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# THE INFLUENCE OF FRICTION COEFFICIENT ON A STRESS AND STRAIN DISTRIBUTION ON BLOCK-ON-RING FEM MODEL

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***Abstract:*** *This paper presents a FEM simulation of a dry sliding contact, with a constant temperature on the friction surfaces. This assumption was included based on experimental studies, done on block-on-ring tribotester (block made of PBT and ring made of hardened steel). The block material was considered bilinear and the ring material was considered elastic, justified by the high difference between the mechanical properties of two involved materials. The model applied simplifying hypothesis, including that wear is not taken into consideration, the main objective being to analyse the strain and stress distributions. A solid element type SOLID186 was used for having a reliable mesh and the possibility of high strains on the polymeric block. The friction introduces a shear stress on each contact surface element, proportional to the normal pressure on the element and a constant characterizing the couple of materials (the friction coefficient). The simulation includes three steps: a statical analysis (without friction), a thermal steady state analysis (the contact surface temperature being constant), the obtained solution is then „loaded" with the stresses generated by friction. For the load taken into consideration, the increase of the friction coefficient (from 0.2 to 0.5) pointed out an extension of the contact area and an increased degree of asymmetrization of the von Mises stress distribution in the rotation direction of the ring. The increase of the friction coefficient attenuates the edge effects, the values being proportional to the friction coefficient, but with lower stress gradients for the higher value of the friction coefficient.*

***Keywords:*** *FEM simulation, linear contact, bilinear material, dry friction.*

## 1. INTRODUCTION

Heat generated by friction produced a thermal field into the triboelement in contact that has to be taken in consideration as it modifies the mechanical properties of the materials in contact and also changes the stress and train distribution, especially when dealing with very different materials in contact, like metal-polymer (or composite). Heating by friction could be considered as generated by a local source of heat flow and, because the heat equation are linear, the thermal distribution could be found as a superposition of punctual heat sources, similar to the elastic stress distribution [1]. In sliding contact, the heat is generated on the contact interface as a heat flow:

$$\dot{h} = \mu \cdot V \cdot p \tag{1}$$

where $V$ is the sliding speed, μ is the friction coefficient and $p$ is the pressure on the interface.

The aim of this paper is to evaluate the influence of the friction coefficient value on stress and strain distributions taking into account friction and heat generated by friction. This analysis makes possible to design, an initial range for the testing parameters (load, speed, friction coefficient, materials in contact) a friction couple without failure (high deformation, high temperature etc.). The results of this type of simulation reduce the costs of supplementary tests made for delimiting the exploitation of a particular friction couple.

## 2. FEM MODEL OF THE BLOCK-ON-RING TRIBOSYSTEM

### 2.1 The model

In order to solve this model of the sliding contact in block-on-ring system, the software ANSYS 15.0 was used and the mesh and geometry of the system is given in Figure 1. The Static Structural module was used for calculating strain and stress generated by the external loads and for this time was not a variable. A simplifying hypothesis was used; as the wear is very small for this friction couple (steel on polymer, namely PBT) [2,3], the material loss is not taken into consideration. Kónya and Váradi took into consideration wear for a simulation pin-on-disk, but the wear had significant values and changes the contact [4]. The aim of this paper being to evaluate strain and stress fields and to see if the model give plastic strains. Initially, the model was considered isothermal and the stress and strain fields were determined for a normal load $F$ = 30 N. The simulation is considered to have a constant temperature on the surface contact. It is also a simplifying hypothesis, sustained by the monitoring of the temperature near the contact (Fig. 2) and by SEM investigation revealing that polymer softening is similar all over the contact, the quantitative conclusion being that the difference in temperature on the friction surface is small. The steel ring was considered elastic, taking into account the difference in properties of the materials in contact.

The steel properties were taken from the Ansys library for harden steel. The simulation is done for a stable regime (a constant temperature on the contact interface, a constant value for the friction coefficient, an average value for stable regime as obtained from block-on ring tests (last 2000...3000 m of the total sliding distance of 5000 m) [2,3].

