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Research Article

Development of Model for Creep Relaxation of Soft Gaskets in Bolted Joints at Room Temperature

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Abstract

A mathematical model is proposed for predicting the residual clamp load during creep and/or relaxation in gasketed joints. An experimental procedure is developed to verify the proposed model for predicting the gasket relaxation under a constant compression, gasket creep under a constant stress, and gasket creep relaxation. To study gasket creep relaxation, a single-bolt joint is used. The bolt is tightened to a target preload and the clamp load decay due to gasket creep relaxation is observed over time under various preload levels. Experimental and analytical results are presented and discussed. The proposed model provides an accurate prediction of the residual clamp load as a function of time, gasket material, and geometric properties of the gasket. A closed form solution is formulated to determine the initial clamp load level necessary to provide the desired level of a steady state residual clamp load in the joint, by taking the gasket creep relaxation into account.

Keywords: *Bolted Joint, Gasket, Creep, Clamp Load Relaxation*

Introduction

For years, many different types of gasket have been used to seal bolted connections. A gasket is a compressible material, or a combination of materials, which when clamped between two stationary members prevents the passage of the media across those members. The gasket material selected must be capable of sealing mating surfaces, resistant to the medium being sealed, and able to withstand the application temperatures and pressures. *A device for sealing two surfaces, by storing energy between them*. Thus the gasket has to react to the forces generated by the bolts, and therefore the work and energy imparted to the bolted joint becomes „stored" within the gasket itself. A gasket performs the basic function of keeping the process fluid where it belongs. It acts as a retaining seal between rigid stationary surfaces. The gasket will stay seated when the friction, relative to the sealing surface, is large enough to overcome the pressure exerted on it from the process fluid. Because gasket material is normally softer than the parts it is sealing, the gasket will, to some extent, flow into the irregularities in the joint faces to close off any leakage pathways.

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Considerations for Gasket Selections

Many factors should be considered when selecting a gasket to ensure its suitability for the intended application. Gasket properties as well as flange configuration and application details are part of the selection process. Gaskets can be classified into three categories: soft cut, semi-metallic and metallic types. The physical properties and performance of a gasket will vary extensively, depending on the type of gasket selected and the materials from which it is manufactured. Physical properties are important factors when considering gasket design and the primary selection of a gasket type is based on the following:

- Temperature of the media to be contained
- Pressure of the media to be contained
- Corrosive nature of the application
- Criticality of the application

In general, there are two main types of gaskets: those used in full-faced joints and those wholly situated within the bolt circle (the circle defined by connecting the centers of the bolts). Full-faced gaskets have more surface area, so a greater compressive load will be required for sealing compared to that used by those used within the bolt circle. In general, full-faced gaskets are used in piping systems operating pressures up to about

300 psi, whereas gaskets situated within the bolt circle can be used for pressures as high as 3,000 psi. Gaskets can be classified into three main categories:

- Non-Metallic (Elastomers, Cork, Compressed Fibre, Graphite, PTFE etc.)
- Semi-Metallic (Spiral-Wound, Clad Joints, Kammprofile, etc.)
- Metallic (API Ring Joints, Lens Rings etc.)

Gasket creep, relaxation, and creep relaxation behaviors have a significant effect on the residual clamping force in gasketed joints. Bouzid proposed a mathematical model to predict the gasket behavior at room temperature, and an experimental procedure is established to determine the necessary gasket constants for the model. The effect of gasket stress level and the gasket thickness on the gasket constants used in the model is investigated. The gasket constants are found to be independent of the gasket stress level but are affected by the gasket thickness for the gasket material considered in this study _red rubber_. A closed form solution is formulated for the clamp load as a function of the time elapsed after the initial tightening of the joint. The clamp load formulation has been successfully used to provide a closed form solution that determines the initial clamp load level that is necessary to provide the desired level of a steady state residual clamp load in the joint, by taking the gasket creep relaxation into account. The good agreement between the mathematical model results and the experimental data suggests that the proposed model can be used to accurately describe the gasket behavior and the clamp load loss due to gasket creep relaxation.

2. Forces Acting in a Bolted Joint Assembly

The initial bolt load generated upon tightening is transferred to the gasket via the flanges. This initial seating stress compresses the gasket and tightens it within itself. The hydrostatic force generated by the system pressure, tends to unload and reduce the stress on the gasket. The stress remaining on the gasket is considered to be the 'operating' or 'residual' stress. It is this degree of stress, or energy left in the joint that will determine the degree of tightness achieved in the system. It should be noted that on a raised face assembly such as the one shown here, there will be some deflection of the flanges themselves ('flange 'rotation'). This is a function of the load applied, the flange material and the geometry of the flanges. Thus, the operational stress towards the outside edge of the gasket tends to be greater than on the inside edge. The mechanics concerning flange rotation are altered with flat-faced flanges. The overall contact area of a full-face joint can be typically twice as much as an inside bolt circle (IBC gasket).

