Finite Element Analysis of Bonded Steel Pipeline

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الخلاصة

تم إجراء تحليل إجهاد ثلاثي الأبعاد على وصلات لاصقة لإصلاح خطوط الأنابيب، وفي التحيل تم الاخذ في الاعتبار تأثير ظروف الضغط الداخلي، والتي غالبًا ما يتم مواجهتها أثناء تدفق السوائل المختلفة. الحلقة الأضعف في النظام هي عادةً الوصلات. في هذه الدراسة تم فحص أحد سيناريوهات التحميل الأكثر شيوعًا في أنظمة الأنابيب، الضغط الداخلي والشد فيما يتعلق باستجابة تصميمات الوصلات المختلفة.

النمذجة والمحاكاة اعتمدت على طريقة العناصر المحدودة التي تم إنشاؤها في هذا العمل قادرة على إجراء فحص شامل للضغوط ثلاثية الأبعاد بالإضافة إلى تحليل كسر المفصل المترابط، حيث تم استخدام برنامج يسمى ABAOUS لإنشاء النموذج العددي. وكذلك إيجاد تمركز الاجهادات كدالة في طول الوصلة اللاصقة حول المفاصل.

Abstract

A three-dimensional stress analysis was performed on bonded pipeline repair joints for the current investigation. The present analysis has taken into account the influence of internal pressure circumstances, which are most frequently encountered during the flow of various fluids. The system's weakest link is typically its joints. In this study, one of the most frequent loading scenarios in piping systems internal pressure and tension is examined in relation to the response of various joint designs. The modeling and simulation approaches based on the finite element method that were created in this work are capable of carrying out a thorough examination of the three-dimensional stresses as well as a fracture analysis of the bonded joint. Software called ABAOUS was used to generate the numerical model. The stress concentrations as a function of different overlap lengths at and around the joints.

Key words: Pipe, Tubular socket joint, Araldite 2015, Finite element analysis, ABAQUS.

Introduction

Oil and gas are primarily transported through pipelines. Because of its benefits, including good fatigue resistance, cheap cost, and ease of usage, the bonded repair technique is one type of pipeline repair technology used when cracks, corrosion, and other types of failures occur. Yet, the capacity of pipe joints is typically what limits the total system's performance. With the improvement of adhesive materials and techniques in adhesive bonding in the past decades, a number of adhesively bonded joint structures have been increasingly applied in engineering constructions, such as the single lap shear joint, single strap joint, double lap shear joint and pipe (tubular) joints in, automotive, aeronautics, civil engineering structures etc. As a result, the pipe joints are crucial to the overall integrity of the majority of piping systems [1,2]. Tension loading is one of the basic loading types among all conceivable loading configurations. Lin-song Song et. al. [3] used the experiment system to studied the stress distributions of the bonded pipeline repair under the action of tension load, and then the effects of some parameters such as the thickness and length of the adhesive were discussed. There aren't many theoretical studies in the literature since it's difficult to analyses interfacial behavior. Moreover, the elastic region of interfacial behavior was the focus of all previous analytical studies. The finite element modelling and simulation technique developed for the bonded TSJ, analytical results by Zou and Taheri [4]. The adhesive shear and normal stresses were studied using the conventional thin-shell theory by Lubkin and Reissner [5], who also took Poisson's effect into account. An explicit closed-form solution based on the Lubkin and Reissner model was achieved using the Laplace transform [6,7]. Shi and Cheng [8] arrive at closed-form solutions using the notion of minimal complementary energy. To forecast the severity and distributions of stresses, Nemes et al. [9,10] introduced σ_{rr} and σ_{zz} into the potential energy formulation to predict the intensity and the distributions of stresses. Yang [11] created an analytical model based on the first-order laminated anisotropic plate theory to comprehend the mechanical behavior. Distributions of adhesive peel stress and shear stress are found. Pugno and Carpinteri [12] concentrated on the joint's static and dynamic characteristics. For standard and optimized joints, a fracture energy criterion to forecast brittle crack propagation was provided. Yet, many adhesives display nonlinear stress-strain behavior, especially close to failure. An investigation of an adhesive tubular lap junction that adheres to a nonlinear stress-strain law was published by Nagaraja and Alwar [13]. Hossein and Ochsner [14] used a finite element mesh in two dimensions to model the cross section. A two-dimensional (2-D) stress analysis of adhesively bonded DLJs subjected to combined thermal loadings through a thermal stress analysis conducted by the finite element software ABAQUS [15]. Those studies already found the stress fields produced in the adhesive layer and on the interfacial surfaces [16,17]. Three-dimensional stress studies have been performed [18–20] based on the Tsai-Wu coupled stress criterion. In their study of the axial strength and fatigue resistance of tubular lap joints, Reedy and Guess [21] used a linear elastic fracture mechanics approach. In the initial analysis of stress concentrations, Cognard et al. [22] used revised finite element calculations with a linear elastic assumption. In order to predict the strength, Oliveira et. al. [23] used the Finite Element Method (FEM) with Cohesive Zone Models. Among the numerical methods, finite element method has been extensively used with success and countless studies on various adhesively bonded joints via this technique were performed by many authors [14,18,22,24]. Effect of internal pressure and axial loading situations which are most usually practiced during flow of various fluids. The primary factor in the failure process is interface slip, which is challenging to evaluate in an experiment.

Specimen geometry, boundary and materials

The work of Esmaeel and Taheri [1] was used to determine the geometry, configuration, loading, and boundary conditions of the bonded Tubular Socket Joint (TSJ) specimen, which are depicted in Figure 1. Adherends include two steel tubes. According to the measurements in Table 1, both adherends are equal in length and thickness.

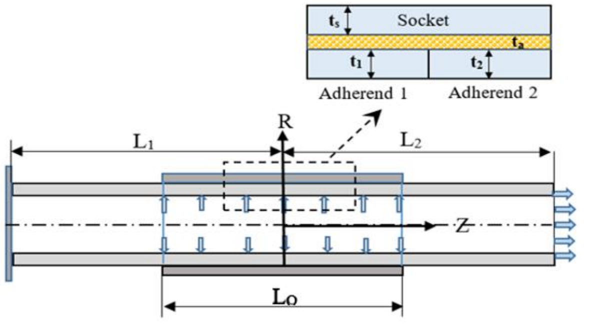

Figure 1. Specimen geometry and boundary conditions of the bonded socket joint.

Table.1 Specimen geometry

Geometry	Parameter	Magnitude
Adherend lengths	**L_1 (Inner adherend 1) =L_2 (Inner adherend 2)**	**100 mm**
Overlap (Outer adherend) Socket length	**L_o (Overlap) L_s (Socket length)**	**40 to 100 mm 40, 60 ,80 and 100 mm**
Adherend /Socket thickness	**t_1 (Inner adherend 1) =t_2 (Inner adherend 2) t_s Socket (Outter adherend)**	**4 mm 4 mm**
Adhesive thickness	**t_a**	**0.5 mm**
Outer radius of adherend / Socket	**R_1 (Inner adherend1) =R_2 (Inner adherend2) R_s Socket (Outter adherend)**	**15 mm 19.5 mm**

In Table 2, material characteristics as well as adhesive and adherend strength values are listed. According to Figure 1, a thin layer of epoxy adhesive (Araldite 2015) has been used to join the two tubes. Both an axial pressure of 10 MPa at the free edge and an internal pressure of 10 MPa at the joint region have been applied to the bonded TSJ. The present research has taken into account a zero gap in accordance with the findings of Das and Pradhan [2]. For improved performance of the bonded TSJ under the impact of axial and circumferential pressure loading, overlap length/socket length

(L_0) and adhesive thickness (t_a) have been considered as the joint characteristics that need to be tuned. The overlap length/socket length (L_0) has been adjusted from 40 mm to 100 mm in an effort to find the joint characteristics that are optimal. Further consideration has been given to an adhesive thickness of 0.5 mm.

Table.2 Material properties

Property	Glass cloth	steel	Epoxy Adhesive (Araldite 2015)
Young's Modulus (GPa)	76	200	2
Poisson's Ratio	0.21	0.3	0.36
Tensile Strength (MPa)	310	535	40
Shear Strength (MPa)			26

Finite element analysis (FEA)

A numerical model was implemented and developed using the commercial software ABAQUS. The objective of FEA is to develop a model that could accurately predict the experimental results and present a detailed stress distribution and failure evolution analysis of the bonded TSJ. Figure 2 illustrates the bonded TSJ specimen's FEA mesh. For modeling the steel adherends/socket and the epoxy adhesive layer, the ABAQUS FEA package's SOLID BRICK 8-node was utilized. The benefit of replicating both structural and layered aspects is offered by these elements. To deal with significant stress gradients at the free edges of the joint, a very thin mesh has been used. However, a somewhat coarse mesh has been used for the section of the tubular adherends that lies outside the overlap zone. The meshing pattern has been made somewhat finer near the joint and course toward the free and fixed edges for better outcomes, as already shown in Figure 2.

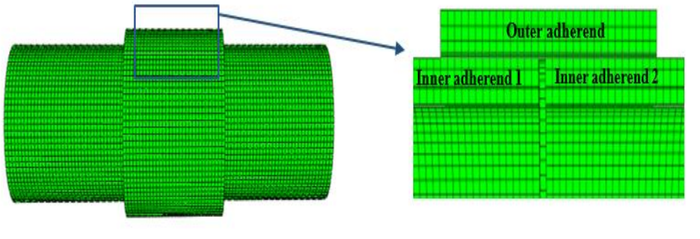

Fig. 2. Finite Element Mesh of the bonded Tubular Socket Joint.

Results and discussion

According to the current analysis, adhesion and cohesion failures are mostly caused by tensile, peel, and shear stresses (σ_z, σ_r, τ_{zr}) (Das and Pradhan [2]). Therefore, only these stresses have been taken into account at all bondline contacts throughout the joint region's stress analysis. The essential bondline contact has been found based on the highest magnitude of stress concentration effects at distinct bondline interfaces. As it has been established that three-dimensional stresses have a symmetrical nature, two-dimensional stress profiles with nodes at Z = -50 mm to + 50 mm have been taken into consideration.

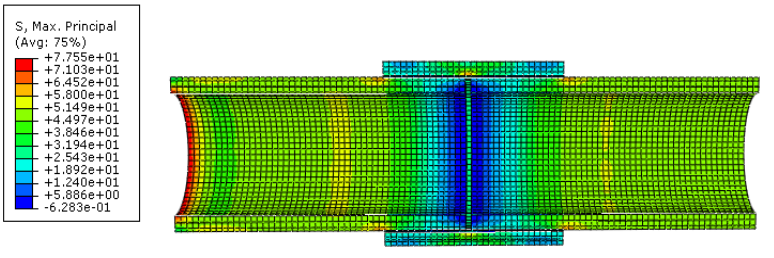

Figure 3. Max. Principal stress contour plot of the TSJ at the cohesive failure point with adhesive thickness

Maximum Principal stress distribution of the TSJ is plotted in Figure 3. The stress states of the printed adherends immediately before cohesive collapse. The graph also reveals that the maximum stress level at the TSJ with adhesive thickness. Understanding how stresses vary along the length of the adhesive bond is crucial because it helps to maintain the overall stiffness and integrity of the TSJ structure. Stress distribution in the adhesive layer.

In designing adhesive joints, three significant stress components are taken into account: Tensile stress σ_z, peel stress, which runs along the thickness of the adhesive layer (component σ_r in the current model), and transverse shear component (τ_{zr}) which are depicted in Figure 4.

