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The experimental study of the strength of bonded pipeline under tension loadings

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ABSTRACT

Pipelines are the main transportation means of oil and gas. “The bonded repair technology” is a kind of pipeline repair technology when the cracks, corrosion and other forms of failures occur, because of its advantages such as good resistance to fatigue, low cost, easy to operate. In this paper, on the basis of studying previous steel and plates adhesive joints strength tests, a set of bonded pipeline repair joint experimental system was developed. In this paper, an appropriate kind of adhesive joints and surface treatment method was developed which simulated the bonded pipeline repair joint. A set of the bonded pipeline repair joint experiment system was designed and the compositions of the system including experimental preparations were explained. The stress distributions of the bonded pipeline repair were studied using the experiment systems, and then the effects of some parameters such as the thickness and length of the adhesive were discussed.

Key Words: experimental system; adhesive joint; stress distributions

1 Introduction

With the steel tube is more and more widely used in ocean oil exploitation, the steel pipe connection engineering increasing, at the meantime, steel construction and maintenance, and repair engineering is also raised. At present, the priority steel pipe connection method is welding, however, if we use “The bonded repair technology” to repair and connect the pipe, it will reduce the cost, simplify process and improve production efficiency. Hence, the bonded repair technology has good prospective development.

At the same time, the experimental study of bonded repair technology has large practical application value. Compared with the weld connection, it has the unique and

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can't replace advantages. Its advantage is mainly manifested in the following aspects:
1）Bonded connections can make the best use of the strength of the adhesive material
2）Bonded connections can improve the fatigue life of joint
3）Bonded component can effectively reduce the weight of the joint
4）Bonded connection joint can be used according to requirements, it can select the appropriate binder, endowed with binding knot with specific function.
5）The applicability of cementing material is wide, it can be used for the connection between metallic or materials and non-metallic or materials.
6）The resistance of bonded joint in environment is strong
7）Bonded process is simple and low proficiency requirements for operation, at the same time, it is easy to automatic product and the quantity of high production efficiency, low cost.

In the related study of pipe connection, foreign countries have started early and rapidly.(Volkersen 1965) first studied the torsional stress problem of pipe joint, the tube of two pipe jointed synechia through mechanics method processing, and the circumferential shear stress was ingorned, the adhesive layer could be regarded as a kind of "shear spring". Then (Volkersen, Adams and Peppiatt1977） improved Volkersen's conclusion though the study of the thickness of adhesive layer. Roberts concluded in the 1989: Adhesive layer of the peel and shear stress could be reduced by changing the pipe load and the joint geometry edge materials. (Chen and Cheng 1992) discussed the stress distributions about the bond pipe under the action of torsional force though the basis study of the variational principle of complementary energy method.

The above research model only considered isotropic material tube. (Chon 1982) used the two-dimensional coupling polarization theory to analyze the pipe joint, in which the unknown parameters related with the composite material layer; The more layer number, the more unknown parameters. (Graves and Adams 1981) used the finite element analysis to the bond consequence of steel pipe and multiple tube. Yang, respectively, in 2000, in 2002 (and others) used one-dimensional model to simulate the composite pipe joint response under the tensile load, though two-dimensional orthogonal theory to analyze the multiple pipe joint's performance under the bending load.

Some experiments of adhesive bond joint pipe are studied, the domestic research on this aspect is not thorough. For the form of bond, there is no experimental study of the steel pipe that bonded with the adhesive and the reinforcing layers. In this paper, the specimens used in the experiment are made by the epoxy resin and glass cloth, incorporated various design and material parameters including. The strength and mechanical properties of bonded pipeline will be tested and verified with the study.

2 Experimental program

2.1 Fabrication

The bonding process will typically require several operations, including surface roughening, degreasing, marking, adhesive application, positioning and clamping, and finally curing. The bonding surfaces of the steel components were prepared by grit blasting or heavy abrasion by silicon carbide/emery paper. Typically an average roughness of 5 μm would give a good adhesion. All bonding surfaces were cleaned using a cleaning and degreasing agent. Some special measures should be used because of the bonding process of the two round steel pipe. One of the measures would be used to ensure the two different steel pipes are concentric. PPR plastic pipe can be solved it. A section of PPR plastic pipe that the diameter is 25mm would be put into the steel pipe. Since the equal of the outer diameter of the plastic pipe and the inner diameter of the steel pipe, it was concentric that the two steel pipes are. After the adhesive cured, the plastic pipe should be taken it out. Another measures would be used to protect the pipe from fracturing at the point of the clamps. Steel columns could be filled in the pipes at the ends of the pipes where contact with clamps. Markings were put on the steel bars and straps to ensure correct fit-up of the joint when being bonded.

