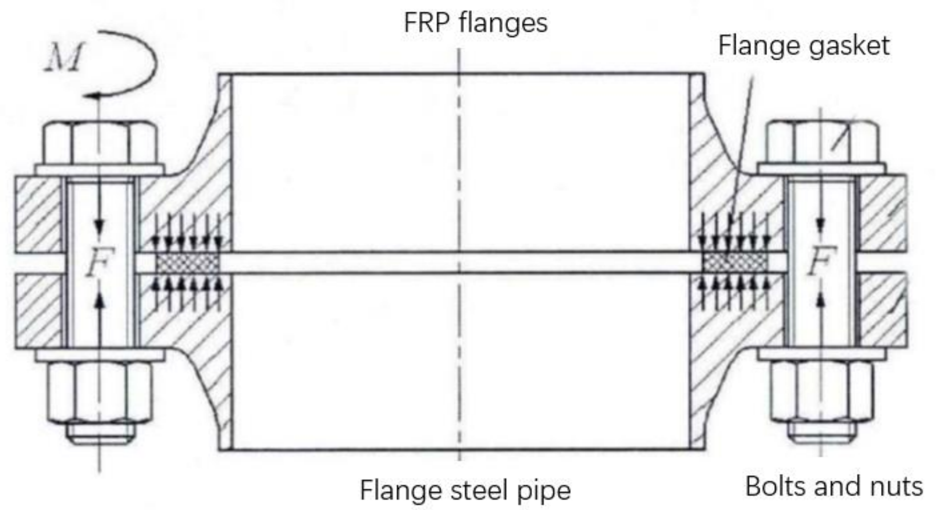


Figure 1 Bolt flange joint system

2.2. The mechanism of flange sealing

The sealing is achieved by the strong compression of the gasket by the connecting piece. The bolts and nuts in the flange holes shrink the two flanges to the middle and cause the sealing surface to bear the load[9]. The difference in the bolt pre-tightening force is caused by The sealing surface bears the uneven load. In order to eliminate the surface leakage caused by the uneven bolt load, the sealing element-gasket appears between the sealing surfaces of the upper and lower flanges. The gasket material has the characteristics of softness and variability. Therefore, when subjected to uneven bolt load, the gasket material is compressed and deformed. Although the force is different, due to the compression and resilience of the gasket, the pressure can be uneven. The resulting small gaps on the sealing surface are eliminated. For example, when the flange is affected by the internal pressure medium or temperature, or the flange is damaged (composite flanges may experience minor damage to the sealing surface under pressure and temperature), the gasket can be unloaded according to pressure changes

ISSN: 2664-9640

Rebound, that is, eliminate this unloading displacement through the rebound of the gasket, and ensure enough remaining sealing surface pressure to ensure that no leakage occurs[10].

Considering that the rigidity of FRP flanges is lower than that of steel flanges, non-metallic gaskets are generally used for the connection between FRP flanges and steel pipe flanges, which not only have good compression resilience performance but also do not affect the bolt load. Destroy the sealing surface of the FRP pipe flange. There are several types of non-metallic gaskets: rubber gaskets, PTFE gaskets, expanded PTFE gaskets, and flexible graphite gaskets.

2.3. Failure mechanism of bolt flange

The current general definition of failure refers to a product or function that is insufficient to meet its design requirements, and it is considered invalid when it loses its original function. Failure analysis of mechanical components or structures is a newly developing discipline, which has become increasingly mature in recent years[11]. Most of the current studies attribute the failure of bolt flanges to the following points:

(1) Strength failure

When certain parts of the machinery or structure appear fatigued, large plastic deformation and cracks until they break, it can be considered that strength failure has occurred.

(2) Seal failure

Although the pressure vessel or the connecting piece meets the component strength requirements, leakage still occurs at the connection, which is a failure caused by the reduction of the sealing pressure or the damage of the sealing surface.

The purpose of the bolt flange is to prevent the leakage of the medium flowing in the pipeline or pressure vessel[12]. For common connections between steel flanges, seal failure dominates, and there are two main types of joint leakage. One is leakage along with the flange sealing surface interface, and the other is leakage through the gasket material itself. However, when considering that the FRP flange is a composite material, the rigidity is far less than that of the steel flange. When it is subjected to a sufficiently large preload, it is prone to breakage, resulting in strength failure, as shown in Figure 2. Therefore, this article will combine the material properties of FRP and consider the following three leakage methods:

(1) Leakage along with the interface of the flange sealing surface;

(2) Permeation and leakage along with the gasket material itself;

(3) Leakage along the damaged part of the FRP flange.

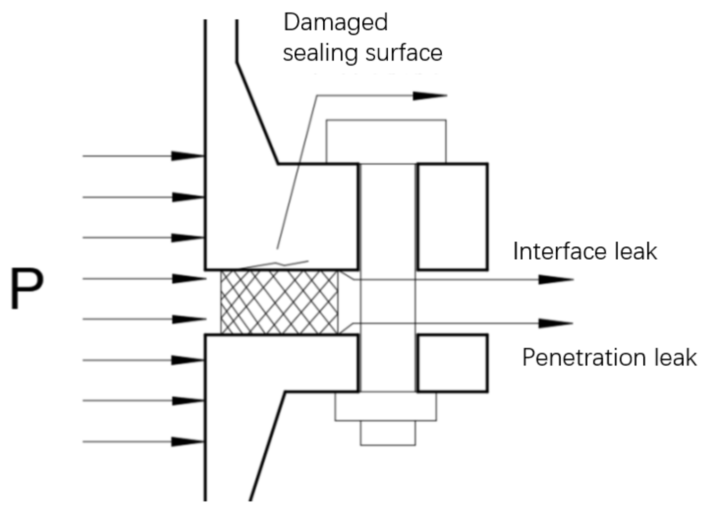


Figure 2 Three failure modes of flange bolt interface

ISSN: 2664-9640

3. FRP flange shape and sealing surface design

Flange shape design

The stress distribution of the integral flange is shown in Figure 3.

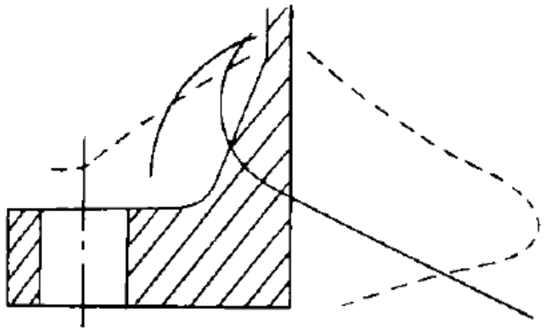


Figure 3 Overall flange stress distribution diagram

Starting from the cylinder part about 6-9 times the wall thickness from the bottom of the flange ring, the longitudinal and hoop stresses begin to increase sharply as the distance decreases[13]. The hoop stress starts to increase slowly, but from the flange ring thickness area. The upper surface to the bottom surface of the ring quickly increases to the maximum value, that is, the maximum ring stress is in the flange ring, and the longitudinal stress is the maximum at the junction of the flange ring and the cylinder. It can be seen from Figure 4 that if the flange adopts the same wall thickness structure as the wall thickness of the cylinder, it is impossible because the strength and rigidity of FRP are much lower than that of steel (only 1/10 to 1/15 of steel). Increase the wall thickness of the cylinder indefinitely, which may cause deformation or even damage due to excessive local stress. A reasonable wall tube structure should appropriately increase the wall thickness according to the increase in stress, so as to improve the overall strength and rigidity of the flange and achieve equal strength. This goal can be achieved by adopting a tapered neck structure (see Figure 4), which is suitable for hand lay-up or cold-pressed FRP molding.

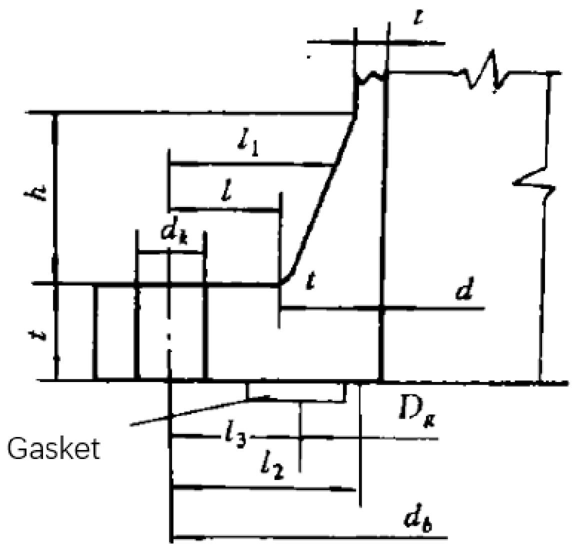
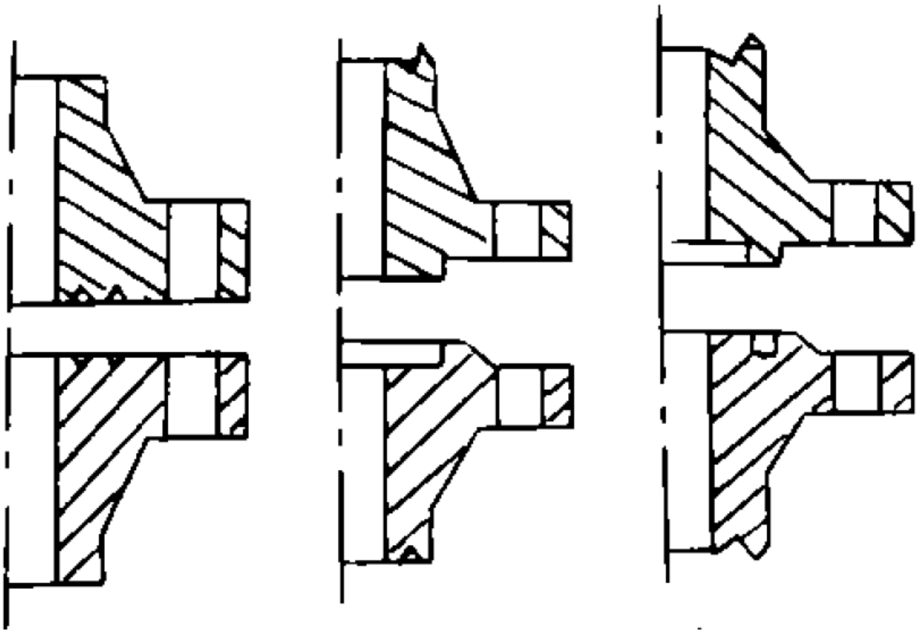


Figure 4 Outline drawing of taper neck flange

ISSN: 2664-9640

3.1. Design of flange sealing surface

The sealing surfaces of FRP flanges are mainly flat, concave-convex, and bar-groove (see Figure 5). The flat structure is simple and sealed, but for FRP pipes that are mostly used in low- and medium-pressure systems, their tightness can fully meet the requirements. We generally use a flat sealing structure, and the other two sealing structures are also used in special situations such as high pressure or toxic media transportation[14].



(A) Flat type (b) Concave-convex type (c) Lump type

Figure 5 Schematic diagram of three types of sealing structures by FRP method

3.2. Structural design of FRP flanges

The sealing principle of the flange is realized by the tightening force of bolts and nuts to deform the gasket between the flanges and fill the sealing surface of the flange.

Flange bolt pre-tightening load When the flange is pre-tightened, the bolt pre-tightening load P_1 is determined in the pre-tightening state (the flange is called the pre-tightening state before entering the medium after the bolt is tightened), the role of the flange in the bolt pre-tightening force, The pre-tightening pressure is generated on the gasket to achieve the pre-tightening seal, at this time the pre-tightening force of the bolt is P_1

$$P_1 = \pi b D_g y = S_\rho y$$

D_g—the diameter of the gasket load application point, when b_0≤6.5mm, $b = b_0$, then D_g is equal to the average diameter of the gasket contact surface; when $b_0 > 6.5mm$,$b = 0.8\sqrt{b_0}$, then D_g Equal to the outer diameter D_0 of the gasket contact surface minus twice the effective width, then $D_g = D_0 - 2b$;

y—Gasket sealing specific pressure is the load of the gasket during pre-tightening and sealing per unit effective sealing area. It has nothing to do with the pressure of the medium, but only with the material and shape of the gasket. For non-textile or high-content asbestos fiber cotton For synthetic rubber, when the Shore hardness is lower than 75, y=0; when the Shore hardness is greater than or equal to 75, y=1.4MPa; for rubber asbestos, y=11MPa.

During the pre-tightening seal, the pressing force on the gasket is called the gasket load P_2. When the pre-tightening seal is reached, $P_1 = P_2$.

Flange bolt operating load P_3 When the pipe is passed through the medium, the flange bears the effect of internal pressure and medium temperature, which is called the operating state of the flange. Under the action of internal pressure, the flange generates an axial force opposite to the belt tension force, which is the internal pressure load. It is divided into two parts, one is the internal pressure load P_x^1 acting on the inner diameter end face of the pipe; The second is the internal pressure load P_x^2 acting on the flange end face of the gasket load line of action, the total internal pressure load $P_x = P_x^1 + P_x^2 = \frac{\pi}{4} D_g^2 P_3$ (P_3 is the design working pressure). Under the action of P_x, the two contact surfaces of the flange tend to separate, which reduces the pressing force on the gasket, resulting in a slight separation. If the gasket has resilience at this time, it can also maintain the sealing of the interface. When the compression force on the gasket is reduced to the minimum value that keeps the sealing port leak-proof, it is called the minimum residual compression force, which is the operating state. Under the gasket load P_3, when the gasket material and shape are selected, the size of P_3 is

$$P_3 = \pi 2 D_g P_3 m = S_1 P_3 m$$

In the formula, S-the effective pressing area of the gasket;

m-shim coefficient, that is, the ratio of the compression load of the gasket to the total internal pressure acting on the effective compression surface of the gasket is a dimensionless quantity obtained by experiments. For gaskets of the same material and shape, m is a constant. For synthetic rubber without textiles or high-content asbestos fibers, m=0.5 when the Shore hardness is less than 75; when the Shore hardness is greater than or equal to 75, m=1; for rubber asbestos gaskets, m=2.75.

The bolt load P_2 of the flange in the operating state is equal to the total internal pressure load P_1 and the gasket compression load P_3. That is, $P_2 = P_x + P_3$.

(3) The bolt load that the flange must-have. The bolt load necessary to ensure the sealing of the flange should be larger than P_1 and P_2.

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