Experimental investigations of micro-contact parameters by aid of laser profilometry and micro-indentation

Cornel Suciu [1), 2)], Marilena Glovnea[1)], Ionut Cristian Romanu[1)]

[1)] *Department of Mechanics and Technologies, Stefan cel Mare University of Suceava, Romania, 13 University Street, 720229, Stefan cel Mare University, Romania, e-mail: suciu@usm.ro*

[2)] *Faculty of Faculty of Electrical Engineering and Computer Science, Stefan cel Mare University, 720229 Suceava, Romania, e-mail: camil.suciu@student.usv.ro*

The present paper proposes an experimental test rig and methodology for the optical evaluation of micro-contact parameters in the case of micro-indentation tests of elastic materials with rigid indenters. Micro-contacts between small steel punches, of various shapes (considered rigid) and the flat surface of a synthetic glass (considered elastic), were investigated experimentally.

The dimensions of the micro-indentation imprints determined by aid of laser profilometry were compared to theoretical results yielded by theoretical models from literature, [1, 2, 4], and good agreement was found. In order to verify whether the contact took place in the elastic or plastic domain, the tested surface was rescanned after a longer period of time, and it was determined that no remnant imprint was left. This confirms that the test was conducted in the elastic domain.

Keywords: micro-contacts, micro-indentation, contact parameters, laser profilometry

1. INTRODUCTION

One of the fundamental hypotheses of elasticity theory is that the media from which mechanical bodies are made are continuous. This hypothesis allows to easily applying the theory of continuous variable functions for the macroscopic scale studies. At the micro and nano-scale however, matter is discontinuous and elasticity theory might not apply.

Numerical modelling of any process or phenomenon is accepted only if its results are validated by other analytical, numerical or experimental approaches. Validation of numerical modelling of elastic contact problems can be performed on both Hertz and other elastic contacts for which analytical solutions exist in the literature.

The work presented in this paper aims to experimentally verify whether classical contact mechanics theory is applicable to micro-contacts parameters. Also, the obtained experimental results are compared to theoretical results found in literature [1, 2] and to results obtained, using numerical modeling proposed by the authors in [4].

Figure 1 shows the indentation (penetration) problem with a rigid spherical indenter of an isotropic elastic half-space characterized by a Young's modulus, and Poisson's coefficient. The centrally applied normal force produces a penetration depth at the tip of the indenter. The resulting contact domain is a spherical cap and its projection on the plane is a circular surface.

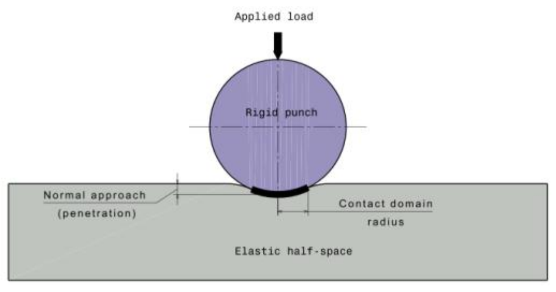

Figure 1. Contact between a rigid spherical punch and an elastic half-space

2. EXPERIMENTAL SETUP AND METHODOLOGY

In order to conduct the proposed experimental tests, an experimental set-up previously developed by the authors, [3], was adapted and reconfigured. The test rig structure is represented three dimensionally in Figure 2.

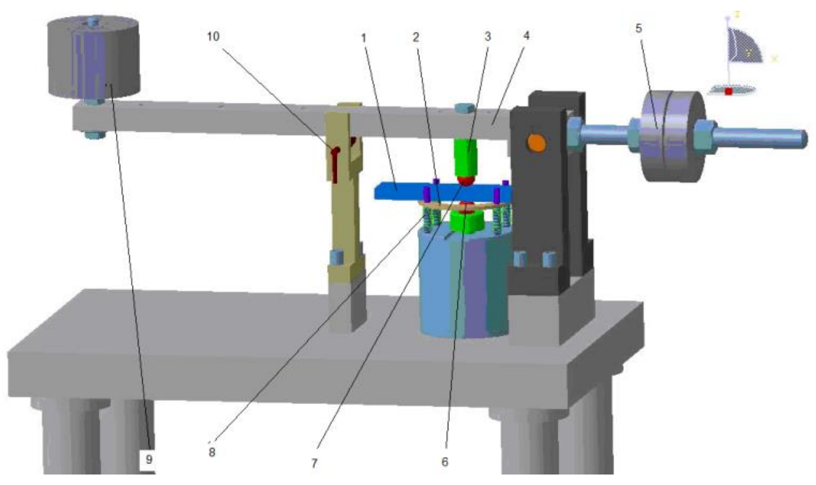

Figure 2. Experimental set-up for load application (3D model)

The test plate (1) is placed on a metal ring (2) which is in turn guided on four metal rods. Sliding adjustments have been made between the guide rods and the metal ring, so that the ring is only allowed to move in the vertical direction.

