Mechanics Research Communications 53 (2013) 57–62

Contents lists available at ScienceDirect

Mechanics Research Communications

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

Thermo-mechanical modelling of the contact between rough surfaces using homogenisation technique

Saoussen Belghith[a,*], Salah Mezlini[a], Hedi BelHadjSalah[a], Jean-Louis Ligier[b]

[a] Laboratoire Génie mécanique, École Nationale d'Ingénieurs de Monastir, Université de Monastir, 5000, Tunisia
[b] Renault S.A., Powertrain Engineering Division, Rue des Bons Raisins, 92508 Rueil Malmaison, France

ARTICLE INFO

Article history:
Received 10 February 2013
Received in revised form 8 August 2013
Accepted 9 August 2013
Available online 22 August 2013

Keywords:
Thermo-mechanical behaviour
Thermal contact resistance
Numerical simulation
Rough surface
Microscopic and macroscopic scale

ABSTRACT

In this study, thermo-mechanical behaviour of contacting rough surfaces has been modelled. Firstly, a numerical microscopic contact model that considers the properties of engineering surfaces has been developed. Geometrical characteristics of rough surfaces are deduced using the standard procedure for roughness and waviness parameter determination according to the so-called "motif" procedure. Secondly, an equivalent macroscopic contact model using a homogenisation technique has been presented. The interfacial behaviour of this model has been governed by the curves deduced from the microscopic model. The transition from microscopic to macroscopic scale was also validated.

1. Introduction

Contact of rough surfaces occurs through interactions of surface asperities. These interactions govern heat transfer and lubrication. The contact interface constitutes a barrier to heat flow especially at low pressures, and the related thermal resistance is mainly due to constriction of the heat flux to the spots of real contact of surface asperities (Zavarise et al., 1992a, 1992b).

There are several of theoretical, numerical and experimental studies that provide the state of the art in thermal contact resistance (TCR). Particularly, Cooper et al. (Cooper et al., 1969) proposed theoretical correlation of thermal contact conductance in a vacuum. They show that the TCR depends especially on geometrical characteristics of contacting surfaces and applied pressure. They considered that asperities have cylindrical forms and have been all deformed plastically. Later, Mikic (Mikic, 1974) extended the work of Cooper et al. (Cooper et al., 1969) by considering the effect of elastic deformation on thermal contact conductance for low contact pressure. Afterwards, Bahrami et al. (Bahrami et al., 2005) account for the effect of elastic deformation beneath the plastically deformed micro-contacts with including the interaction between neighbouring asperities on TCR which is not considered by Cooper et al. (1969) and Mikic (1974). They developed a parametric study which has been compared with Milanez et al. (2003) and Hegazy (1985) experimental results. The model showed a good agreement with experimental data at low loads and under predicts TCR for moderate to high contact pressure.

Gill et al. (2009) studied the non-uniformity of TCR over the interface of mated surfaces. They developed an inverse problem to estimate the variation of the TCR along an interface in a two-dimensional configuration. They provided a series of numerical examples to validate their approach.

Amara et al. (2009) developed a three-dimensional numerical model to simulate heat transfer in materials consisting of two layers (splat and substrate). They are interested in the solidification of metal droplets (splats) brought into contact with cold substrate. TCR has been estimated considering a random distribution of contact points rather than the uniform distribution at the interface between the splat and the substrate. The computational results for the cooling rate of the splat obtained using the random contact distribution model are in good agreement with available experimental results of Liu et al. (1995).

Singhal et al. (2005) predicted thermal contact conductance between two nominally flat metallic rough surfaces. In this model, asperities have been modelled as a semi infinite cylinders terminating in the frustum of a cone. Numerical steady state analysis have been performed with a finite volume approach using the computational fluid dynamics software FLUENT. Thermal contact conductance has been determined between two contacting surfaces with different roughness and different materials. Comparison

* Corresponding author. Tel.: +216 22782165.
E-mail address: belghith.saoussen@gmail.com (S. Belghith).

0093-6413/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.mechrescom.2013.08.004

between numerical and experimental study has been realised and a good agreement have been obtained. However, the proposed model is only valid at low contact pressures.

Zhang et al. (2003) proposed a new method for numerical simulation of TCR. They firstly predict the contact spot distribution of two rough surfaces at various loads using an equi-peripheral grid in cylindrical coordinates. Further, a network method using such an equi-peripheral grid has been developed in order to solve a three-dimensional conduction problem where two cylindrical specimens were connected to each other along the longitudinal direction. Numerical results have been compared to experimental one obtained for cylindrical brass specimens and good agreement has been found.

Salti and Laraqi (1999) developed a three-dimensional numerical model to study the local temperature and TCR between two sliding bodies. They showed that TCR decreases while both velocity and relative contact size increase. In this model, roughness is represented by square-shaped asperities and heat transfers through interstitial gaps are not taken into account.