The adhesive used was LOCTITE E -30CL, a two-part toughened epoxy adhesive which was mixed and applied by spatula in two stages. The first stage was to prime the surfaces with a thin layer of adhesive. The second stage was to apply more adhesive and spread the excess amount. Then, the joint was closed so that the entire bondline was filled with adhesive. Finally, glass cloth was wrapped around the joint as shown in Fig.1. Each layer of glass cloth was filled with adhesive. The curing of the adhesive joints was done for 4 hours at 25℃.This may also be warm-cured at much higher temperatures, for shorter periods. Finally, any excess adhesive from the joint was mechanically removed so that there were no effective adhesive fillets within the double lap joint. It was assumed that this would reduce variability and make modelling of the specimen configurations easier.

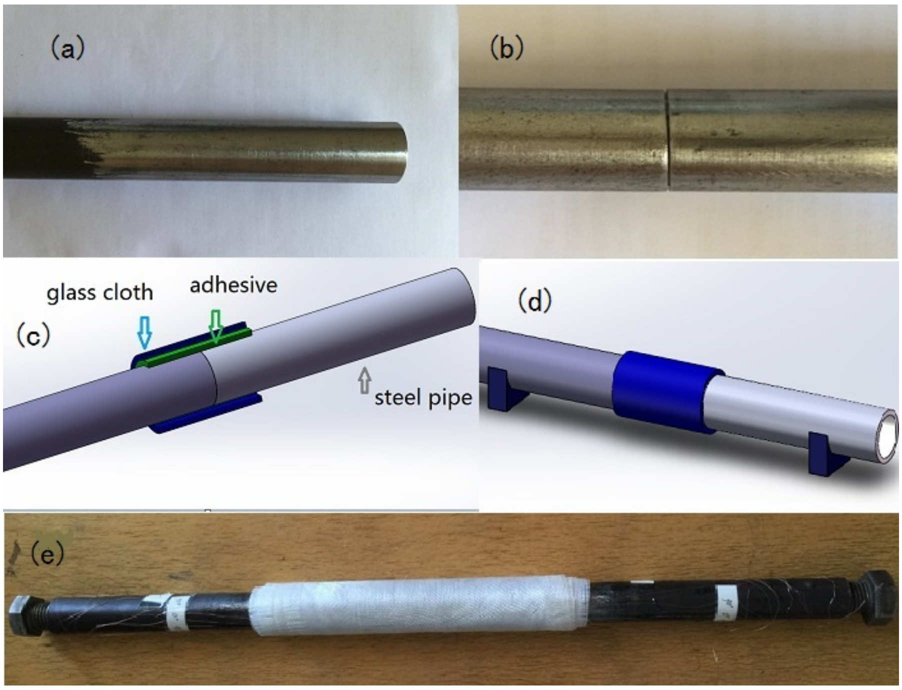

Fig.1 Aspects of the adhesive bonding processes: (a)surface preparation,(b) protecting ends,(c)adhesive application and (d)clamping and curing (e) The bonded specimen.

The bonded specimens, all 500 mm length(composed by two 250mm steels), incorporated various design and material parameters including overlap length ranging about 200 mm as well as various material combinations. Over 20 specimens were fabricated, designated and tested at the institution.

2.2 Mechanical testing

The bonded specimens were then tested to destruction under monotonic loading on manual hydraulic universal testing machine at ambient temperature. Besides failure loads, both strain and displacement values were recorded. In Fig.2 it shows the test arrangement including positions of the strain gauges. There are three gauges at 0mm, so and 25mm, 50mm, 75mm. Fig.3 shows Tthe force–strain is illustrated in Fig.3 and Fig.4 shows the load–normal/shear stress curves are showed in Fig.4. The curve in Fig.4 is calculated by the normal stress Eq. (1) and the shear stress Eq. (2). The material properties used for the analysis are based on the values from Table.1.

$$\delta = E \bullet \varepsilon_0 \tag{1}$$

$$\tau = E \bullet (\varepsilon_0 + \varepsilon_{45} + \varepsilon_{90}) / 2(1+\mu) \tag{2}$$

Table.1 Material properties

Property	Units	Epoxy resin	Glass cloth	API 5L X65 steel
Young's modulus	Gpa	1	76	200
Poisson's ratio		0.38	0.21	0.3
Tensile strength	Mpa	55	310	535
Shear Strength	Mpa	29	-	-