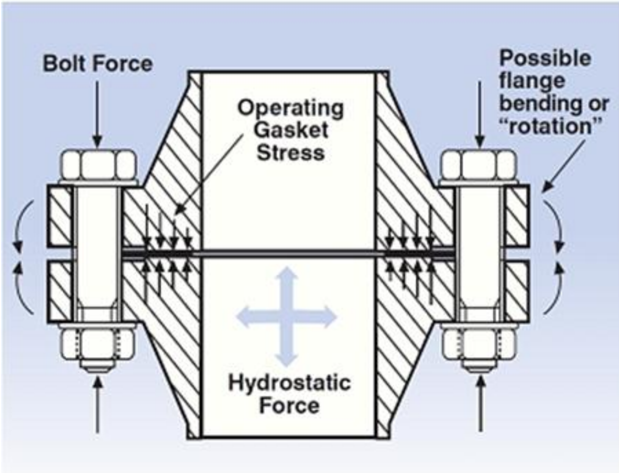

Figure 1 Bolted Joint Assemblies

When designing a bolted flanged joint, it is necessary to consider the in-service clamping force required for the assembly. The initial clamp has to be high enough to compensate for all of the mechanisms which may reduce the clamping force to the in-service level, including:

1) Embedment relaxation
2) Elastic interactions
3) Creep of metal parts, gaskets, etc.
4) External Tensile Loads
5) Hole interference
6) Resistance of joint members to being pulled together
7) Prevailing torque
8) Differential thermal expansion

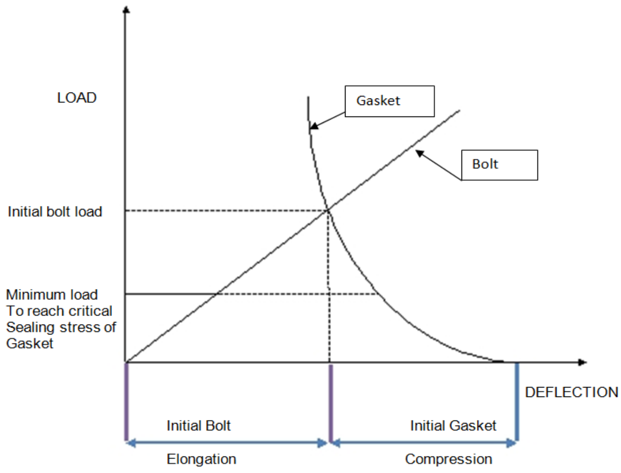

Figure 2

3. Creep Test

Creep of materials is classically associated with time-dependent plasticity under a fixed stress at an elevated temperature, often greater than roughly 0.5 T m, *where Tm is the absolute melting temperature* .Creep is the progressive time-dependent inelastic deformation under constant load and temperature. Relaxation is the time-dependent decrease of stress under the condition of constant deformation and temperature. The creep process is accompanied by many different slow microstructural rearrangements including dislocation movement, ageing of microstructure and grain-boundary cavitation.

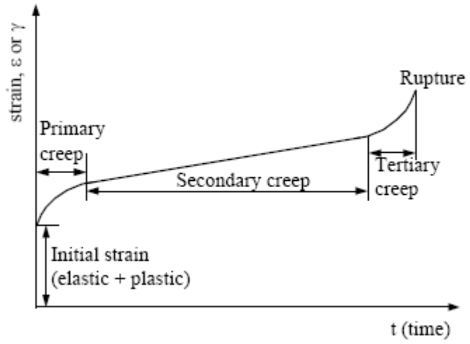

Figure 3

Components that are put under loads for long periods at high temperatures will, in addition to the strain given by Hooke's Law (ε = σ/E) also experience plastic deformation (εplast) with time. This property of materials, which is known as creep, depends on stress, the effective temperature ϑ and time. Springs are subject to creep under load. This is sometimes evident in old cars where the sustained weight on the suspension springs over the years has caused a permanent shortening of the spring‟s overall length and the car body‟s ground clearance is reduced. This shortening by creep is known as set. In the creep test, the gasket load remains constant throughout the test while the gasket compression thickness reduction will be monitored . A UTM testing machine is used to conduct the creep test. The gasket material is cut into 75mm×75mm specimens that are placed between two steel plates, as shown in Fig. The two steel plates are entered between the two jaws of the MTS machine, and then the upper jaw is brought down slowly until it touches the specimen. Then the desired force is quickly applied and maintained for 40 min. Real time data on the gasket load and displacement are collected using a data acquisition system. A curve will be obtained and used to calculate the gasket constants K 1, K 2, C 1, and C2. These constants can be used to construct the gasket creep versus time plot using the already derived equation and compare the results to the ones obtained experimentally. Figure shows a typical stress-strain relation of a gasket. The modulus of elasticity for bolting- up, or compression, is quite different from that for internal pressurization of the vessel, or decompression of the gasket. The ratio of elasticity in decompression to that in compression may exceed 10. When the gasket is decompressed, it shows strong hysterisis which is remarkably non-linear and causes permanent deformation. This deformation naturally results that the gasket does not recover the original thickness. In analyzing gasketed flanges, we must take special care about the status of the gasket, either in compression or in decompression, to choose gasket modulus of elasticity and the stress-free thickness.

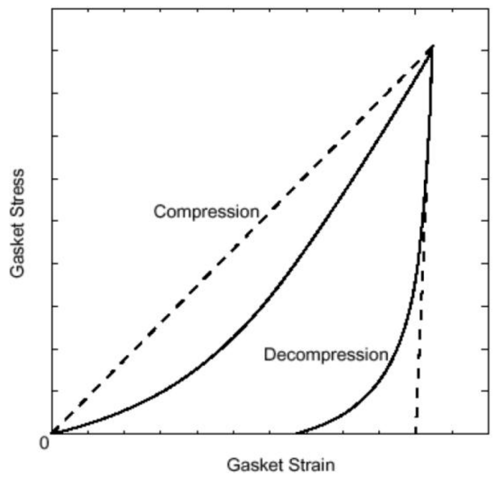

Figure 4

Conclusions

Gasket creep, relaxation, and creep relaxation behaviors have a significant effect on the residual clamping force in gasketed joints. A mathematical model is presented to predict the gasket behavior at room temperature and an experimental procedure is established to determine the necessary gasket constants for the model. The effect of gasket stress level and the gasket thickness on the gasket constants used in the model is investigated. The gasket constants are found to be independent of the gasket stress level but are affected by the gasket thickness for the gasket material considered in this study red rubber. A closed form solution is formulated for the clamp load as a function of the time elapsed after the initial tightening of the joint.

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