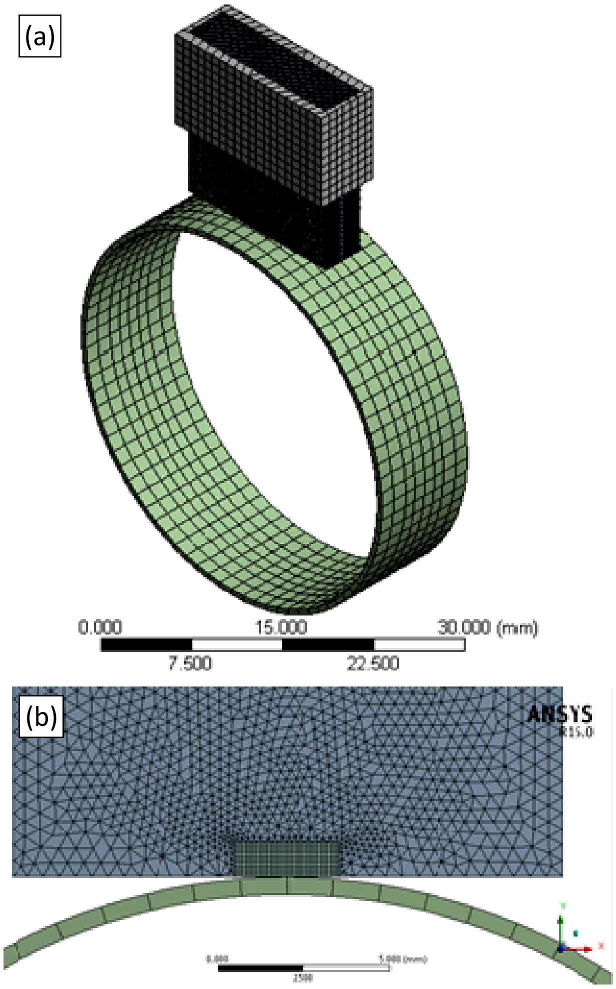


**Figure 1.** (a) FEM mesh and (b) detail of the contact zone

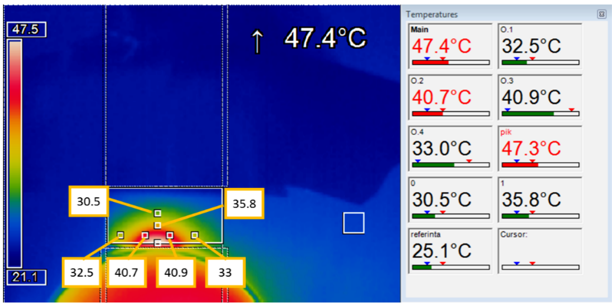


**Figure 2.** Image from thermographic camera during a block-on-ring test with a block made of PBT, load $F$ = 30 N, sliding speed $v$ = 0.75 m/s and sliding distance $L$ = 5000 m

The selection of CONTA174 offers an option for defining a maximum value for the stress on the contact, $\tau_{max}$, and thus, indifferent to the contact pressure, the sliding occurs if this value is overpassed.

## 2.2 Models for the materials

The block material is considered homogenous and isotrop and its properties were introduced based on traction and tribological tests and the thermal properties were determined based on DSC test. Poisson coefficient was taken from the literature ($\nu_{PBT}$ = 0.38) [5]. The interface temperature is considered constant, a simplification that could be accepted based on temperature monitoring [2]. The mechanical properties of PBT at 23 °C were given by traction tests on PBT samples. Mechanical properties at higher temperatures were taken from literature [6,7]. Mechanical and thermal properties, as used for this model, are given in Figure 3. PBT was considered to behave like a bilinear material, with a tangent modulus equal to zero.

The model for the material the ring is made of is “structural steel”. The values for the module of elasticity and yield strength at 23 °C are obtained and copyrights for specific heat curves and linear expansion coefficient are obtained by author.

## 2.3 Simulation conditions

Elements type SOLID186 [8] were used because of large displacements supposed to happen on the polymeric block. SOLID186 is an advanced 3D element, with 20 nodes, three freedom degrees on each node – the translations on directions x, y and z.

This model used the isotrop friction, considering the friction coefficient, µ, as being constant and the effect superposition is applied for obtained the strains [9-14].

The discretization was done in a semi-automatic way in order to obtained elements with maximum side of 1 mm for all the model, except the submodel (a volume near the contact – see Fig. 1) with a finer mesh, where elements with maximum 0.1 mm where design on the finer mesh near the contact, the inventory of the elements and nodes being given in Table 1. The FEM analisys was done is steps presented in Figure 4.

