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AN ISOTHERMAL MODEL FOR EVALUATING STRESS AND STRAIN IN THE POLYMERIC BLOCK OF THE BLOCK-ON-RING SYSTEM

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ABSTRACT

This paper presents the results of simulating an isothermal frictional contact between a polymeric block and a steel ring. The model takes into account the elasto-plastic behavior of the polymeric materials and the friction coefficient of the two triboelements in dry regime as determined from tests done on a block-on-ring system. The results given by the model are compared to some characteristics of the actual test ring (geometry of the wear track). The mechanical characteristic of the polymer material were modeled in accordance to the results obtained from the traction tests.

KEYWORDS: isothermal model, friction, stress and strain distribution, block-on-ring tester

1. Introduction

Finite element models have been successfully used to analyze contacts, but this takes a considerable amount of time and a high computational cost [2]. Some of these techniques yield closed-form solutions which generally involve some simplifying assumptions. Many of them are limited to a certain range of geometries or loading conditions. Special two and three-dimensional elements have been developed for stress and displacement analyses in tribological contacts [4, 5, 12, 13, 14].

Wear and friction, introduced as supplementary processes in the contact models, make the model closer to the actual one as friction modifies the stress and strain values [1, 6-9, 10, 11].

2. The fem model of the bloc-on-ring system with friction

In order to evaluate the contact in this particular problem of block-on-ring contact with friction, the authors used the program COSMOS/M version 2.9 [16].

The aim of this paper is to point out the behavior of polybuthylene therephthalate (PBT) in contact with friction and to evaluate the stress and strain fields for different contact loads.

The hypotheses characterizing this model are:

- the material loss due to the wear process is not taken into account. This is a first step in modeling the contact and the hypothesis is good enough for a starting analysis as the authors made tests on a performative tribometer and the wear parameter have low values as compared to, for instance, the test done with PTFE blocks [3, 4];
- the model is isothermal (the temperature is kept constant at 20°C for the ring and the block);
- the material ring is hardened steel (elastic behavior) and could be considered rigid as compared to the block material (polymer);
- the block and ring materials are considered homogeneous and isotropic;
- the mechanical properties of the steel ring have been selected from the program library for a steel with the hardness close to that of the rings and for PBT, there were selected representative points from the experimentally obtained strain-stress curve, using the TESTOMETRIC M350-5AT equipment [17], having a force cell of 5kN, as recommended by EN ISO 527-2, in the Laboratory of Polymeric Materials Research (Faculty of Mechanical Engineering, "Dunarea de Jos" University of Galati).

The elements that have been used in this simulation were:

- the modeling of the block was done with the help of PLANE2D elements plane stress, with 4 nodes having a side of 0.1 mm (thus, the block model contains 5,050 elements); the block width is 4 mm;

- the ring modeling used rigid elements type BEAM2D with 2 nodes, the ring width is 10 mm;
- the contact modeling between the block and the ring used contact elements type GAP, node to line with automatically generated friction and the value of the friction coefficient is set here at 0.2 as determined from experimental tests.
- the values for the mechanical properties were determined from tensile tests made on PBT bone samples and the Poisson coefficient was set at ν = 0.4), as given in literature [15].

The FEM model is presented in Fig. 1.

