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Evaluation of pipe stub flange behaviour during hydrostatic pressure testing

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2008-05-16T07:19:21Z
http://hdl.handle.net/10539/4833

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2 LITERATURE SURVEY

2.1 Codes and Standards relating to GRP stub flanges

Standards can be defined as published documents that set out technical specifications or other criteria necessary to ensure that a material or procedure will consistently achieve the required purpose that it is intended to do. In piping systems where glass fibre reinforced plastic materials are intensively used, proper material selection and adherence to codes and standards is essential, because standardization provides safety, substantially reduces manufacturing costs and facilitates installation. In addition, standardization makes it possible to unify the recommended practices in design, manufacturing procedures, installation and testing procedures of pipe flanges. Therefore, a survey of some international standards relating to the design, testing procedures and leakage evaluation of pipe flanges made out of glass fibre reinforced plastic materials was conducted. Different international standards related to design and testing procedures of fibre reinforced plastic flanges are listed in Appendix A.

2.1.1 British Standards

- BS 7159:1989 covers the code of practice and provides guidance for design and construction of glass reinforced plastic piping systems for individual plants or sites. This standard also provides information concerning the design specifications of flanged joint components. However, it does not cover detailed specifications about the test procedure of the flange. The standard recommends that as the pressure test combined with bending is performed, it must be proved that the flanged joint specimen will not leak under the combined force of the maximum design pressure and applied bending moment. The applied bending load is calculated from the formula 10.1 presented in section 10.4 [(2)]. The test procedure is restricted to flanged joints up to 600 mm that are connected to pipes with a pressure rating of 10 bar. BS 7159 specifies that the maximum test pressure shall be equal to six times the pressure rating of the specimen.

- BS 5480:1990 specifies the requirements for materials, dimensions, classification, design and testing procedures for pipes, fittings and joints made from glass reinforced plastic (GRP) with or without aggregate filler. This standard is applicable to pipes (pressure and non-pressure) and associated fittings that are intended for the conveyance of potable and non-potable water, foul sewage and storm water. The pipes and associated fittings should have nominal diameters of 100 to 400 mm and should be designed for pressures up to 25 bar. This standard describes various types of tests relating to pipes and different types of pipe joints:

Methods of test for leaktightness performance of flexible joints

The standard specifies the procedure and requirement of the pressure test to be performed for flexible joints such as spigots and socket joints of glass-reinforced plastics with elastometric sealing rings for above ground and buried pipeline applications. This procedure is intended to prove the design of the joint for pressure (negative pressure as well) or non-pressure applications, while they are subject to angular deflection or misalignment. Note that the method presented in appendix M [(3)] is technically equivalent to the corresponding methods covered in ISO/DIN 8630.

Methods of test for leaktightness of rigid joints

The test procedure covered in this section is similar to the corresponding test for flexible joints covered in appendix M [(1)]. However, the rigid joints are not subject to any angular deflection or draw.

- In the design of reinforced plastic equipment, BS 4994 and BS 6464 suggest that the calculations should be performed in terms of the unit load (force per unit width) rather than stress (force per unit area). The maximum allowable unit load for each type of lamina is determined taking into account the material properties of both reinforcement and matrix. The advantage of this procedure is that each lamina of the laminate construction is designed to carry the proportion of the total applied load appropriate to its strength. Thereby, overloading and subsequent failure of a particular layer can be avoided. The calculations are simplified by assuming that a single material property (ultimate tensile unit strength or unit modulus) can be allocated to the lamina over the entire laminate. However, it should be noted that a consistent material distribution cannot be achieved using the hand lay-up technique, especially when the construction consists of complex geometry and a large number of reinforcement layers is required. The design factor of the laminate construction, K, is determined by multiplying a coefficient λ to a set of five different factors (k1, k2, k3, k4 and k5). The coefficient λ is a constant that links the strength of the material to the long-term loading effect on the structure. Each factor k1, k2, k3, k4 and k5 is related to the method of manufacturing, long-term behaviour, temperature, cyclic loading and curing procedure respectively. In common practice, a design factor not less than 8 is recommended [(3)].