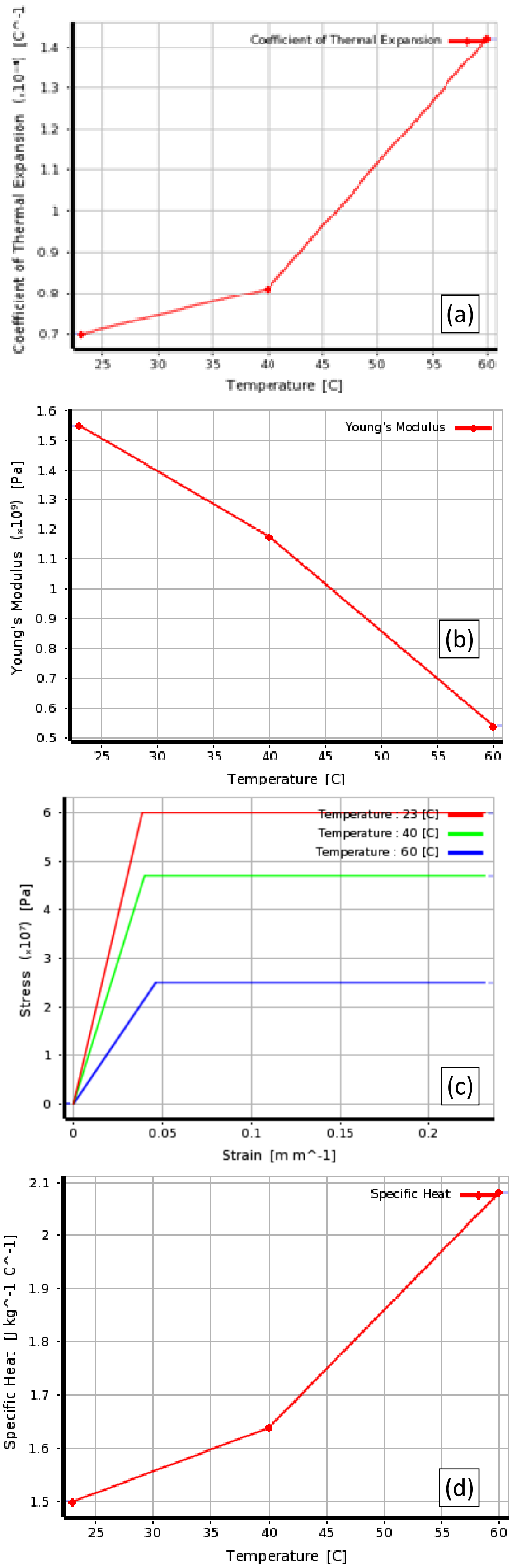


**Figure 3.** Material properties as introduced in the program: (a) the thermal expansion coefficient [2], (b) Young modulus curve, (c) functions for stress – strain dependency and (d) Specific heat (experimental data for PBT) [2]

**Table 1.** Nodes and elements for block-on-ring model

| No. | Element | Number of nodes | Number of elements |
|---|---|---|---|
| 1 | Steel ring | 4880 | 640 |
| 2 | Block | 91000 | 241838 |
| 3 | Submodel | 53861 | 12000 |
| 4 | Guiding support | 4194 | 572 |

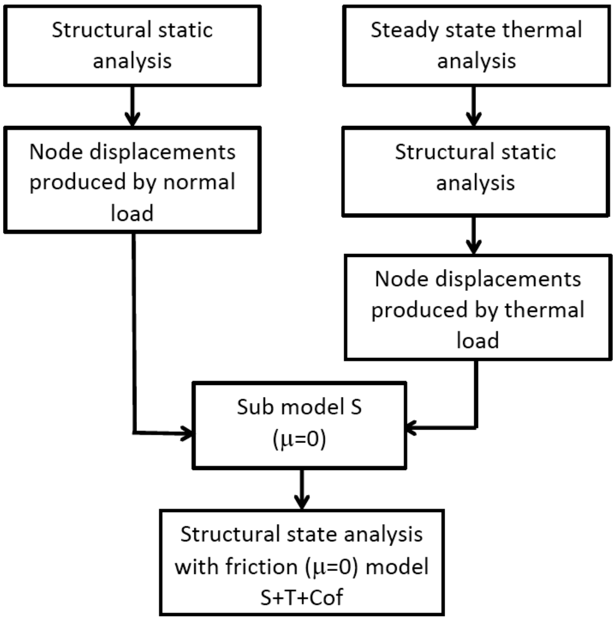


**Figure 4.** The logic flow of the FEM analysis

The results are presented for the submodel (the volume of the block, near the contact), this being loaded with node displacements as resulted from the statical analysis with notmal load and with thermal displacements (Fig. 5 presents the conditions for thermal load).