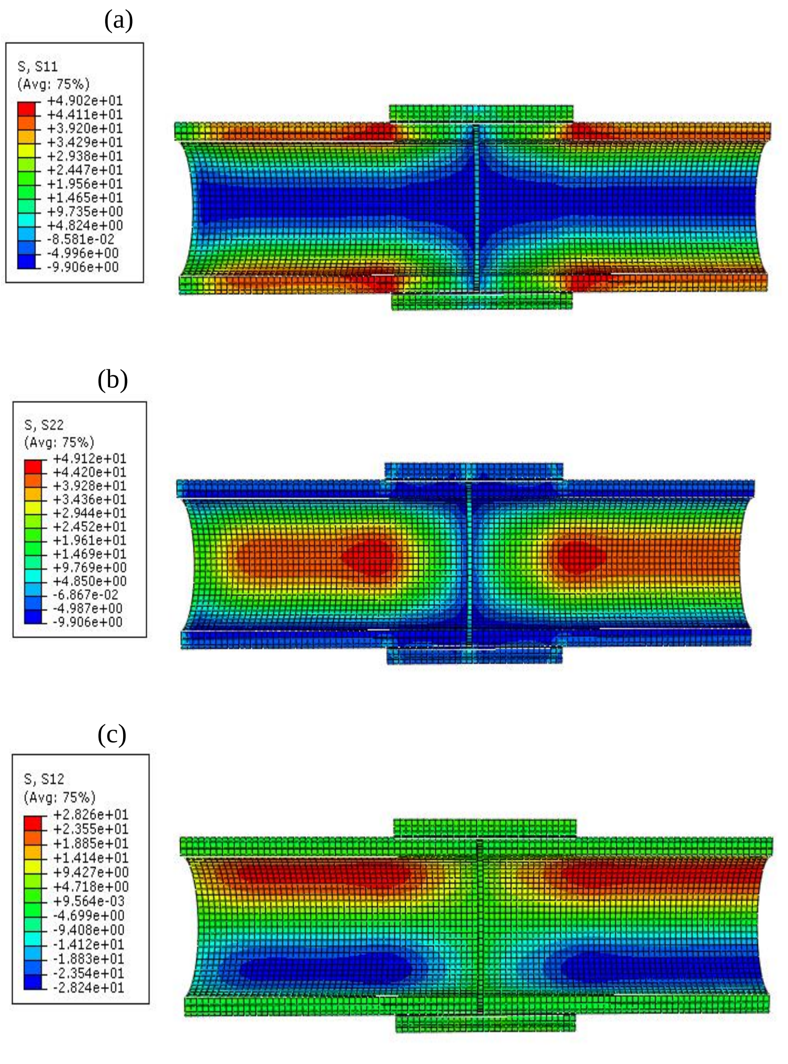

Figure 4. Stress contour plot of model with 20 mm Overlap; (a) Tensile Stress ($S_{11}= \sigma_z$), (b) Peel Stress ($S_{22}= \sigma_r$), and (c) Shear Stress ($S_{12}= \tau_{zr}$).

A. Stress analysis in the joint

Tensile stress (σ_z) variations in all the bondline interface (Figure 5 (a)) have been observed to be symmetric about the mid-plane of overlap/outer adherend length (Lo =40mm).

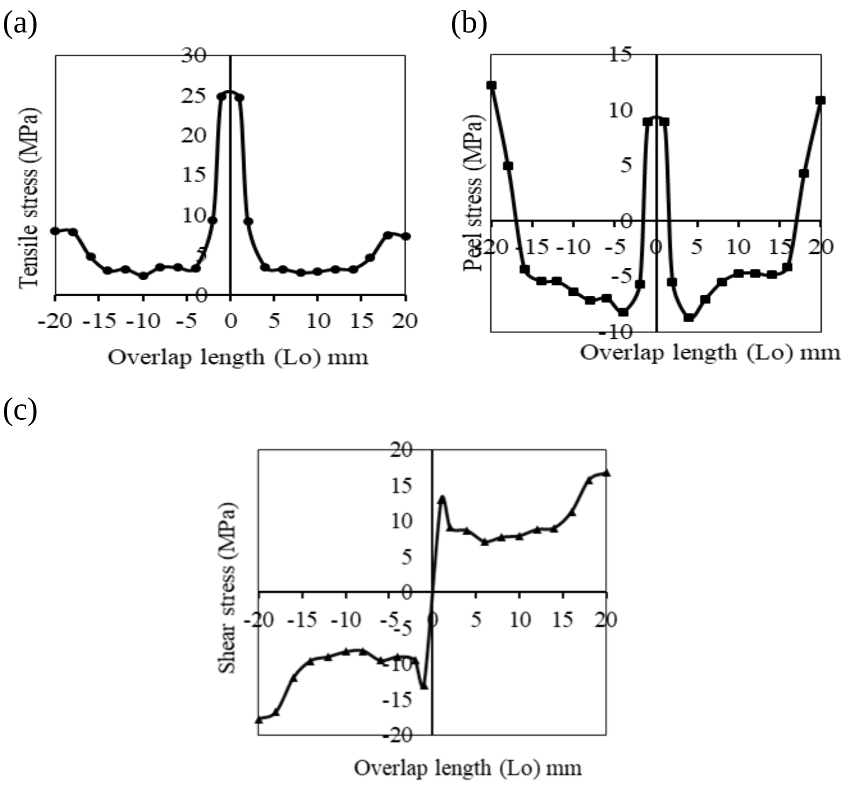

Figure 5. Stress distributions at bondline interface of model with 20 mm Overlap; (a) Tensile Stress, (b) Peel Stress, and (c) Shear Stress.

Tensile stresses have been observed to be concentrated near the adherend junction and free edges of the overlap length. It has been reducing drastically and remains constant over most of the portions of the overlap region.

Peel stress (σ_r) variations in all the bondline interface (Figure 5 (b)) have been observed to be symmetric about the mid-plane of overlap/outer adherend length (L_o =40mm). Peel stresses have been observed to be concentrated near the adherend junction and free edges of the overlap length. It has been reducing drastically and remains constant over most of the portions of the overlap region.