In order to prevent contact between the test plate (1) and the penetrator (6) until the normal loading force is applied, the metal ring rests on four identical springs (8). They keep the contact open until the load is applied. For the load applied by the cantilever arm (4) to the contact, to be normal, the test plate (1) is pressed by means of another punch, (7). The upper punch (7) rests on a conical surface fitted inside the support (3) at the top and on the test plate at the bottom. This mechanism ensures a normal loading of the contact between the penetrator (6) and the plate (1), even if the cantilever arm (4) has a slight inclination. The system consisting of the upper ball (7) and its support (3) is placed in an elongated hole made in the cantilever arm (4), fixing it in a centric position, by aid of a screw. The cantilever arm's (4) own weight is balanced by the counterweights (5), thus the applied force is only given by the deadweights (9) and the cantilever's arm lengths. For the described experimental set-up, if Q denotes the force with which the micro-indentation is to be performed and G is the gravitational force generated by the deadweights (9), depending on the component lengths of the rod (4) we can write: $G=(70/365)\cdot Q$. Figure 3 shows a detail of the loading area of the test specimen, the penetrator being materialized by a roller. The metal ring, the guide rods and the four identical springs can be seen.

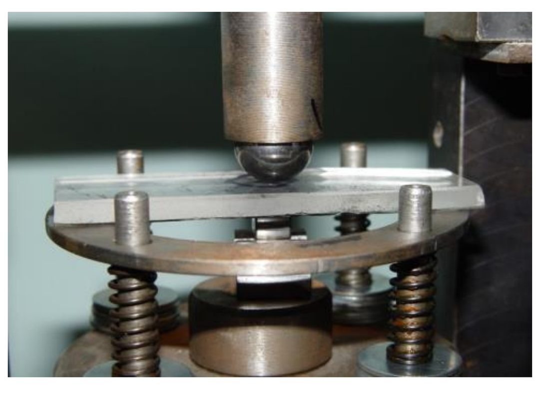

Figure 3. Detail of the loading area

3. EXPERIMENTAL TESTS AND RESULTS

Using the test rig described above, two types of tests were conducted, using two different shape penetrators, pressed against the flat surface of a synthetic glass plate. A steel ball with a diameter of 6.33 mm and a roller with a length of 7.4 mm and a maximum diameter of 8.46 mm were used as penetrators. Both elements being bearing bodies are considered as rigid penetrators.

The test material was initially a synthetic glass plate with numerous scratches on the front surfaces. The penetrator used was a 6.33 mm diameter bearing ball. Measurements were repeated with a plate of another type of synthetic glass, 9.05 mm thick, much more transparent and with a flat test surface without major defects. The elastic parameters of the synthetic glass are: $v=0.35$ and $E=2.38\cdot 10^{11}$ Pa . The micro-contact tests in this case involved the use of both penetrators. A picture of the Plexiglas plate and the penetrators is shown in Figure 4.

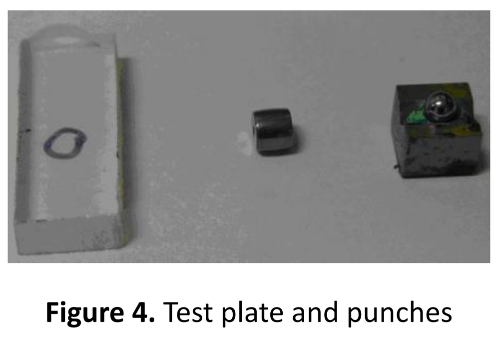

Figure 4. Test plate and punches

The loading force was 200 N, achieved by means of the lever system described above, using 2.28 kg counterweights and 3.83 kg deadweights.

For both tests the procedure was identical: the test plate was positioned on the metal ring, with the investigated surface down, above the penetrator. The weights used to achieve the desired load were positioned on the cantilever arm (4), during which time the micro-contact was kept open by means of the eccentric (10) and the springs. By rotating the eccentric, the arm (4) and the support (3) lower, so that the test plate is pressed against the penetrator.

