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Thermo-mechanical analysis of the magnetic head–disk interface with a fractal surface description

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ABSTRACT

Rigid rough surface of a magnetic head and smooth surface of a hard disk are chosen to perform a comprehensive thermo-mechanical contact analysis at the magnetic head–disk interface, which is characterized by using the fractal geometry. The effects of mechanical and thermal surface loadings on deformation of the semi-infinite medium in normal and sliding contacts are analyzed simultaneously by developing a 2D finite element model. It is shown that frictional heating increases not only the contact area but also the contact pressure and stresses. The maximum temperature occurs at the tip of the asperities of the semi-infinite medium.

1. Introduction

The topography of engineering surfaces influences contact, friction, and wear due to imperfect contact resulting from surface roughness. Therefore, the realistic representation of engineering surfaces becomes the main issue in order to obtain more accurate information about the stresses and the deformation fields. In this respect, studying thermo-mechanical surface loading due to frictional heating occurred in sliding contact of a rough surface on a smooth medium becomes very important.

The analytical studies were generally focused on either thermal or thermo-elastic analysis in semi-infinite homogenous media imposed surface heat sources, decoupling mechanical stress analysis from the thermal one. The temperature rise at the contact surfaces due to moving heat surfaces was studied by Blok [1] and Jaeger [2] while the Fourier transformation analysis was utilized to obtain analytical solutions for temperature and thermal stress fields in a semi-infinite medium with a thin hard coating [3], in a layered medium [4,5], and in elastic half space [6]. Because of the complex analytical relations for fully coupled thermo-mechanical contact problems, there are a few studies on the subject such as Azarkhin and Barber [7]. They presented the solution for the transient Hertz problem by using Green's function and Fourier transformation while the brake disk sliding between two friction pads was investigated by Lee and Barber [8] for one-dimensional model. Then, a two-dimensional [9] and a three-dimensional [10] contact models were studied for two infinitely large rough surfaces.

The developments in computer technology and numerical techniques have made remarkable contributions on the application of Finite Element Method (FEM) for analyzing thermo-mechanical surface loading. Kennedy [11] presented the thermal response of sliding bodies subjected to constant heat source using the finite element model while the boundary element method was used to test the effect of surface coating on the temperature rise at the sliding contact interface of a layered medium due to frictional heating by Vick et al. [12]. Day and Newcomb [13] used the finite element model to study thermal behavior in automotive disk brakes. In the studies mentioned above, effects of thermal and mechanical loading on the sliding media responses were not considered simultaneously. Ye and Komvopoulos [14] presented the finite element model of elastic–plastic medium to study the thermo-mechanical surface traction while Gong and Komvopoulos studied a fully coupled finite element analysis for an elastic–plastic patterned surface in contact with an elastic–plastic sphere [15] and for a semi-infinite elastic solid [16].

Recently, a dynamic indentation of an elastic–plastic multi-layered medium by a rigid rough surface that exhibits fractal behavior was studied by utilizing the finite element method in order to investigate the effects of surface roughness, layer thickness, indentation speed, and cyclic indentation on the contact pressure and subsurface stresses and strains [17]. Later on, a comprehensive analysis of layered elastic solids in contact with a rough surface

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characterized by fractal geometry was performed to obtain relationships for the mean contact pressure and the real half-contact width in terms of the asperity radius, truncated half-contact width, layer thickness, and elastic properties of the layer and the substrate [18]. They provided insight into the initiation of yielding and the tendency for cracking in the layered medium by giving the results for the contact pressure, the surface and the subsurface stresses.

An alternative approach using fractal geometry was introduced to study the force-deformation relationship of a linear-viscoelastic surface obeying a standard linear solid constitutive law [19]. Moreover, a study was pursued to predict the maximum and average local flash temperature rise at the nanoscale contact spots and its distribution over the whole contact zone using a comprehensive fractal model [20]. Another study was performed by Sahoo and Ghosh [21] to analyze non-adhesive, frictionless elastic/elastic–plastic contact between a rigid flat plane and a fractal rough surface using the finite element method. They performed parametric studies to consider the general relations between contact properties and key material and surface parameters.

When two bodies with rough surfaces are in sliding contact, the friction at the interface leads to energy dissipation in the form of heat. This is called frictional heating which, in fact, is responsible for temperature rise resulting in thermal stresses, variations in the real contact area, and contact pressure distributions at the interacting sliding surfaces. The frictional heating in the interacting sliding surfaces depend upon the real contact area and contact pressure or vice versa. It can therefore be deduced that thermal and mechanical stress fields are completely coupled and they must be determined simultaneously rather than sequentially.