The axial-radial shear stress (τ_{zr}) has been observed to be concentrated near the adherend junction and free edges of the overlap length (Figure 5 (c)). It has been reducing drastically and remains constant over most of the portions of the overlap region.

B. Effect of Overlap length

Four values of the overlap length/socket length (Lo) 40mm, 60mm, 80mm, and 100mm will be used to represent adhesively bonding connections with the socket acting as the outer adherend. There was a 0.5mm thick adhesive layer on each model. The boundary conditions for each model under investigation were the same. Figure 2 illustrates how each model uses the same underlying mesh. Figure 6 shows all four models with contain the largest peak tensile stress values. The critical bondline interface having stress concentration regions at the adherend junction of the bonded joints

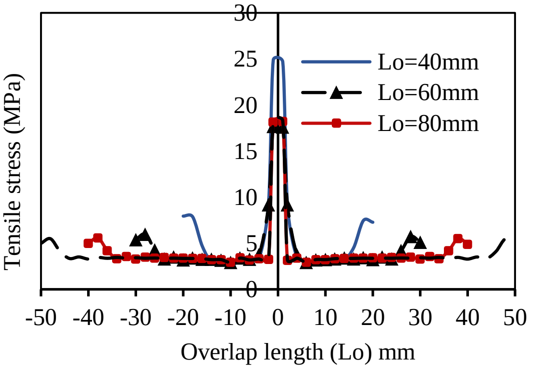

Figure 6: Shear stress distributions with various overlap lengths

The peel stress distributions in the adhesive layer for different overlap lengths are presented in Figure 7.

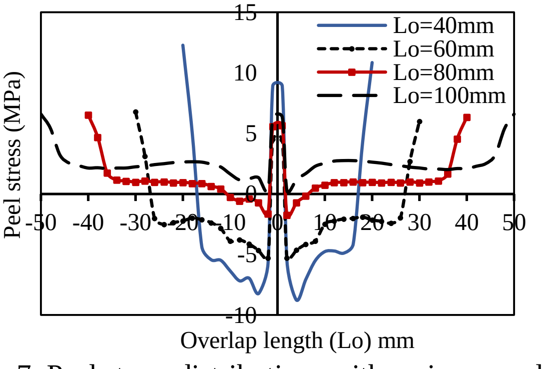

Figure 7: Peel stress distributions with various overlap lengths

The stress peaks located on the free edge of the overlap region. However, the critical bondline interface having stress concentration regions at the adherend junction of the bonded joints. The four models with the highest peak shear stress values are shown in Figure 8. At the end of the joint overlap, the adhesive layer has a shear stress value. These findings lead to the conclusion that the adhesive appears to reach plasticity at its highest shear stress. For all models, the plastic zone length is the same. Four alternative lap lengths Lo = 40 mm, 60 mm, 80 mm, and 100 mm were studied in the examination of joints.

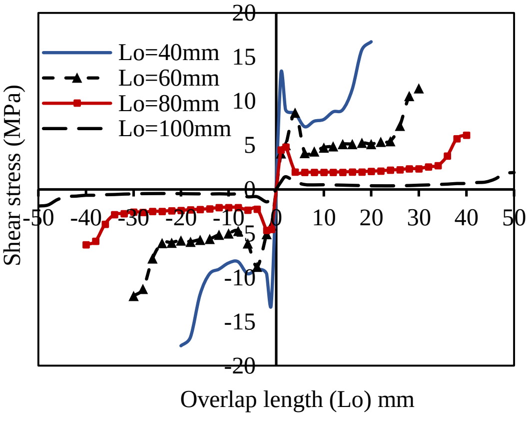

Figure 8: Shear stress distributions with various overlap lengths

The results show that although the shear stress at the mid-plane of the adhesive layer remains constant for the majority of the lap length, the rate of change of the stress nevertheless fluctuates as the adhesive length changes, and the maximum stress decreases as the length of the adhesive increases.

Summary and conclusions

The finite element method was used to study a joined component consisting of two steel pipes joined by a TSJ and subjected to internal pressure and axial tensile loads. Analysis of 3D stress profiles within the connection area can be well handled by the ABAQUS FEA package. Based on stress studies, it was found that the significant bondline contact was within the bond area. Here are the main conclusions:

- Adhesive mid-layer has been identified to be the critical bondline interface having stress concentration regions at the adherend junction of the bonded TSJ.
- The adhesive plastic shear zone at failure remains the same length when increasing the overlap length of the TS Joint.
- The shear stress at the mid-plane of the adhesive layer remains constant for the majority of the lap length.

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