After about 15 seconds, the load was removed and the micro-contact was opened. An imprint has remained on the lower surface of the sample, the shape of which is dependent on the type of penetrator. The synthetic glass plate is removed from the stand and its surface micro-topography is mapped using a laser profilometer.

Barrel roller punch – synthetic glass plate micro-contact

The profile of the penetrating roller is shown in Figure 5a, while Figure 5b shows a 3D sample measurement of the imprint.

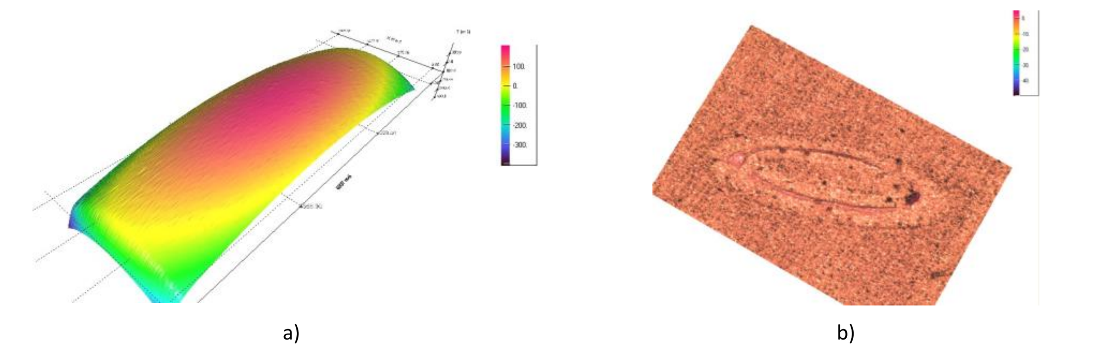

Figure 5. 3D Representation of a) roller punch surface, b) micro-indentation imprint

Using the laser profilometer, the roller shown in Figure 5a was scanned to see exactly what the radii are in the longitudinal and transverse directions. Figure 6 shows the reports given by the profilometer software on the values of the searched radii. These were $R_1 = 27.615\cdot 10^{-3}$ m (Figure 6a) and $R_2 = 4.311\cdot 10^{-3}$ m (Figure 6b).

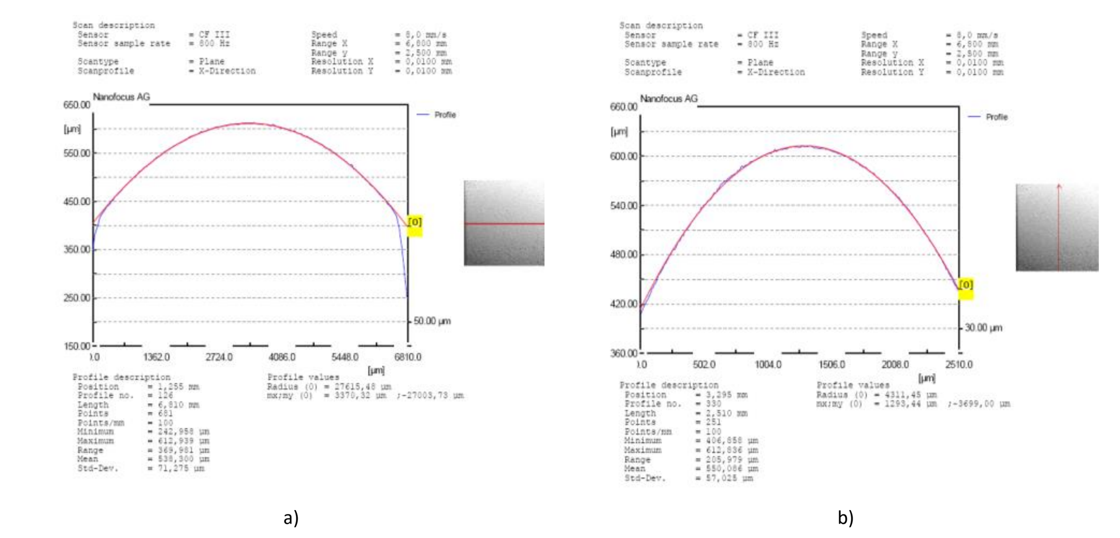

Figure 6. Reports on the roller indenter radii: a) profile along transverse direction, b) profile along longitudinal direction

A measurement report obtained on the micro-indentation contact ellipse shape and dimensions is shown in Figure 7.