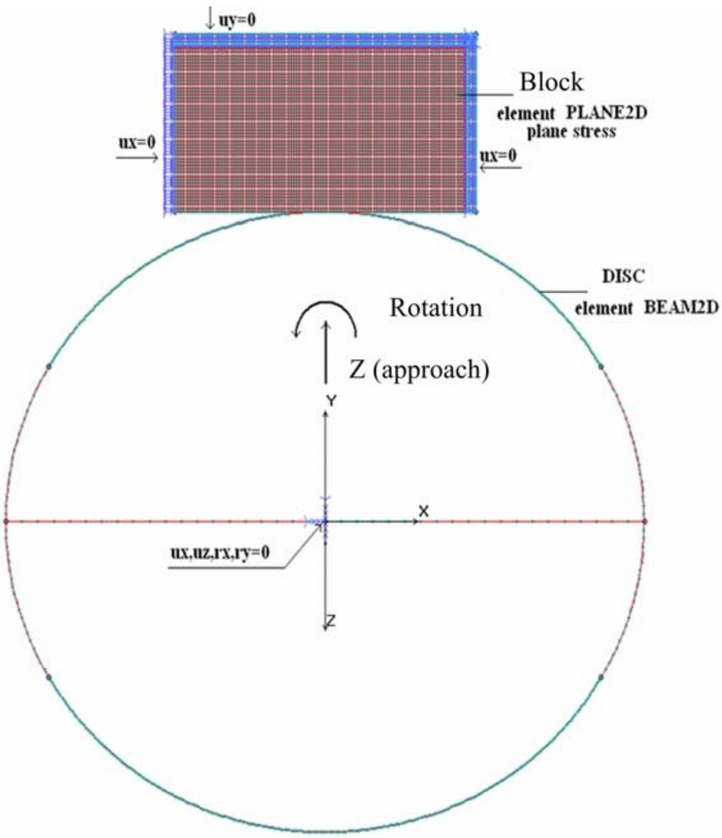


Fig. 1. *Model for the block-on-ring system*

The calculation was done quasi-statically, the friction coefficient being considered independent on the sliding speed.

Models of materials:

- non-linear elasto-plastic model (von Mises isotropic), using the information from the strain-stress curve experimentally determined for PBT;
- linear model for the BEAM2D ring material (hardened steel).

This contact model is a non-linear one, even if the structure has small deformations. The equilibrium is attended by incremental increase of the normal force, imposing the displacement on the force direction.

In order to solve the contact problem, the Newton-Raphson method was used; generally, 6...7 iterations are needed, on each step for getting a convergence with the help of this method [2, 5].

In order to get the contact points and the stresses in this zone, the Total Lagrangian method was used (the plastic deformations are small). The incremental values is automatically set, activating the clause “autostep”. The cases taken into discussion in this paper are given in Table 1. The values of the contact width on the PBT blocks were obtained by measuring at room temperature (20...22°C).

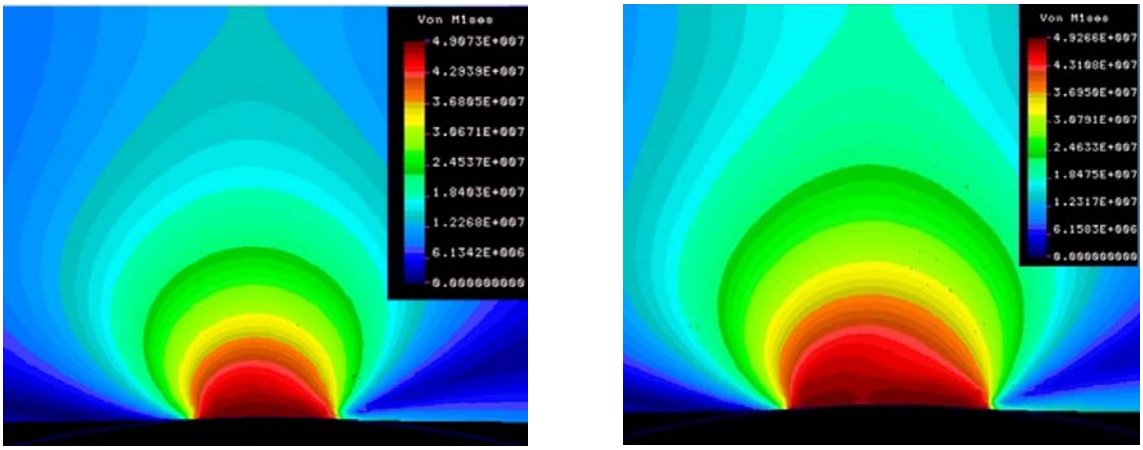
3. Results and discussions

Analyzing the values in Table 1, one may notice that the results obtained from the FEM modeling are in good agreement with those experimentally determined.

Figures 2...7 present the stress distributions for the following stresses: von Mises, main stresses σ_1 and σ_2, shear stress in plane xy and the strain distributions for the cases of F=5 N and F=20 N.

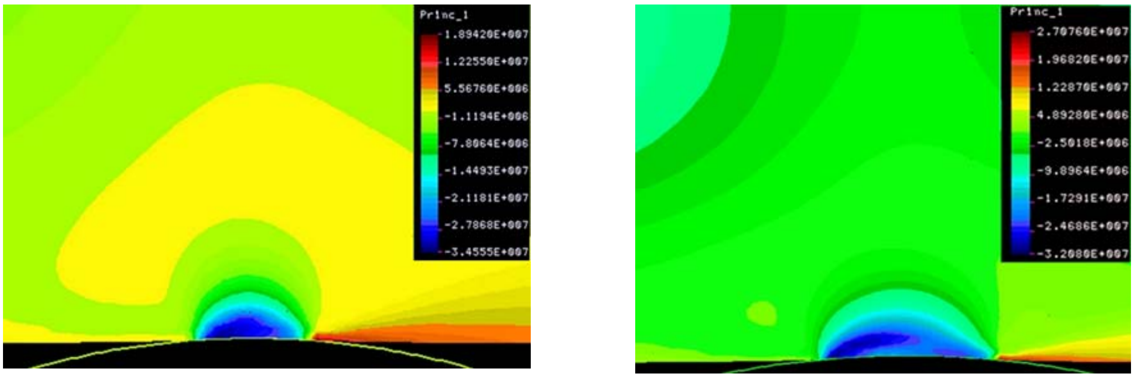
Table 1

Case	F	Imposed displacement of the block, *Z*	Calculated width of the contact	Measured width of the wear track (experimentally)
	[N]	[mm]		
1	1	0.0341	1.5	1.6
2	2,5	0.0151	1.79	1.3
3	5	0.0185	2.12	2.1
4	10	0.0539	2.94	2.8
5	20	0.1108	3.43	3.5



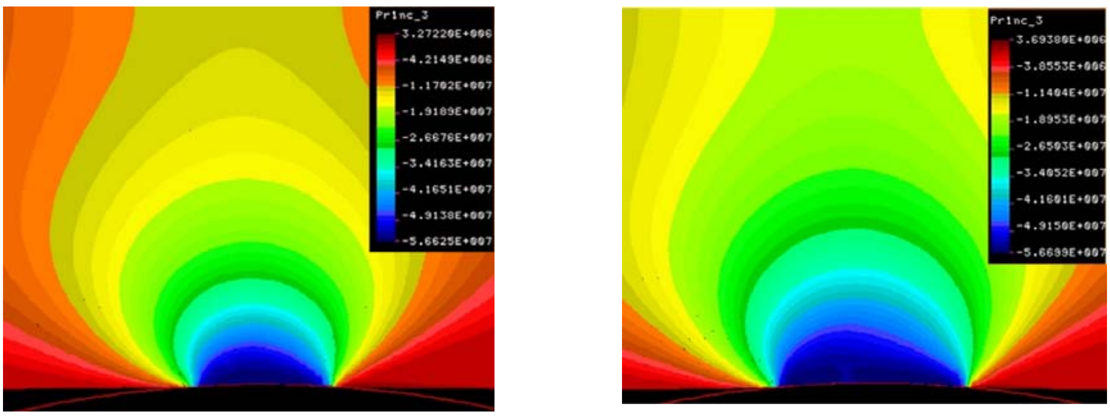
a) F = 5 N c) F = 20 N

Fig. 2. *Influence of the normally applied load on the distribution of von Mises stresses*



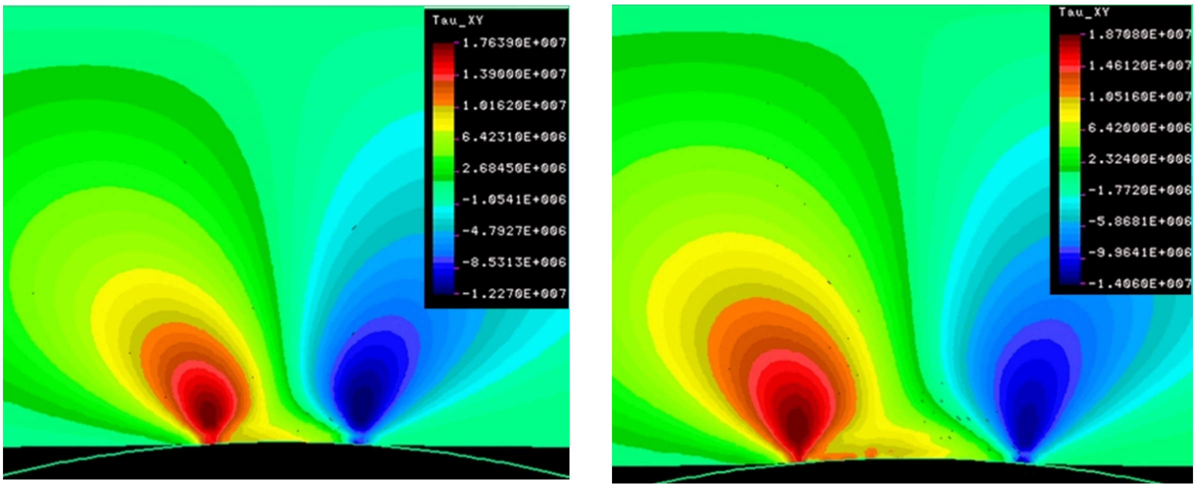
a) F = 5 N c) F = 20 N

Fig. 3. *Influence of the applied load on the main stress 1 (σ_1)*



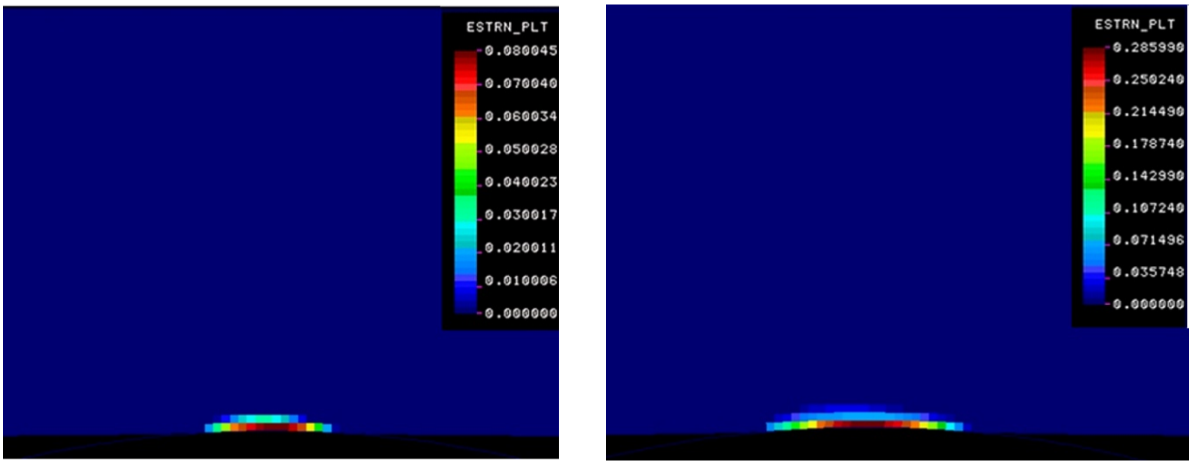
a) F = 5 N c) F = 20 N

Fig. 4. *Influence of the applied load on the distribution of the main stress 3 (σ_3)*



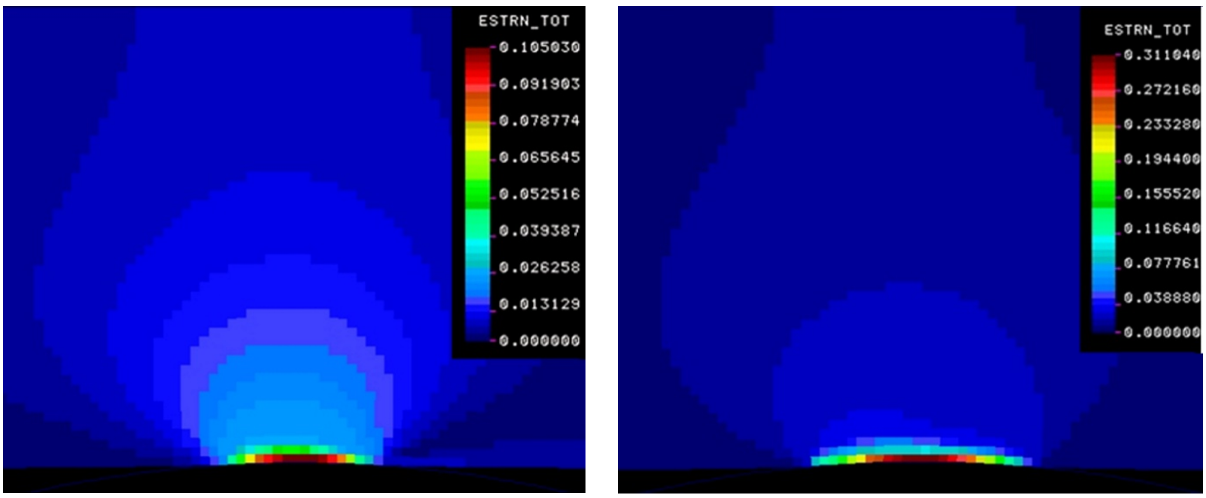
a) F = 5 N c) F = 20 N

Fig. 5. *Influence of the applied load on the shear stress (τ_{xy})*



a) F = 5 N c) F = 20 N

Fig. 6. *Influence of the applied load on the total plastic strain distribution*



a) F = 5 N c) F = 20 N

Fig. 7*. Influence of the applied load on the distribution of the total deformation*

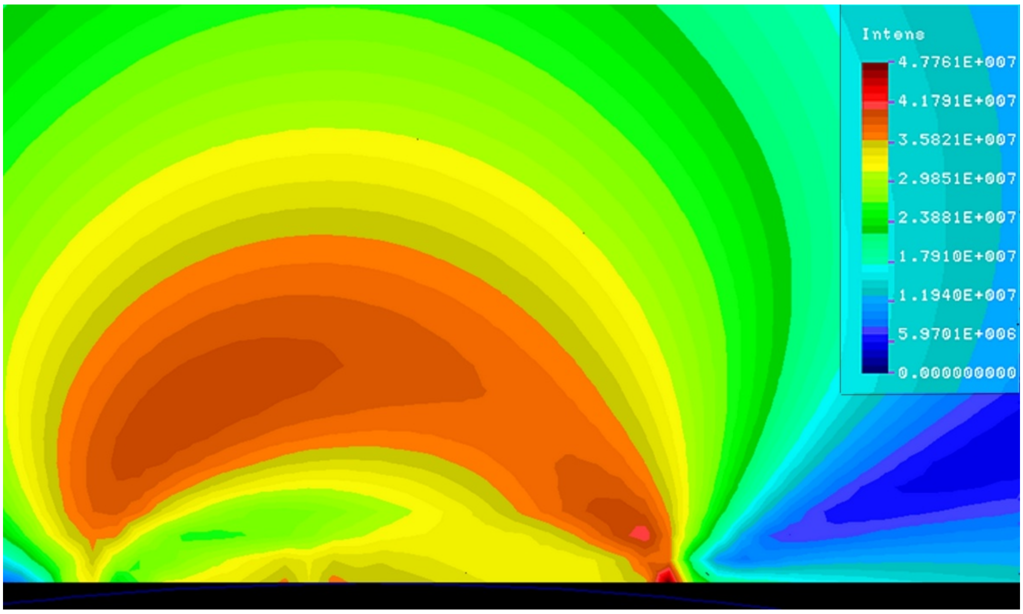


Fig. 10. *Distribution of the values for the STRESS INTENSITY parameter (difference between maximum main stress and minimum main stress, σ_1-σ_3)*

Figure 8 gives maximum values of von Mises stresses characterizing the PBT block as a function of normally applied load. One may notice that von Mises stress asymptotically approaches the yield limit experimentally established for the polymer.