  BS 4994 suggests that the laminate should be cured in accordance with the resin supplier's instructions, and preferably at the manufacturer's works. However, the standard also suggests that the curing procedure should be carried out according to the design requirements and resin system used. To comply with the test requirements, the tested laminate should not exhibit any evidence of incomplete cure such as resin pick-up by acetone test, tackiness, or low hardness.

BS 6464 specifies that stub flanges with loose steel backing rings shall be used for pipes that have a design pressure above 1.60 MPa. It also specifies that tests shall be carried out on flange specimen to prove that the joint shall not fail by leakage when subject to a combination of the maximum design pressure and applied bending moment. The bending moment shall be determined from equation 21 in section 26.4.4 [3]. This standard also suggests that the pressure applied to flanges of nominal size less than 600 mm (with a pressure rating up to 1.00 MPa) shall be equal to six times its operating pressure.

2.1.2 American Standards

- 2001 ASME section 10 suggests that the design of flanges must be based on the allowable stress of the laminate. It is required that the flange thickness must be designed such that the allowable stress does not exceed 0.001 times the modulus of the laminate used to fabricate the flange. The design modulus must be the lower of the longitudinal and transverse moduli of the flange laminate. The design calculation of the flange is performed following the procedure presented in section RD-1176.3 [12]:
    1. determine the design conditions, material properties, and dimensions of the flange;
    2. determine the lever arms of the inner and outer parts of the gasket;
    3. determine the gasket dimensions by calculating the seating load and gasket factor (y and m);
    4. determine the loads and the bolting requirements;
    5. calculate the flange load, moments and lever arms;
    6. determine the flange moment at gasket seating condition;
    7. calculate the stress and compare it to the allowable stress of the laminate.

This standard does not provide detailed specifications concerning the curing and post-curing process to be carried out. However, it is recommended that the curing and post-curing processes should be performed according to the resin supplier's instructions.

- ASTM F 37 covers two test methods for sealability of gasket materials (Method A and method B). These two methods provide a means of evaluating the seal characteristics of a gasket material under different compressive loads. The difference between the two methods is that Method A is restricted to liquid measurements whereas Method B can be used for both gas and liquid. When liquid is used as the test medium, the results of the sealability tests are expressed as a leakage rate in millilitres per minute under the specific conditions of the test. The critical leakage rate of the joint in service has to be determined by the user.

- ASTM F 586 is intended to evaluate the leak tightness capability of the flange gasket joint in terms of two factors, namely, the *y* and *m* factors. The *y* factor, or yield factor, represents the minimum gasket stress required to ensure that the gasket is sufficiently compressed and conforms to the flange face irregularities. The *m* factor, or maintenance factor, is used to calculate the additional preload through the bolts in order to maintain the sealing pressure on the gasket after the internal pressure *p* is applied to the joint. The use of these two factors allows calculation of the required bolt load. Given the complexity and variety of gasket materials, these two factors are often determined empirically. Therefore, the choice of gasket material and the capability assessment of the gasket in service require a preliminary discussion between the user and the gasket's supplier.

2.2 Different types of flanged joints in piping and vessel systems

According to BS 5480, two categories of pipe joints are defined, namely, rigid joints and flexible joints. Rigid joints are defined as joints, which do not allow any angular deflection and can resist axial loads. These types of joints include flanged joints, butt joints, cement socket and spigot joints, threaded joints, etc. Flexible joints are defined as joints capable of allowing relative movement between the components parts. They include joints such as socket and spigot joints with elastomeric sealing elements, flexible locked sockets and spigot joints, clamped joints, etc.

Flanged joints can be classified either in terms of their function or in terms of their type. BS 6464, as mentioned in section 26.4.4 [3], classifies flanges according to their types (Figures 2.1 to 2.4):

- Type A: Stub flange with backing ring.
- Type B: Full faced flange with or without thermoplastics liner.
- Type C: Full faced flange with or without thermoplastics liner with backing ring.