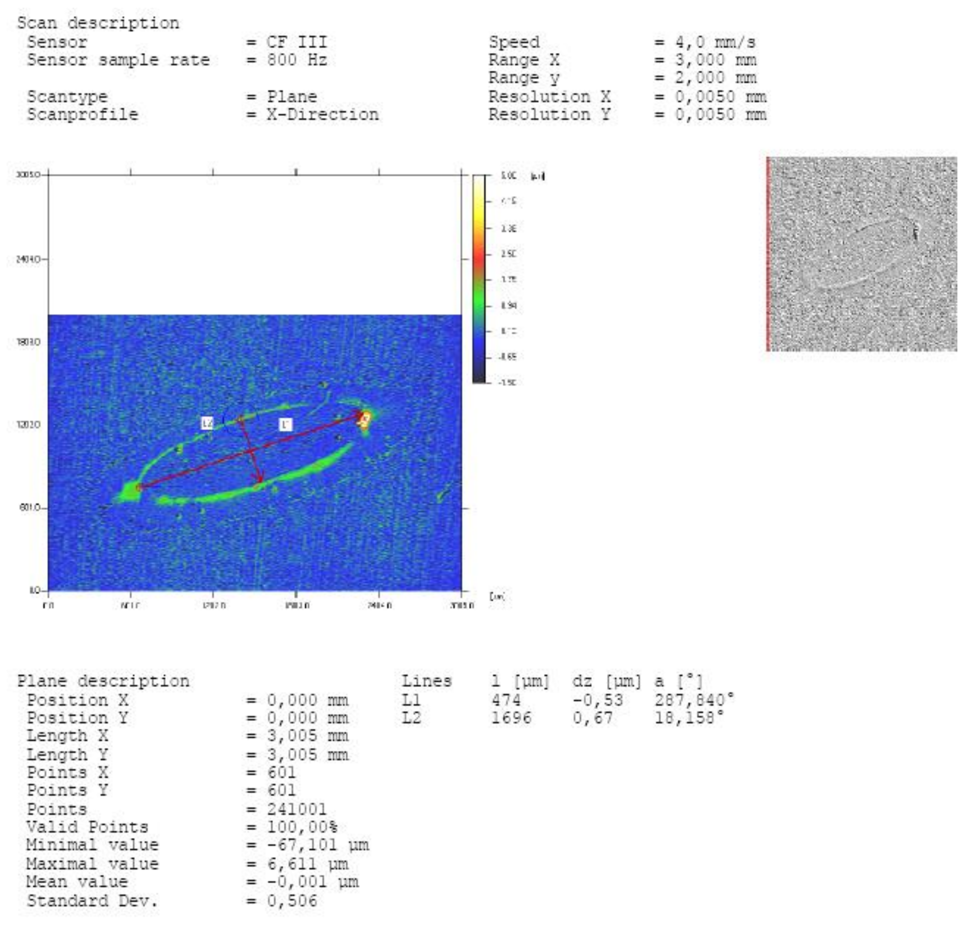

Figure 7. Micro-indentation ellipse dimensions

Spherical punch – synthetic glass plate micro-contact

As stated, initial tests were conducted using a Plexiglas plate with multiple signs of damage. As the fingerprint was not visible, the "carbon black method" used by the late Professor Ioan Crudu in Galati, transformed into the "toner black method" in Suceava, was used. Thus, a very thin layer of toner was deposited on the surface to be tested and the indentation was made. The impression obtained was analyzed with the laser profilometer. The results obtained are visualized as shown in the Figure 8: imprint surface micro-topography (Figure 8a) and imprint reflectivity (Figure 8b). In Figure 8a the presence of numerous surface irregularities can be observed.

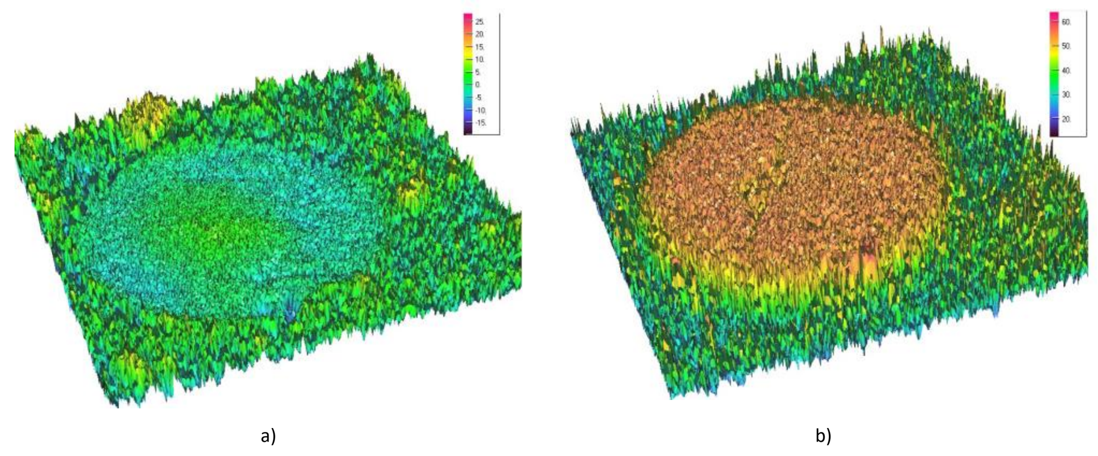

Figure 8. a) Imprint surface micro-topography (with toner); b) Imprint surface reflectivity (with toner)

Since the initial results were unsatisfactory, the tests were repeated using a higher quality synthetic glass plate. A 3D image of the micro-indentation imprint is shown as a 3D representation of micro-topography in Figure 9.

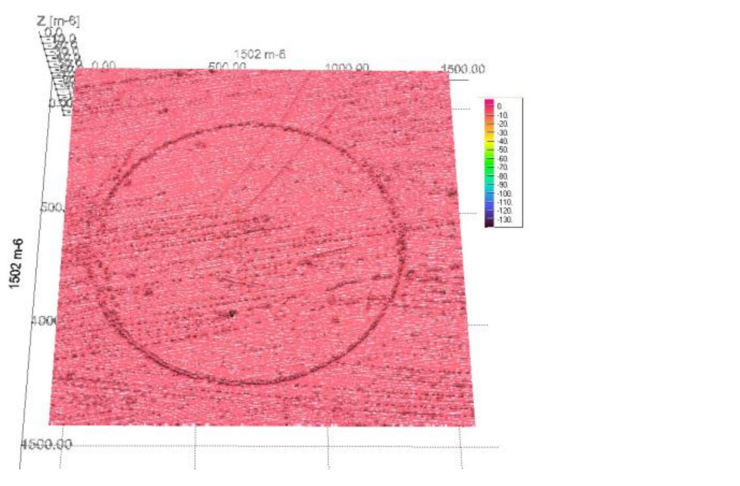

Figure 9. 3D representation of micro-indentation imprint micro-topography

Sample profilometer reports on this type of micro-indentation, showing the contact circle, are shown in Figures 10a -profile and Figure 10b - reflectivity.

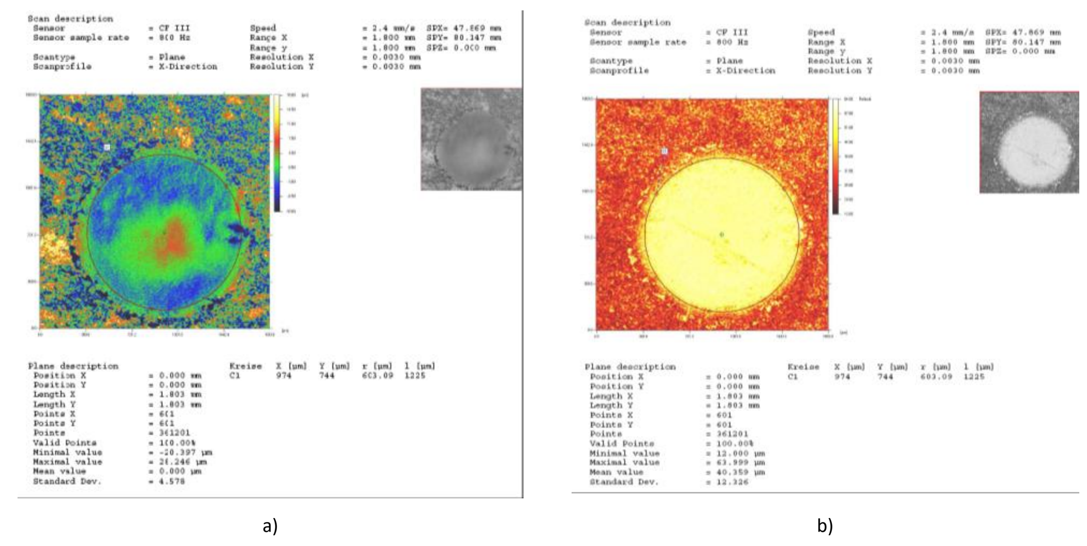

Figure 10. Laser profilometry report on the micro-indentation area: a) surface micro-topography; b) reflectivity

To verify that whether the contact took place in the elastic or plastic domain, the tested surface was rescanned after a period of time, and it was determined that no remnant imprint was found, as shown in Figure 11. This confirms that the test was conducted in the elastic domain.