Sadowski and Stupkiewicz (2010) studied the macroscopic thermal contact conductance between two rough contacting surfaces. A two-scale finite element model has been developed using roughness topographies. Moreover, TCR at real contact spots has been deduced and included to the macroscopic model. The finite element results have been approximated by an analytical function. However, the developed approach is only accurate for predominantly plastic deformation in the surface layer and not includes the evolution of surface roughness and real contact area during contact interaction.

In our previous results (Belghith et al., 2010) a two-dimensional rough surface numerical model has been proposed. This model allows to studying the mechanical behaviour of the asperities subjected to low pressure. Real contact area and contact pressure have been determined for microscopic scale and compared with analytical results (Robbe-Valloire et al., 2000, 2001). Furthermore, an equivalent model based on the homogenisation technique has been presented. The interfacial mechanical behaviour of this model has been governed by the curve deduced from the microscopic one.

The goal of the present paper is to apply a homogenisation technique to a thermo-mechanical contact model. A microscopic thermo-mechanical contact model between two rough surfaces has been developed. Geometrical characteristics of rough surfaces are deduced from an experimental profile and using the standard procedure for roughness and waviness parameters (ISO12085). The contact of two rough surfaces is modelled using the concept of the sum surface (O'Callagham and Cameron, 1976; Francis, 1977). The proposed model simulates heat transfer between the two contacting surfaces. Analysis of temperature field near the contact area has been performed for different levels of crushing. The variation of TCR with the surfaces separate distance has been determined. Besides, a homogenisation technique has been developed to build an equivalent macroscopic model based on a microscopic one. This technique allows us to facilitate the modelling of large structures taking into account the presence of the roughness.

2. Microscopic study of thermo-mechanical contact between rough surfaces

2.1. Micro geometry standard parameters (motif parameters)

In this study, the contact between rough surfaces has been transformed to a contact between a smooth surface and a rough surface, which is called sum surface. This equivalence has already been used in previous studies (Belghith et al., 2009, 2010).

Table 1
Motif parameters of the rough surface.

The average of the height values of the roughness motifs: **R** (μm)	3.19
The average of the width values of the roughness motifs: **AR** (μm)	157
The root mean square of the height values of the roughness motifs: **SR** (μm)	0.8
The root mean square of the width values of the roughness motifs: **SAR** (μm)	122.4
The average of the height values of the waviness motifs:**W** (μm)	6.9
The average of the width values of the waviness motifs: **AW** (μm)	976.5
The root mean square of the height values of the waviness motifs: **SW** (μm)	0.84
The root mean square of the width values of the waviness motifs: **SAW** (μm)	284

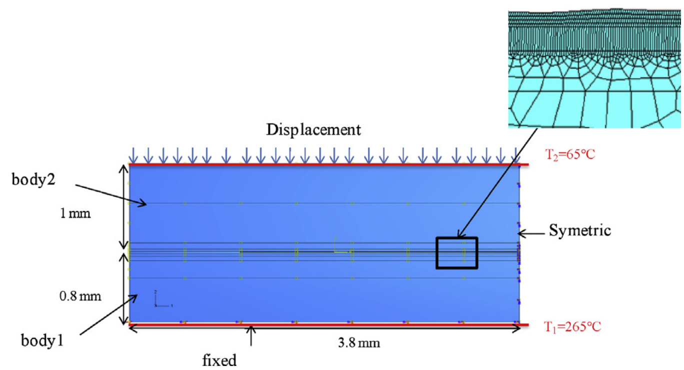

Fig. 1. Boundary conditions, dimensions and mesh used in numerical simulation.

Two rough surfaces have been considered. Profile of each surface has been experimentally measured and microgeometry parameters of each surface have been deduced. Microgeometry characteristics of the sum surface are deduced from each surface in contact. Motif roughness and waviness parameters have been presented in Table 1.

The profile of the sum surface has been generated with a Matlab program. This program allows the regeneration of both the waviness and roughness profiles. The surface profile has been obtained using a superposition of the roughness profile upon the waviness one.

2.2. Numerical model

The materials' properties of the two contacting bodies are shown in Table 2. The material's behaviour of the rough surface (body1) is modulated using large deformation and elastoplastic theory. More specifically, the plastic flow is described via the Von Mises plasticity criterion. A non-linear elastoplastic behaviour has been used.

The profile of the rough surface has been introduced in a two-dimensional model presented in Fig. 1.

2D model has been simulated using ABAQUS/Standard (Fig. 1). The width of the two contacting bodies is 3.8 mm The heights of the smooth and rough bodies are respectively 1 and 0.8 mm. Free meshes type have been considered. They are particularly refined near the interface having a size between 3 and 5 μm, but are sufficiently large away from the rough surface having a size of 100 μm. The bottom surface of the rough body is fixed and the right lateral surface of the two bodies is symmetric. The left one is thermally isolated. The initial temperature in the structure is taken equal to 20 °C.

The simulation has been performed in two steps: