Tribology International 125 (2018) 100–109

Contents lists available at ScienceDirect

Tribology International

journal homepage: www.elsevier.com/locate/triboint

# A multi-scale finite element contact model for seal and assembly of twin ferrule pipeline fittings

Yangyang Yan, Jingyu Zhai, Peixin Gao, Qingkai Han*

*School of Mechanical Engineering, Dalian University of Technology, Dalian, 116024, PR China*

ARTICLE INFO

*Keywords:*
Twin ferrule pipeline fittings
Multi-scale contact model
Seal characteristics
Assembly process

ABSTRACT

As the seal and connection piece of pipeline, assembly method and the seal characteristics of pipeline fittings are important for the safety and reliability of hydraulic system of aircraft. According to measured data of roughness of the target surfaces, a multi-scale model for considering the rough surfaces is established and the assembly process of the pipeline fittings is simulated. In the process of simulation, the seal status and seal characteristics of fittings, as well as the influence of fluid pressure on the seal performance are studied in detail. The results show that the change in stress distribution extends around two high stress regions, and multi-scale model could really reflect seal characteristics during the assembly process of pipeline fittings. Moreover, the variation of contact area between front ferrule and pipeline can be described in the linear relations of three stages, and with the increase of fluid pressure, the rate of change of contact area will also increase.

## 1. Introduction

The twin ferrule pipeline fittings has been widely used in hydraulic pipeline system of aircraft due to its convenient assembly and working ability both in the low and high fluid pressure. The metal to metal seal, and the connection between pipelines are achieved by the contact between pipeline fittings and pipeline under a certain preload. As a base seal and connecting piece, its seal and assembly characteristics will directly affect the working performance of hydraulic pipeline system. Therefore, it is very important to study the seal characteristics and assembly method of pipeline fittings to improve the safety and reliability of hydraulic pipeline system of aircraft.

There have been some achievements on the assembly method and the seal characteristic of pipeline fittings. For example, the macro deformation and stress distribution of assembled pipeline fitting are studied based on finite element analysis and experiment (Mihsein [1]). However, the research did not take into account the seal status and seal characteristics during assembly process. The research on the seal performance of metal to metal has been widely concerned by scholars at present, which can usually be carried out by the multi-scale contact model with rough surface. Waddad [2] analyzed the frictionless contact between rough surfaces, which are described by parabolic asperities. Belghith [3] proposed a contact models with the rough surfaces using the standard procedure for roughness and waviness parameters. Wagner [4] investigated a multi-scale finite element framework for the calculation of sliding rubber samples on rough surfaces. Poulios [5] presented a finite element model for studying the frictionless contact between nominally flat rough surfaces. Karupannasamy [6] proposed a multi-scale contact model to predict the friction characteristics occurring in the SMF processes. Sadowski [7] developed a two-scale model for the study of thermal contact conductance (TCC), in which the TCC coefficient is obtained by the solution of heat conduction problem. From the reviewed works, most of the current strategies are excellent to handle the contact characteristics between rough surfaces. However, there are few works on the investigation of the seal characteristics over the past decades.

Currently, the seal characteristics of seal structure has also received considerable attention. Wenk [8] proposed a three dimensional, multi-scale, finite element contact and deformation model for a worn-in radial lip seal. Pérez-Ràfols [9] studied the contact mechanics between rough metal surfaces and the liquid flow through the rough surfaces. Chen [10] analyzed the end face deformation and mechanical seals of O-ring based on ANSYS software. Jia [11] used a computational model to predict the pumping rate of rotary lip seals from the air-side to the liquid-side. Based on three-dimensional finite-element contact analysis, Zhang [12] proposed a novel approach to calculate leak channels and leak rates between seal surfaces for specific surface topographies. Thatte [13] used a visco-elastohydrodynamic model to investigate viscoelastic effects on the performance of a hydraulic rod seal. In general, it is concluded that the above studies are mainly focused on seal characteristics and leak channels between the contact surfaces with rough surfaces. Currently, the assembly method has received

* Corresponding author.
*E-mail address:* qingkaihan@hotmail.com (Q. Han).

https://doi.org/10.1016/j.triboint.2018.04.028
Received 10 December 2017; Received in revised form 30 March 2018; Accepted 25 April 2018
Available online 26 April 2018
0301-679X/ 

considerable attention. S. Hashimura [14] proposed a new assembly method for bolt/nut assembly, which was tightened by pulling the bolt thread portion protruding through the nut with a force corresponding to the target clamping force. S. Ganeshmurthy [15] used a joint model with non-parallel contact under the bolt head to simulate the torque-only and the torque-turn process control methods for achieving a desired level of the bolt preload at initial assembly of the joint.

From the reviewed researches, most of the current studies are available to deal with the contact characteristics between rough surfaces and the leak behavior between rough surfaces, which have been motivated to investigate the metal to metal seal and seal characteristics during assembly process based on the multi-scale method. In this paper, the seal characteristics and assembly process of pipeline fittings are investigated using the multi-scale contact model with rough surfaces. The assembly process is simulated in detail, and the variation of strain and stress distribution are discussed during the axial motion of front ferrule. The seal characteristics is given based on the contact status of seal zones, which includes the variation of seal area and seal stress. In addition, the influence of fluid pressure on the seal characteristics is further investigated.