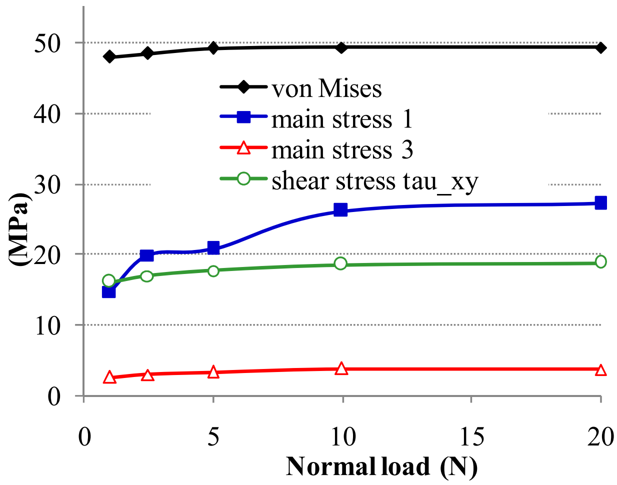


Fig. 8. *Maximum values of stresses in the polymeric block, as a function of the applied load*

Due to the elasto-plastic nature of the block, the maximum von Mises stresses could overpass the yield limit of the material (47.3 MPa, as determined from tensile tests). For the studied loading interval, the running program evidenced an almost linear dependence of the maximum total strains and the maximum plastic strains with the normally applied load (Fig. 9).

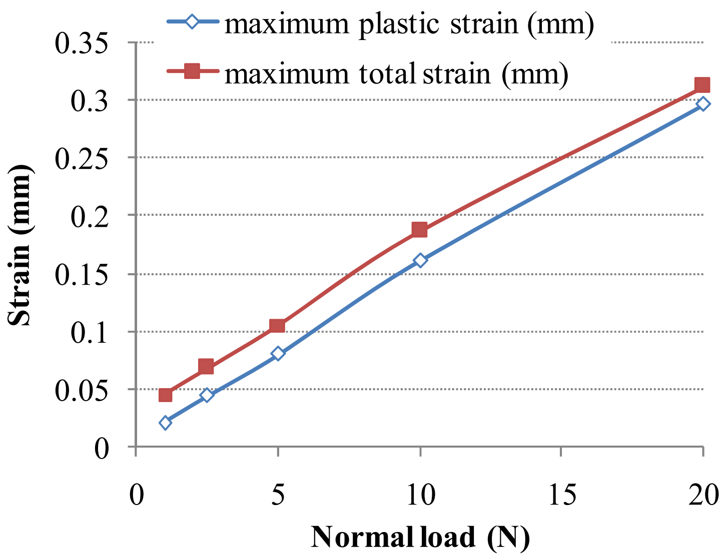


Fig. 9. *Maximum strain in the polymeric block, as a function of the applied load*

Figure 9 presents the dependence of the maximum total strain and of the plastic strain on the normally applied load. The value of the total maximum deformation is very close to maximum plastic one.

This FEM modeling could help the designer to evaluate a frictional contact even without conducting laboratory tests.

The conclusion from this figure is that the material could support high loads because of its elasto-plastic nature.

4. Conclusions

After running the model for several normally applied forces, the authors have drawn the following conclusions.

The zones with plastic deformations are small as compared to the block size for all analyzed cases. The deformations are transmitted toward the clock interior, along the direction of the normal force. The shape of the block in the contact zone has the tendency of becoming that of a shoe, this explaining the distribution of stress and good behavior of the polymer at high forces (Figs. 6 and 7).

The block material could support high loads due to local plastic deformations that do not allow the generation of local high stress peaks.

The shear stresses (τ_{xy}) have high values, theoretically close to the shear limit (here considered approximately 20% of the tensile limit for many thermoplastic polymers [3, 4].

The distribution of the STRESS INTENSITY parameter (the difference between the main stresses σ_1 and σ_3) is relevant for evaluating the damaged zone of the contact, especially when the friction is introduced (Fig. 10, for F=20 N). When this parameter reaches maximum values, the zone is that where the material could be broken and then dislodge through wearing.

This model is useful for reducing the design time and the time for evaluating the contact.

A FEM model will behave closer to the actual one if experimentally determined parameters are introduced. The model presented used the information obtained from tensile tests, introducing points from the stress-strain curve as obtained from actual tests and information obtained from tribological tests (here, the friction coefficient).

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