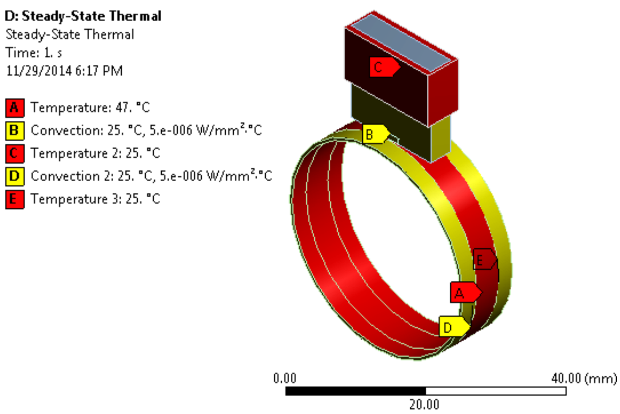


**Figure 5.** Boundary conditions for thermal analysis in the block-on-ring system, for a load *F* = 30 N, and *v* = 0.75 m/s

In a "static structural" model, the block is statically loaded with a distributed load on the upper face of the block. This could slide with a very small friction coefficient (0.05) inside the guiding element (the influence of this friction could be neglected). The determined strains are transferred to the next model – "structural thermo" model, for which the upper surface of the block is considered locked and on the bottom surface the thermal load is applied (a constant temperature source). Thus, the strains caused by mechanical and thermal load are. For this model, the contact surface is considered to be isothermal, the introduced values being those given by the thermal monitoring of system on a tribometer [2], when the thermal regime become stable. After that, the shear stress distribution introduced by friction is added in the last model, coded (S+T+Cof).

The distribution of von Mises stresses on the contact surface of the block, is presented in Figure 7 along the contact, for different values of the friction coefficient. Figure 8 presents curves of von Mises stress distribution, but in the sliding direction, in plane coded as in Figure 6. If the friction coefficient is higher, the contact zone extends, the stress values increase but the edge effects are diminished.

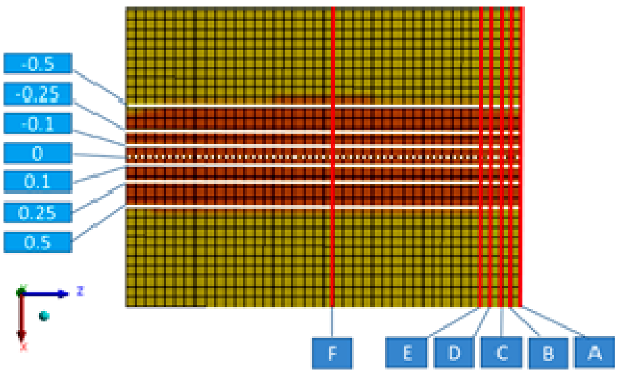


**Figure 6.** Codes for sections in the model

The analysis of the values for the equivalent stress was done on the contact surface, in two families of planes, one being perpendicular to the ring axle (planes A to F), the other one being along the contact (planes -0.5, ..., 0, ...0.5). The selection of these planes was based on the fact that these regions could be characterized by higher gradients of stress and strain, as one may see in Figure 6.

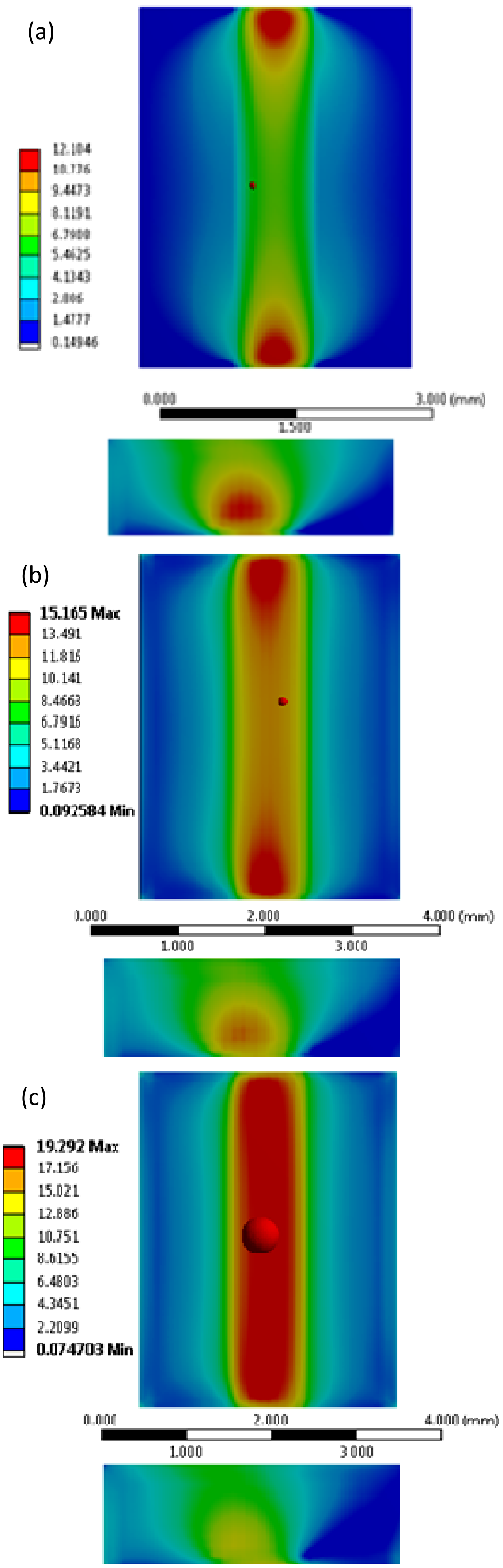


**Figure 7.** Von Mises stress distribution on the contact surface of the block (up) and on the lateral side of the block (down), in MPa: (a) μ = 0, (b) μ = 0.3 and (c) μ = 0.5

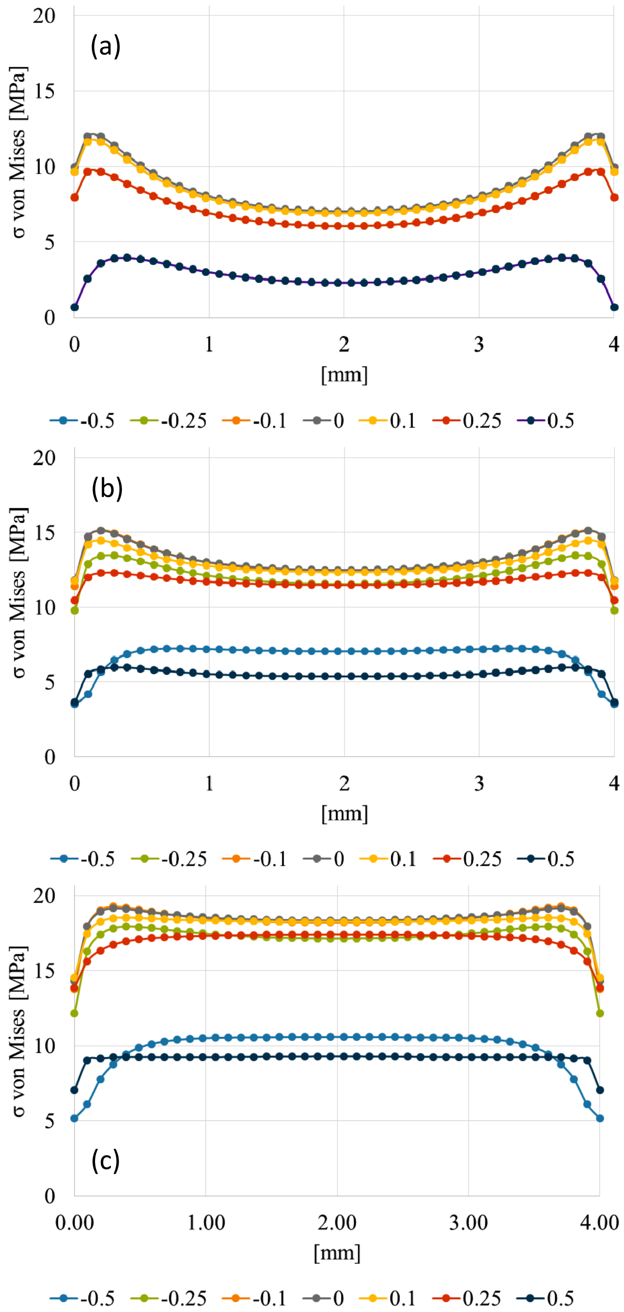


**Figure 8.** von Mises stress distributions along contact, the interface temperature being constant, 47 °C (graphics are drawn on non-deformed shape of the block): (a) μ = 0, (b) μ = 0.3 and (c) μ = 0.5

Section coded A, B, C, D, E, F are planes parallel to sliding direction. Plane B is at a distance of 0.1 mm from plane A, plane C at 0.25 mm to plane A, plane D at 0.5 mm to plane A and plane E to 0.75 mm to plane A, plane F is located in the middle of the contact, that is at a distance of 2.00 mm to plane A. Planes code by numbers are positioned as following: plane 0 is the plane in the middle of the static model and contain the ring axle. Planes -0.5 and 0.5 are located symmetrically in relation to the plane 0, at a distance equal to 0.5 mm. Planes -0.25 and 0.25 are placed at 0.25 mm from the plane 0. Planes -0.1 and 0.1 are placed at a distance of 0.1 mm from the plane 0.