## 2. Method

### 2.1. Experimental measurements of rough surface

The twin ferrule pipeline fittings are composed by front ferrule, back ferrule, fittings body and nut, as shown in Fig. 1. The metal to metal seal of twin ferrule pipeline fittings is achieved by the outer surface extrusion of front ferrule and pipeline and the surface contact of front ferrule and fittings body. At the same time, the connection between the pipelines can also be achieved. After the twin ferrule pipeline fitting is tightened, the plastic deformation and contact state of the front ferrule are shown in Fig. 2. It can be seen from the figure that there is a metal contact seal area between the front ferrule and the pipeline, which can achieve the sealing of the fluid in the pipeline (Fig. 2).

The microscopic appearance of the bonding surface between metal and metal has a significant effect on their contact state and sealing properties, and the accurate and objective description of the microscopic morphology of the metal interface is the key to the study of its sealing characteristics. In this paper, the multi-scale modeling of the sealed area is completed based on the test data of surface morphology of twin ferrule pipeline fittings. The simulation study on the sealing characteristics of the twin ferrule pipeline fittings during the assembly process is carried out. Finally, the change law of the sealing state during the assembly process can be obtained. The corresponding analysis and modeling process is shown in Fig. 3.

The NEW view5022 3D Surface Profiler can be used to obtain three-dimensional surface topography data of the surfaces of front ferrule and pipeline. The device is based on the white light interference principle to test the surface morphology of the specimens. The vertical resolution of the instrument is 0.1 nm, the lateral resolution is 110 nm, and the maximum scanning depth is 2–150 μm. Finally, the surface morphology data of the 1.41 mm × 1.06 mm range on the surfaces of front ferrule and pipeline are obtained, respectively. It covers a certain position corresponding to the test range in the circumferential direction of the pipeline and the front ferrule. Among them, there are 631 equally-spaced data points in the axial direction and 471 equally-spaced data points in the circumferential direction. That is, a scanning dot matrix of 631 × 471 uniform surface topography data can be obtained. Because the sealing property between the front ferrule and the fittings body is mainly caused by the single metal extrusion deformation, and the surface morphology has little influence on the deformation process. Therefore, the 3D shape information between the front ferrule and the fittings body is neglected in the modeling process.

At the same time, in order to verify the test position of the specimen surface topography, there is no effect on the calculated results of the calculation of the multi-scale finite element calculation. That is, the consistency of the surface topography of the seal area between the outer surface of pipeline and the inner surface of front ferrule need to be clearly defined. Then the surface topography of the test piece is selected from three different locations of the outer surface of the pipeline and the seal area of the front ferrule. And the analysis of the surface quality of the test piece has been completed. Among them, the surface property analysis parameters include, arithmetic mean deviation (Ra), contour root mean square (Rq) and maximum profile height (Ry). The meanings of the parameters are the arithmetic mean of the absolute value of the profile offset in the sampling length, and the root mean square value of

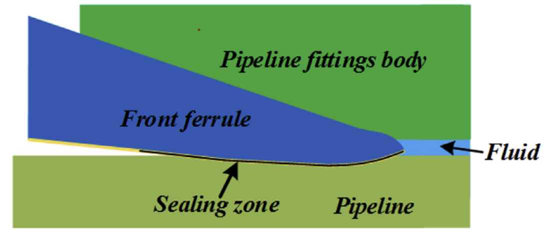


**Fig. 2.** Contact status of front ferrule after tightening process.

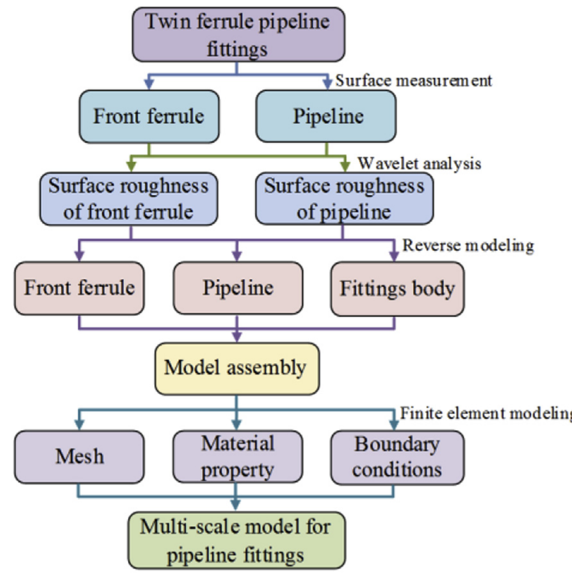


**Fig. 3.** Modeling process of multi-scale contact model.

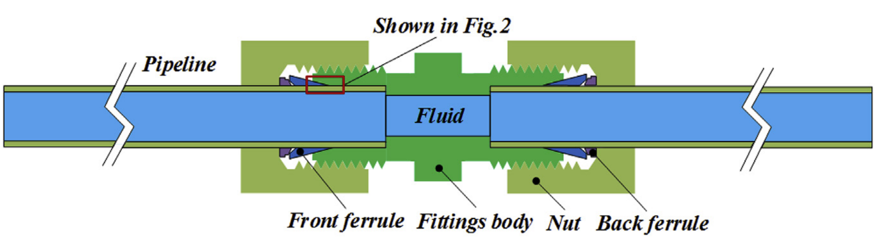


**Fig. 1.** Twin ferrule pipeline fittings.