Twelve strain gauges were mounted to the outer adherends in identical position to assess the level of strain(load). However, not all the specimens were instrumented for strain and displacement measurements but failure loads were recorded. From the test results, the following remarks may be made:

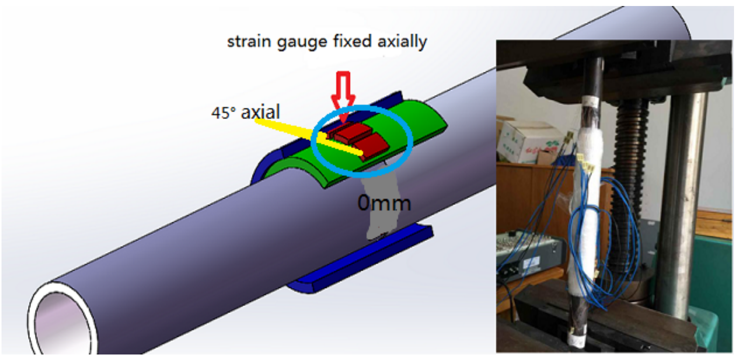

Fig.2 Test set-up and typical

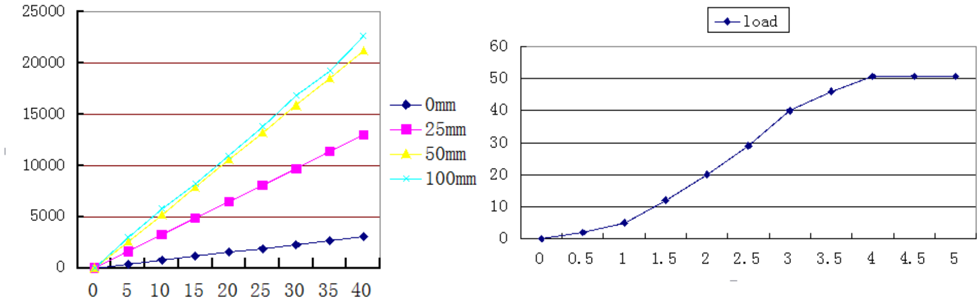

Fig.3 Load–strain and thickness-load

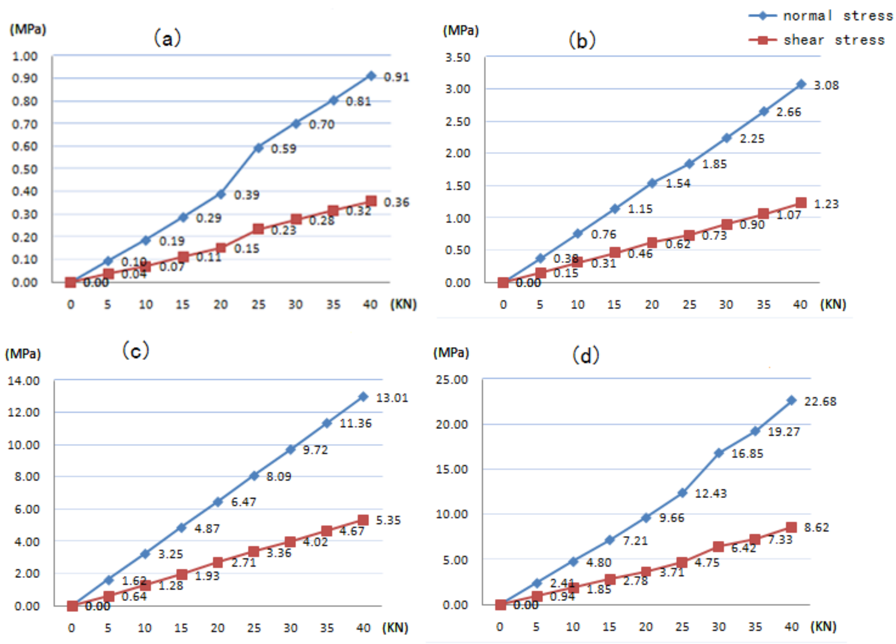

Fig.4 Load–normal/shear stress

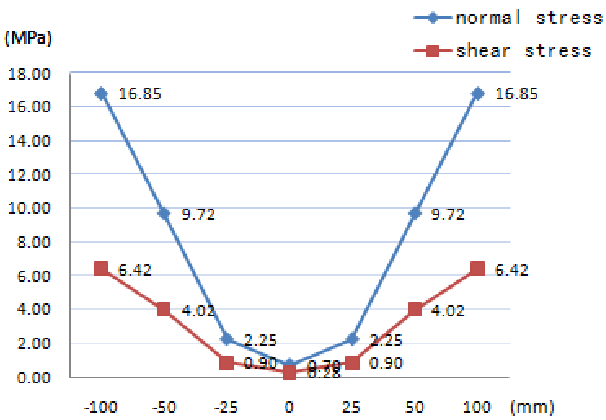

Fig.5 Location–normal/shear stress

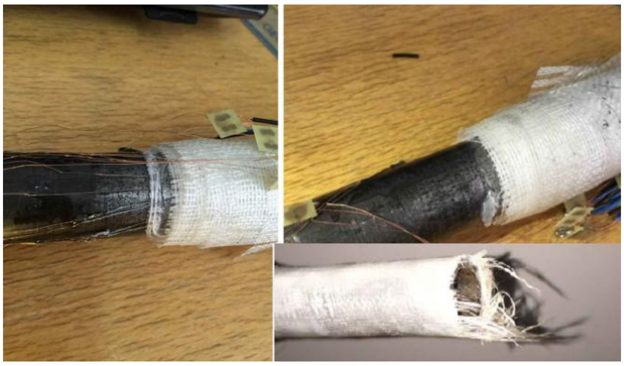

Fig.6 Failure surfaces and failure modes

- Some displacement values are based on strain gauges of various testing machines used in this study. The strain measurements are more reliable.
- The figure indicates that the failure load of specimens is proportional to the thickness of adhesive and up to about 5 mm, where a plateau is reached. An approximate line is plotted.
- The figure indicates that the strains in different locations are different and the strains in the center of the joints are minimum, the strains in the edge of the joints are maximum.
- With the loading, “bangbang” can be hear. It indicates that some cracks must be appeared in the adhesive with the load increasing.
- The plastic deformation occurred before the failure of the adhesive within such joints, the Elastic Modulus of the adhesive increased after plastic deformation.

Investigation of the fractured surfaces and joints, suggests that steel pipe is failing nearer the interface between the surface ply and resin and the adhesive bondline. This is perhaps due to resin or adhesive failure starting at the middle of the joint. It is also possible that tensile failure of the laminate has occurred. The joint shows signs of failure at the adhesive, but only after the shear stress greater than the adhesive force. Fig.6 shows typical failure surfaces and failure modes.

3 Discussion

The standard fabrication method used in this study can be adopted for practical application for marine structures. The quasi-static test results suggest that the bonding process is robust, at least for the short-term strength. Some joints, especially with thicker reinforcing layers, showed satisfactory performances in the tension testing. It indicates that the fabrication method can be used for some applications that they have the challenges of tension loadings only. There are several successor tasks about the experimental study of the strength of bonded pipeline repair. 1)The strength of bonded pipeline repair under torsion loadings and bending moments. 2)The strength of bonded pipeline repair under alternating loadings.