## 3. RESULTS AND DISCUSSION

Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

For the model without friction and rotation (S+T), the curves of the equivalent stresses on the contact surface are symmetrical to a plane perpendicular to the middle of the contact (Fig. 9), the maximum value being obtained in the planes B and C, point out an edge effect and o zone with high equivalent stresses, the lower values being in the plane F. When friction exists, the shapes of the plots for von Mises stress are asymmetric and the maximum values monotonly increase to the value of the friction coefficient. The maximum values are situated in the front of the contact for all cases with friction.

**Table 2.** Maximum values of von Mises stress for the studied cases

| Case | μ | Plane (see Fig. 6) | | | | | |
|---|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F |
| S+T | 0 | 9.90 | 11.9 | 11.6 | 9.98 | 8.77 | 7.01 |
| (S+T+Cof) | 0.2 | 10.8 | 13.5 | 13.4 | 12.1 | 11.2 | 9.90 |
| | 0.3 | 11.7 | 14.7 | 14.9 | 14.1 | 13.3 | 12.3 |
| | 0.5 | 14.5 | 17.9 | 19.0 | 18.9 | 18.6 | 18.2 |

**Table 3.** Maximum values for stress

| Case | μ | $\sigma_{echiv.max}$ [MPa] | $\tau_{xy.max}$ [MPa] | $\tau_{yz.max}$ [MPa] | $\tau_{xz.max}$ [MPa] | $P$ [MPa] |
|---|---|---|---|---|---|---|
| S+T | 0 | 12.10 | 4.94 | 1.06 | 2.23 | 18.43 |
| S+T+Cof | 0.2 | 13.70 | 5.90 | 1.37 | 2.41 | 19.51 |
| | 0.3 | 15.16 | 6.50 | 1.66 | 2.48 | 19.51 |
| | 0.5 | 19.29 | 9.70 | 2.32 | 2.70 | 19.50 |

Along the contact (Fig. 8), in planes (-0.5, ... 0, ..., 0.5), the von Mises stress distributions are symmetric to the plane F (the middle of the

**Table 4.** Maximum values for strains

| Case | μ | Total strain, [mm] | Strain on X [mm] | Strain on Y [mm] | Strain on Z [mm] |
|---|---|---|---|---|---|
| S+T | 0 | 1.1921 e-002 | 1.7551 e-003 | -7.8833 e-004 | 5.8505 e-003 |
| (S+T+Cof) | 0.2 | 1.1921 e-002 | 1.7551 e-003 | -5.5288 e-004 | 6.0432 e-003 |
| | 0.3 | 1.1921e-002 | 1.7551 e-003 | -5.4978 e-004 | 6.1101 e-003 |
| | 0.5 | 1.1921 e-002 | 1.7551 e-003 | -5.4106 e-004 | 6.3145 e-003 |