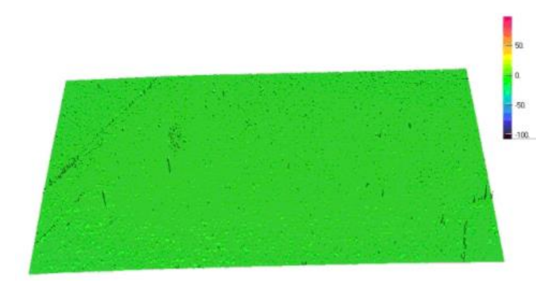

Figure 11. Synthetic glass surface after return

The dimensions of the micro-indentation imprints determined by aid of laser profilometry were compared to theoretical results yielded by theoretical models from literature [4], and good agreement was found.

In the case of micro-indentation with a spherical indenter, the numerical results are shown comparatively in Table 1.

Table 1. Comparison between experimental and theoretical results for contact parameters – spherical indenter

Evaluation Method	Maximum Pressure [MPa]	Normal approach (penetration), [mm]	Contact area [mm^2]	Large half-axis [mm]
Analytic, [4]	316.8063	0.1006	0.9473	0.5491
Numeric, [4]	316.244	0.1062	0.9496	0.5495
Experimental	-	-	1.1417	0.603

The experiment resulted in a micro-indentation radius of 0.60309 mm, as reported in Figure 9. The difference from the theoretical results from [4], shown in Table 1, results from the fact that the experimental micro-penetration was done with a ball having a diameter of 6.33 mm and not 6 mm as considered in the numerical and analytical modelling. Another reason for the difference would be related to the fact that the values for the Poisson's ratio and the longitudinal modulus of elasticity of the tested material are not known exactly.

In the case of micro-indentation with a roller indenter, the numerical results are shown comparatively in Table 2.

Table 2. Comparison between Experimental and theoretical results for contact parameters – ellipsoidal indenter

Evaluation Method	Maximum Pressure [MPa]	Normal approach (penetration), [mm]	Contact area [mm^2]	Large half -axis [mm]	Small half -axis [mm]
Analytic, [4]	146.04	0.06252	2.047	1.488	0.439
Numeric, [4]	146.08	0.06248	1.954	1.488	0.418
Experimental	-	-	2.525	1.696	0.474

4. CONCLUSIONS

A good agreement of the values for the small half-axis of the contact area obtained analytically, numerically and experimentally is observed. A rather large difference appears between the values determined analytically-numerically and experimentally at the large semi-axis. This difference could be attributed to the approximation of the large half-axis on the profilometer image, but also to the values of the elastic parameters of the used synthetic glass.

No micro-indentation tests with ellipsoidal penetrators were found in literature. This is because indentation is usually related to hardness tests, and hardness testers already have well established shapes for hardness determination.

The fact that after some time no traces of micro-indentation were observed confirms that the indentation was done in the elastic domain and the use of Hertz formulas was fully justified.

From the above presented results it can be concluded that the mathematical models developed for the dependence between the micro-contact parameters and the mechanical properties of the materials in contact have been validated both theoretically and experimentally.

REFERENCES

1) Johnson, K.L., [Contact Mechanics], Cambridge University Press, (1985).
2) Dimitriu, D., Rugină, C., „Quasi-static normal indentation of an elastic material with a rigid spherical tip indentation", SISOM 2011 and Session of the Commission of Acoustics, Bucharest , p. 254-258., (2011)
3) Suciu, C., [Theoretical and experimental research regardind the evaluation of contact pressure between real surfaces by aid of reflectivity], PhD Thesis (in Romanian), Stefan cel Mare University of Suceava, 2012.
4) Glovnea, M., Suciu, C., Manolache-Rusu, I.C., "Theoretical modeling of the dependence between micro-contact parameters and mechanical properties of contact materials", The 11th edition of the International Conference "Advanced Topics in Optoelectronics, Microelectronics and Nanotechnologies", Constanta, Romania, (2022)