The failure processes with the increasing loading should be studied more and more, especially the cracks in the adhesives. In this testing, cracks initiation in the specimens starts from the outer edges of the joints. However, failure starts at the center of the joints, at the interface between the adhesive and steel. This phenomenon is due to that the largest stress will be at the center of the joints. About the cracks, an assumption can be presented. If there is a small crack in the joint, perhaps appeared during the fabrication or occur by hitting, what will be happened in the tension testing and how the crack will extend.

It shows that the thickness of adhesives and reinforcing layers is important for the strength of the joints in Figure3. The material of the reinforcing layers should be studied by a large number of testing. Besides glass cloth, polymer blend or polyester fiber maybe behave well. The bonding method of the reinforcing layer and the adhesive will change with the different material of the reinforcing layers.

4 Conclusions

The main conclusions of this study are as follows:

1) The standard fabrication method used in this study can be adopted for practical applications, and the limited test results from fabricated specimens suggest that the bonding process is robust. However, this requires further test results to satisfy the statistical aspects.

2) When the thickness of adhesive in these specimens can be up to 5mm, the joints have the maximum tensile strength. It indicates that the strength of the adhesive with glass cloth will become maximum with this thickness.

3) The results from the mechanical testing confirm that failure starts at the center of the joints, at the interface between the adhesive and steel. Failure initiation in the joints starts from the outer edges of the joints. And failure of the adhesive within such joints would have to account for non-linear inelastic adhesive behavior, in a fracture mechanics context.

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