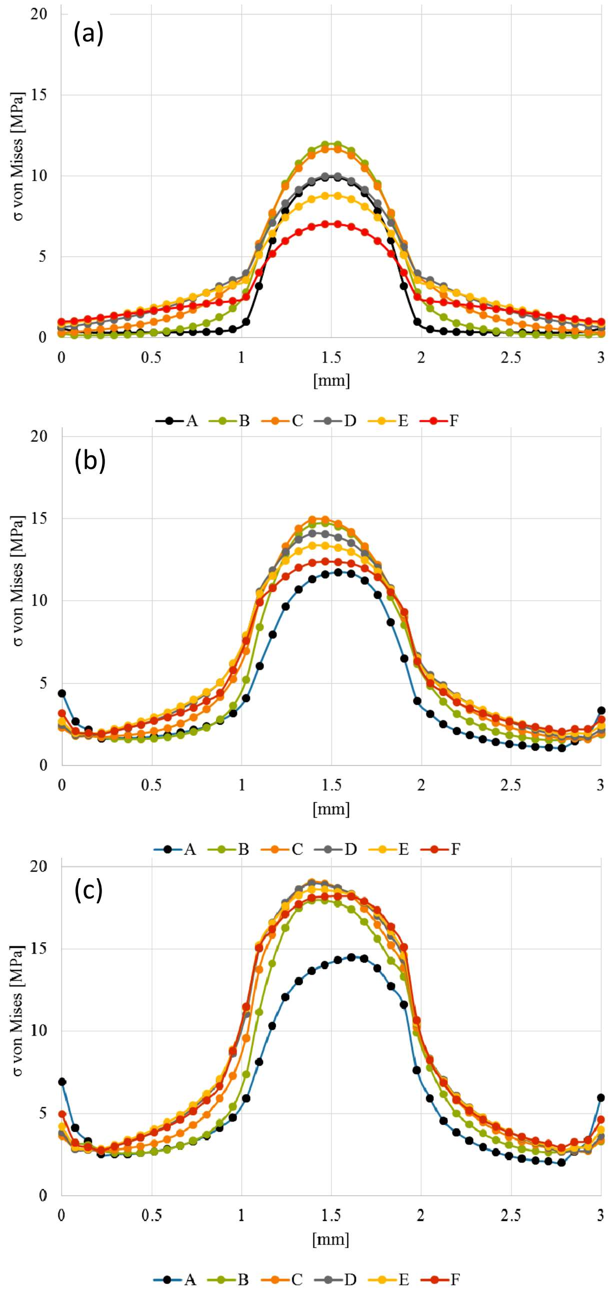


**Figure 9.** Graphics of von Mises stresses in the planes parallel to the lateral side of the block, in the sliding direction (for codes of planes A-F, Fig. 6) (all cases interface temperature is constant, 47 °C): (a) μ = 0, (b) μ = 0.3 and (c) μ = 0.5

contact), but when friction exists, in front of the contact there are maximum values (especially in the planes coded by -0.1 and -0,25) for low value of the friction coefficient (μ = 0.2) and for higher values of the friction ceofficient, the maximum values of von Mises stress are located in the planes -0.1 and -0.25 obtained for the coefficients of friction μ = 0.3 and μ = 0.5. Table 3 presents the maximum values of von Mises stress and shear stresses, for the four analyzed cases. For *F* = 30 N and the interface temperature being constant (47 °C), the values of von Mises stress are kept in the elastic domain for the polymeric block, for all analyzed cases (see also Fig. 8). Due to the low mechanical properties of the block made of PBT, the maximum values of the contact pressure, p, are kept in a narrow range for all cases (Table 3).

In the planes parallel to the sliding direction, an increase of the friction coefficient makes the contact zone to increase and the graphics of the equivalent stresses become more asymmetrical, the maximum values being moved towards the front of the contact.

In planes perpendicular to the sliding direction, the increase of the friction coefficient produces an attenuation of the edge effect, the difference between the maximum values and those between them being smaller for higher friction coefficients.

The total displacements on the contact surface and on the lateral side of the block are given in Fig. 10. One may notice the assymetric field of displacements when there is friction (here, μ = 0.0 - static and μ = 0.5 - with friction) on the contact surface and the displacement of the maximum values in the rotation direction of the ring.

These supplementary stresses, induced by the thermal field, are increased also due to the good insulating properties of the PBT, that do not allow for heat flow to quickly advance in the block, keeping a high temperature near the contact.

## 4. CONCLUSIONS

The thermal field induced by the difference between the values characterizing the steel