Although the mentioned studies above provided useful knowledge about thermo-mechanical analysis of semi-infinite medium in sliding contact with a rough surface, either the rough surfaces were not characterized with fractal geometry or the simultaneous effects of thermal and mechanical deformations were not taken into account. The main objective of this study is, therefore, to develop thermo-mechanical contact analysis between a smooth semi-infinite medium and a rigid rough slider. In order to accomplish this objective, a computer hard disk was chosen as a smooth semi-infinite medium while a magnetic head was selected as a rigid rough slider with realistic description of surface topographies. In order for sliding contact to be occurred physically, normal contact (indentation) has to take place first between a hard disk and a magnetic head. The magnetic head surface was modeled by using the fractal geometry to achieve this purpose. Then, this equivalent surface topography of the head–disk interface (HDI) was incorporated into the finite element model for simulating the mechanical and thermo-mechanical analysis. After performing the mechanical contact analysis at the HDI by using a two-dimensional finite element model, a fully coupled thermo-mechanical finite element model was developed for thermo-mechanical analysis. The finite element analysis was used to obtain contact pressure distribution, surface and subsurface stress/strain fields and temperature rise for the elastic and elastic–plastic semi-infinite medium. The effects of the friction coefficient, μ, and the surface interference distance, δ, on to temperature were investigated while the effect of interference distance on to the pressure and von Mises equivalent stress distributions were also studied.

Table 1
Thermo-mechanical properties of semi-infinite medium used in normal contact analysis [15].

Mechanical properties	Magnitude
Modulus of elasticity, E (GPa)	130
Yield stress, σ_y (GPa)	2.67

2. Material properties and constitutive model

The mechanical and physical properties of the semi-infinite medium are selected to be typical values of magnetic recording disk consisting of carbon overcoat. They are given in Table 1 [15]. The semi-infinite medium were modeled as elastic-perfectly plastic materials, obeying the yield condition

$$\sigma_{\mathrm{M}} = \sqrt{\frac{3}{2}S_{ij}S_{ij}} = \sigma_{\mathrm{Y}} \quad (1)$$

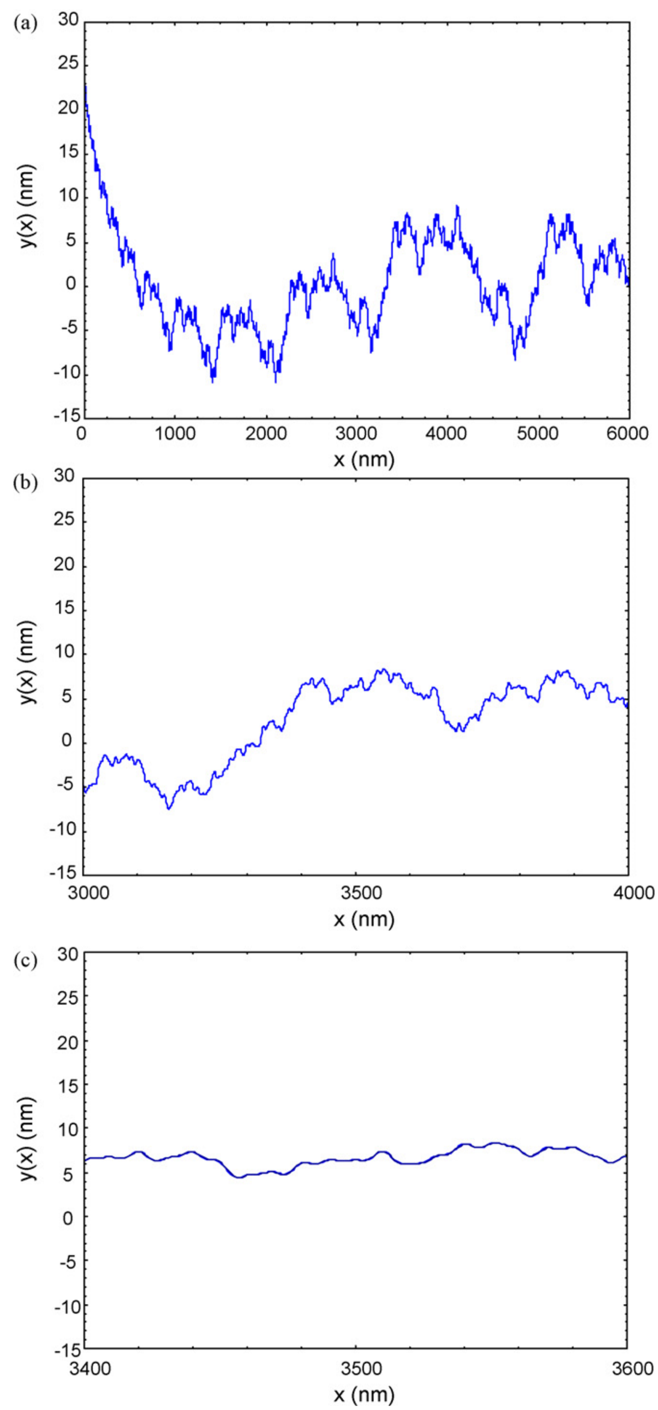

Fig. 1. Development of the fractal surface (a) 0–6000 nm, (b) 3000–4000 nm and (c) 3400–3600 nm [26].