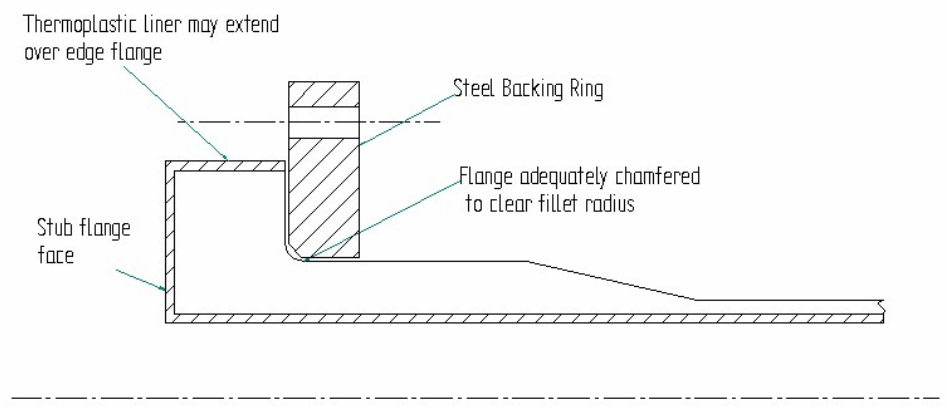


Figure 2.1: Lined stub flange

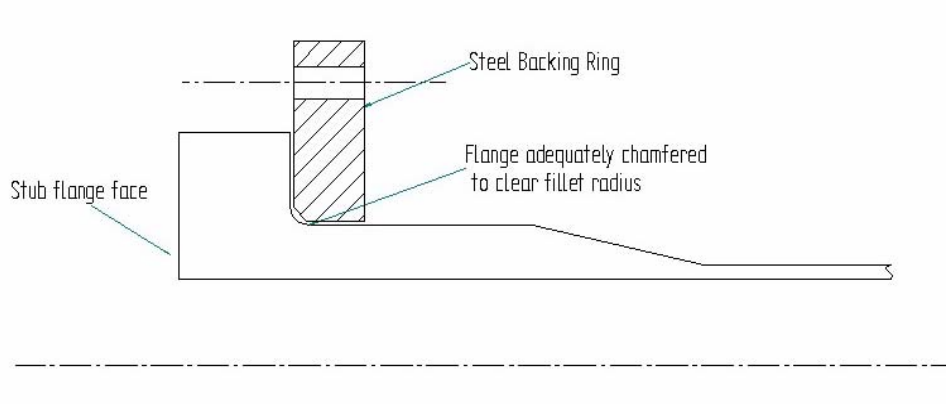


Figure 2.2: Unlined stub flange

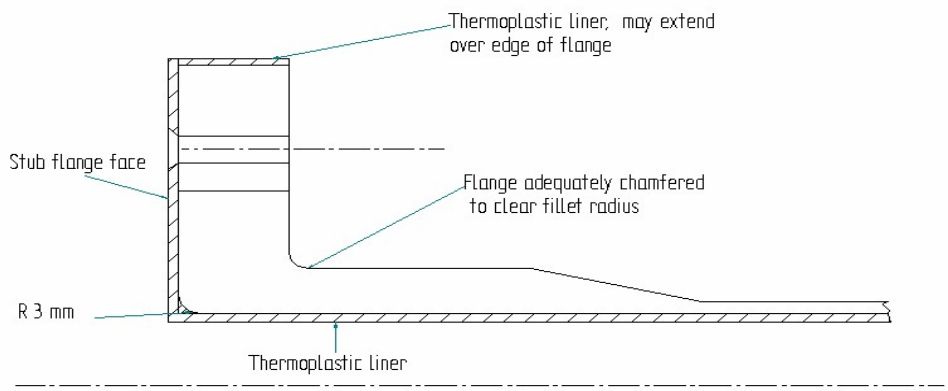


Figure 2.3: Full faced flange with thermoplastics liner (Type B)

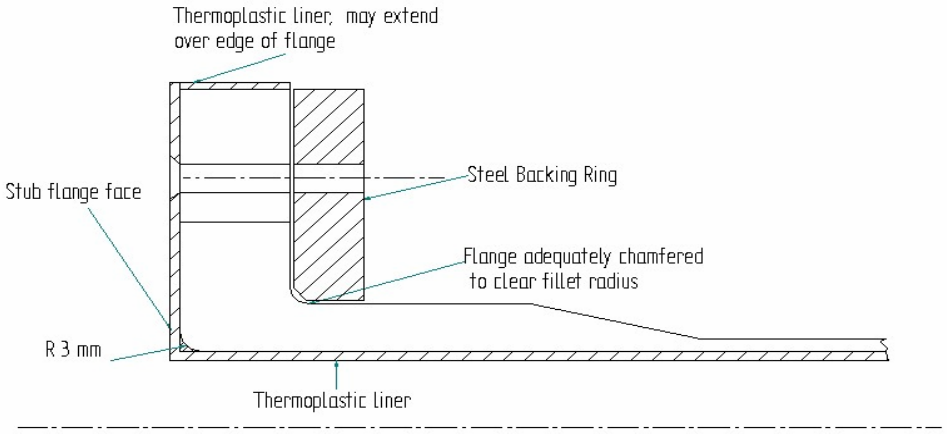


Figure 2.4: Full faced flange with thermoplastics liner and backing ring (Type C)

According to section 18.6 of BS 4994, bolted flanges in vessel systems are classified in terms of the type of vessels being connected.

- Ring-supported circular blind flanges. These flanges are suitable for both pressure and vacuum vessels (Figure 13 within section three of BS 4994).
- Fully supported blind flanges: They are suitable only for pressure vessels (see figure 14 within section three of BS 4994)

2.3 Functions of rigid flanges in piping systems

In practice, a gasketed stub flange joint must be able to perform the function of a joint and to satisfy the desired requirements of the user. For this, it must be able to:

- hold the joint elements together with no relative motion and maintain the seal in service;
- resist external forces tending to distort the joint or joint components;
- resist corrosion due to the internal or external environment;
- resist the thermal effects and to accommodate thermal expansion or contraction.

2.4 Manufacturing processes for pipe flanges

The choice of manufacturing procedure for pipe joints depends on various factors, including the size of the joint, the type of joint (stub flange, full-face flange) and the type of materials (resins and fibres). The manufacturing procedure can be one of two different techniques, namely, spray up and hand lay-up methods. The flanges evaluated in this project were fabricated using the hand lay-up technique.

The hand lay-up technique

Different types of reinforcement, such as chopped strand mat or woven roving, are impregnated with a conditioned resin and applied by hand into a mould, as specified during the design stage. Specific tools (rollers and brushes) are then used to compact and to consolidate the resin and the glass so that entrapped gases can be removed and a uniform distribution of materials achieved within the flange structure. This process must be done carefully to avoid excessive breakage and random distribution of fibres

especially at the flange radius. The flange is than cured and post-cured following the recommendations specified by the resin's supplier. Finally, the stub flange is machined to get the required shape and size. All surfaces machined are covered with an appropriate resin to ensure a complete external corrosion barrier covers the structure.

Often when repair activities are conducted in the field, GRP flanges are fabricated separately and then bonded to the pipe. The bonding of the flange to the pipe may be achieved in different ways, such as:

- The flange is built onto an existing piece of pipe prepared for the purpose. After completion, the fabricated joint is connected to the main pipe by mean of a butt weld. The butt welds are often composed of woven roving and chopped strand mat reinforcements.
- The flange is built up directly in the mould. After completion, the flange is connected to the end of the pipe by means of a butt weld [(3)]

2.5 Pressure tests of GRP pipe joints

Pressure tests are frequently performed by the piping system industry for integrity assessment of pipes and associated fittings during the design and production stage, as well as after maintenance and repair activities. Depending on the kind of test medium, two types of pressure test can be done; the hydrostatic and the pneumatic pressure test.

- **Hydrostatic pressure test**

  As its name implies, tap water is used as the test medium. Water is pumped up to a prescribed pressure in excess of the maximum operating pressure of the system being tested, and held for an extended period of time. If failure occurs, the type of failure and the pressure at which the failure occurs is recorded. The hydrostatic pressure test is also used to test vessels and tanks.

- **Pneumatic pressure test**

  Pneumatic pressure testing of piping systems refers to the use of air or inert gas (such as nitrogen and helium) as a test medium. However, the principal remains similar to that of the hydrostatic pressure test. This type of test is preferably used for leakage assessment of joints and fittings intended for gas transportation. However, the test needs extreme caution due to the stored energy of the compressed gas used as the test medium.

The pressure test can be a simple hydrostatic pressure test where constant pressure load is applied to evaluate strength or to investigate failure modes of the pipe joints, or a more complex test that necessitates a combination of pressure and external loading. BS 5480: 1990 specifies such a test, since in practice joints can be subjected to a combination of bending and internal pressure.

2.6 Strain and Stress measurement techniques

2.6.1 Measurement techniques

For the measurement of strain, an appropriate technique needs to be chosen. Factors to be considered are:

- type, size and nature of the structure being tested and analyzed;
- type of strains and stresses which are to be measured;
- expected strain and stress magnitudes to be measured;
- environmental constraints such as moisture content and test room temperature.

The principals of some techniques commonly used in strain measurement, including the ultrasonic method, inductance strain gauges, mechanical strain gauges and electrical resistance strain gauges are presented below:

2.6.2 Mechanical gauge

The technique consists of measuring the displacement over a given gauge length. The displacement is magnified by mechanical means (often a series of lever arms), so that the recorded displacements may be displayed directly on a built-in scale by the movements of a pointer. The most common devices used are the micrometer and the dial gauge, which are capable of measuring deformations of one ten thousandth of a millimetre.

2.6.3 Inductance strain gauges

The method consists of measuring the electrical signal (output voltage) created by the variation of the inductance of a coil with a ferromagnetic core. The inductance of the coil can be varied by either the displacement of a part of the magnetic circuit or the changes in the magnetic properties of the core. Very accurate strain measurements can be easily obtained using inductance strain gauges.

2.6.4 Ultrasonic method for bolts (bolt meter)

The ultrasonic method for bolts consists of automatically measuring the elongation produced by tightening a threaded fastener. This technique is based on the fact that when a bolt is tightened, its initial length changes. Therefore, the measurement is performed by determining the change in the transit time of an ultrasonic shock wave transmitted along the length of the tightened bolt. A data logger automatically interprets the time measurement to yield the stress or elongation resulting in the bolt.

2.6.5 Electrical resistance strain gauge

Principles of the technique

The strain measurement technique is based on the principal that when a conducting wire is bonded onto a test specimen such that the change in length experienced by the specimen is transmitted to that wire, the measurement of the wire's resistance change can be used to provide an indication of the strain in the direction of the conducting wire. In practice the strain measurement is performed by bonding a connected strain gauge to the specimen for which the strain is to be determined. As the specimen

stretches or contracts due to the applied load, the strain gauge responds with a linear change in electrical resistance. A Wheatstone bridge is connected and the output voltage gives an indication of the strain experienced by the test specimen. The strain gauge is characterized by a factor named “strain sensitivity” or “gauge factor”. Generally, the manufacturer provides this factor and its value varies in range from 1.95 ± 1% to 2.05 ± 1%. The nominal resistance of common strain gauges varies from 30 to 3000Ω, with 120, 350, and 1000 Ω being the most common values.

Strain-gauge circuits

The appropriated circuit used for the measurement of small changes of resistance produced by a strain gauge is based on the simple Wheatstone bridge principle. The Wheatstone bridge is a circuit made of four resistive arms arranged in the configuration of a square (Figure 2.5). An excitation voltage is applied across the input bridge, and the resultant output voltage is measured across the other two vertices of the circuit. Depending on the operational field conditions and the type of strains to be measured, different types of Wheatstone bridge circuits (full-bridge, quarter-bridge or half-bridge) can be used.

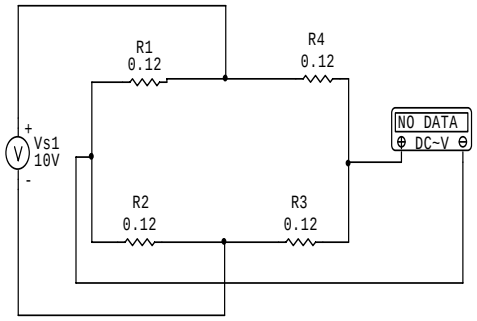


Figure 2.5: Wheatstone bridge

Note: Numerical values allocated to the different resistors in figure 2.5 are similar to those used within the circuit assembly made for the purpose of this project.

2.7 Other research on GRP pipe flanges

Because of the intended function of flanges and the complexity of fibre reinforced plastics materials, research is being focused on flanges made from GRP materials by a variety of other researchers. Generally, these investigations are intended to improve the design and the reliability of GRP flanges in service. It was found that these works are focused on different aspects of flange research, namely, reliability of a particular type of joint with respect to the manufacturing process, joint failure modes and interaction of fasteners and gasket. These are discussed below:

- A design procedure for a modified FRP stub-flange joint is discussed by Estrada, H. and Parsons, I.D [(4)]. The authors claim that most of the problems relating to fibre reinforced plastic joints (stub and full-face flanges) are principally attributed to the geometry of the structures. Analyzing these two types of joints, they found that the bolt holes of the full-face flanges present major material discontinuity issues that may detrimentally affect the integrity of the joints by generating unfavourable localized stress concentration effects. In addition, they found that the leakage performance of stub flanges is superior to that of full-face flanges because the clamping loads generated by the bolts and transferred through the backing ring and stub are distributed uniformly around the gasket. However, the authors claimed that the stub-flange could not be considered as an ideal joint because it is also subject to material discontinuity effects at the butt- weld. The stub flanges are also affected to some extent by the pull-back effects generated during the cure and post-cure stage. These pull-back effects induce overstress of the stub and therefore lead to possible cracks of the joint as the bolts are tightened. Therefore, they described a design procedure of an innovative joint that addresses all these issues. The innovative flange is a tapered filament wound construction. The authors claimed that the advantage of their innovative flange is that an integral

system is employed, since the pipe and hub can be wound simultaneously. The conical configuration allows the minimizing of pull back effects and a longer stub length can be specified to spread the bearing stresses more evenly over the stub. In addition, the flange manufacturing process is machine controlled.

- The relationship between clamping force and joint sealing for stub and full-face FRP flanged joints was studied by Godwin, E.W et al [26]. From their experimental work, the authors also reported the occurrence of the pull-back effect on the hand lay-up stub flanges. They showed that bolt loads could stay constant with increasing pressure up to a certain limit. Above that limit, the bolt loads increased until leakage occurred. They found that the normal stress of the gasket was the principle factor affecting the joint leak tightness. However, this could be improved by reducing the width of the gasket. Furthermore, they concluded that in full-face FRP flanges, exaggerated reduced gasket width induces increased bending in the flange.

- The spring back and residual stress effects associated with the cure of glass fibre reinforced plastic (GFRP) pipe flanges was studied by Whitfield, G.S [6]. The author investigated some factors relating to the manufacturing procedure and which can adversely affect the reliability of the flange in service. With regard to possible creep and unsymmetrical post cure shrinkage, the author claimed that the two causes of the experimental spring back being in disagreement with the predicted results were the creep of the resin at elevated temperature post-cure and the stage lamination effect. The author suggested some relevant recommendations that must be taken into account in the spring back study of glass fibre reinforced plastic pipe flanges during cure and post-cure.

- Matsumoto, M. et al conducted a stress finite element analysis and sealing performance evaluation in pipe flange connections [24]. The stresses arising in a full-face pipe flange connection with a gasket subjected to an internal pressure and an external bending moment were analyzed taking into account the non-linearity and hysteresis of a spiral wound gasket and a joint sheet gasket by using an elasto-plastic finite element method (FEM). Substantial difference in the gasket constants between the experimental values and the estimated values was found when an external bending moment was applied to the connection. The hub stress and variation in axial bolt force were investigated as well. The authors claimed that good agreement was found between the calculated and experimental results. The authors also demonstrated a method for determining the bolt preload in the pipe flange connection under external bending moment for a given tightness parameter.

- A study on the mechanical properties of an L-Joint made out of fibre-reinforced plastic was conducted to investigate the failure type and the different factors that affect joint failure [25]. The authors claimed that there are two customary methods of establishing a mechanical joint. The lap joint that consists of planar members joined in parallel, and the L-joint in which flanged parts are joined. The authors found that the lap joints were mainly characterized by net tension and shear whereas the L-joints were subject to two types of failure mechanisms; a failure by delamination at the part where a change in direction of the fibres occurs (R part) and a failure by cracks around the bolt holes. They concluded that the joint failure is mostly affected by the geometry of the structure, which in turn depends on the width, foot distance, end distance and laminate thickness.