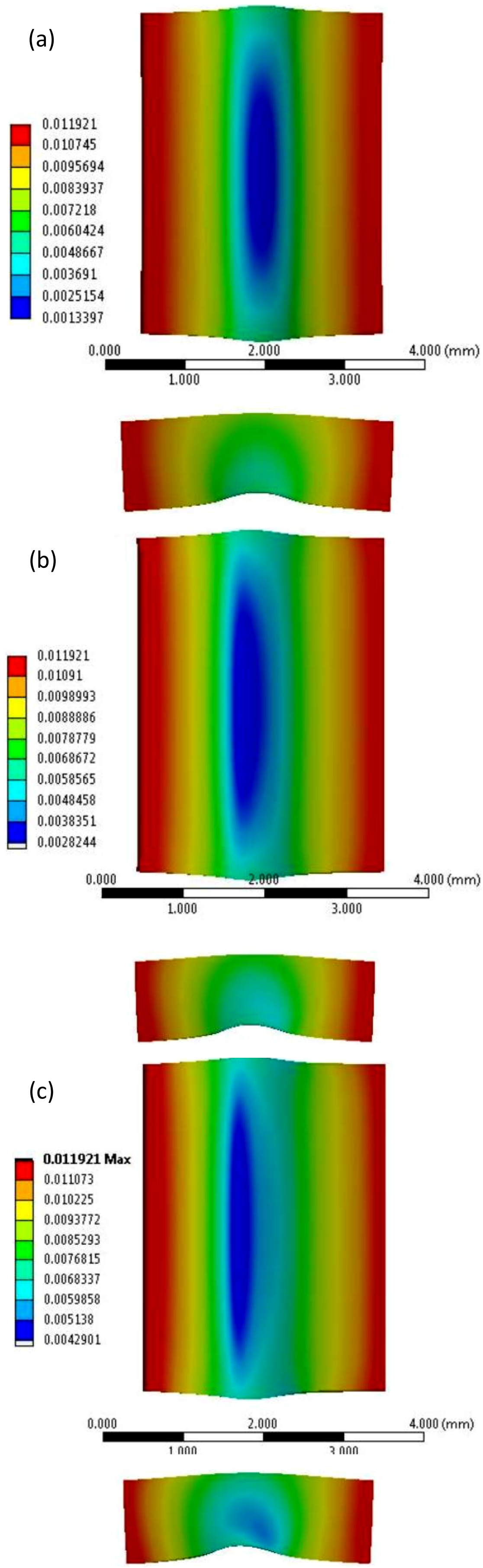


**Figure 10.** Total displacements for two cases (up – view of the block contact surface, down – lateral view): (a) μ = 0.0, (b) μ = 0.3 and (c) μ = 0.5

and the polymer when the contact temperature remains constant and a higher friction coefficient make the stresses to increases in the contact zone of the block. Also, the thermal insulating characteristics of PBT also makes the temperature to be kept high near the contact but to have a high gradient on the block high.

The friction produces an increase of the stress values, higher when the friction coefficient is higher. An increase of the friction coefficient produces a significant attenuation of edge effects, resulting a uniformization of the von Mises stress along the contact of polymeric block.

## ACKNOWLEDGEMENT

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## REFERENCES

[1] K.L. Johnson: *Contact mechanics*, Cambridge University Press, Cambridge, 1987.

[2] M. Botan: Mechanical and Tribological Characterization of a Polymeric Composite Category, PhD thesis, “Dunarea de Jos” University, Galati, 2014.

[3] C. Georgescu: *The Evolution of the Superficial Layers in Wear and Friction Processes Involving Composite Materials with Polybutylene Terephthalate*, Galati University Press, Galati, 2012.

[4] L. Kónya, K. Váradi: Wear simulation of a polymer-steel sliding pair considering temperature- and time-dependent material properties, in: K. Friedrich, A.K. Schlarb (Ed.): *Tribology of Polymeric Nanocomposites. Friction and Wear of Bulk Materials and Coatings*, Elsevier, Amsterdam, pp. 130-148, 2008.

[5] C.A. Harper: *Handbook of Plastics Technologies: The Complete Guide to Properties and Performance*, McGraw-Hill, New York, 2006.

[6] H.J. Radusch: Poly (butylene terephthalate), in: S. Fakirov (Ed.): *Handbook of Thermoplastic Polymers: Homopolymers, Copolymers, Blends and Composites*, Wiley Verlag, Weinheim, pp. 389-419, 2002.

[7] *ULTRADUR Polybutylene terephthalate (PBT)*, available at: http://www2.basf.us//PLASTICS WEB/displayanyfile?id=0901a5e1800bc1a9, accessed: 17.09.2014.

[8] *ANSYS, APDL14.0 User’s Guide*, 2011.

[9] V. Jinescu: *Proprietăţile fizice şi termomecanica materialelor plastice: Vol. I and II*, Ed. Tehnică, Bucharest, 1979.

[10] S.S. Creţu: *Contactul concentrat elastic-plastic*, Politehnium, Iaşi, 2009.

[11] D. Boazu, I. Gavrilescu: *Contactul mecanic. Analiză cu elemente finite*, EUROPLUS, Galaţi, 2006.

[12] D. Boazu, N. Talmaciu: *Teoria contactului*, Evrika, Brăila, 2000.

[13] G. Frunză, S. Spînu: *Fundamentele teoriei plasticităţii. Aplicaţii în mecanica contactului elasto-plastic*, Ed. Universităţii “Ştefan cel Mare”, Suceava, 2010.

[14] H. Benabdallah, D. Olender: Finite element simulation of the wear of polyoxymethylene in pin-on-disc configuration, Wear, Vol. 261, pp. 1213–1224, 2006.