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A CONSEQUENCE OF POST-IMPACT RADIAL PROFILE SHAPE OF INDENTATION. PART I: EXPERIMENTAL EVIDENCES

Florina Carmen CIORNEI[1], Stelian ALACI[2]
[1] Stefan cel Mare University, Suceava, e-mai: florina@fim.usv.ro
[2] Stefan cel Mare University, Suceava, e-mail: alaci@fim.usv.ro

***Abstract*—**The remnant imprint from the surface of a rotating disc collided by a dropping steel ball is experimentally analysed. The study of post-impact indentation performed via laser scanning technique revealed a systematic aspect concerning the radial profile of the imprint, namely a deviation from the slope predicted by theory of elasticity in the region between imprint and the periphery of the disc.

***Keywords*—**Plastic impact, rotating disc, scanned indentation

I. INTRODUCTION

MECHANICAL systems from engineering applications are assemblies of simpler elements that, in order to fulfil the running task, interact with each other. The interaction between the parts of a system can be accomplished in two ways: by direct contact or by means of a field. The handiest example illustrating the two modalities of interaction is the shaft and bore assembly.

The requirement of diminished friction between the two parts conducted to the introduction of a third element, the ball bearing (mechanical contact) or the magnetic bearing (the non-contact solution). In most of the applications from mechanical engineering between the elements of a system a direct contact occurs, and this subject continues to be a matter of awareness.

The first research in contact mechanics domain is due to Boussinesq, [1], who finds the stress state and strain state due to a concentrated normal load acting on the surface of an isotropic elastic halfspace.

The problem for the loading of an isotropic elastic halfspace by a concentrated tangential load was solved by Cerruti. The reference paper in the elastic contact domain was elaborated by Hertz [2], who establishes the relations describing the stress state and strain state between two elastic non-conforming bodies in contact, in the absence of friction. Though the results of Hertz's problem concern the static load, when the normal loading between bodies increases infinity slow from zero to the nominal value, they are applied in different fields of mechanical engineering. When modelling the impact between two bodies, the relation is expressing the dependence of the interaction force by the normal approach raised to power 3/2, is the basis of viscoelastic impact model.

A recent paper of Alves [3], is an exhaustive review of viscoelastic impact models from the literature and confirms the above affirmation. From the 15 viscoelastic impact models presented in the mentioned paper, 14 consider that the relation describing the force variation with normal approach is a Hertz type relation, despite the fact that during impact processes the velocity variations are extremely important and the accelerations reach an order of 10.000g.

Johnson gave a reference book in contact mechanics, [4]; citing Zukas, Johnson shows that the elastic contact hypothesis is extremely restrictive and justifies this affirmation by proving that a ball in impact with a flat surface will produce a plastic indent if the free falling height is of orders of millimetres.

The indentation remnant after an impact process offers important information. One of the essential application of plastic indentations, referring to shape and dimensions, is hardness testing. Tabor [5], proposes a simple theory concerning static and dynamic hardness evaluation. In order to estimate the work of plastic deformation, Tabor adopt Meyer's hypothesis, similar to the elastic contact model, the interaction force being proportional to the approach raised at power q, $1 \le q \le 3/2$, the extreme values corresponding to plastic deformation, $q = 1$ and elastic deformation, $q = 3/2$ respectively. This assumption was adopted by Goldsmith too, [6], who, in addition, accepts that the restitution phase is always elastic. Oliver and co-workers, [7]-[12], consider the same hypothesis and based on theoretical results obtained by Sneddon, [13] propose a new method of hardness evaluation, based on impact force variation with normal approach. Field and Swain, [14], [15] and Swain, [16], use the imprints obtained by spherical indenters in hardness estimations. Another domain where the analysis of plastic imprints is a main source of information is the automotive crash study, [17]-[19].

II. Imprint Shape subsequent to Disc and Free Falling Ball Impact

The post-impact kinematics for a system with percussions was the main subject studied in a series of recent own works. The requirement of obtaining analytical models compels to using shapes as simple as possible for the impacting bodies. Therefore, numbers of works concerning dynamical modelling of systems with collisions consider the unidirectional collision of two spheres as the basic model. With the intention of maintaining geometric simplicity and obtaining a spatial motion between the elements subjected to collision, the impact between a disc rotating around a vertical axis and a free falling metallic ball was considered, Fig. 1.

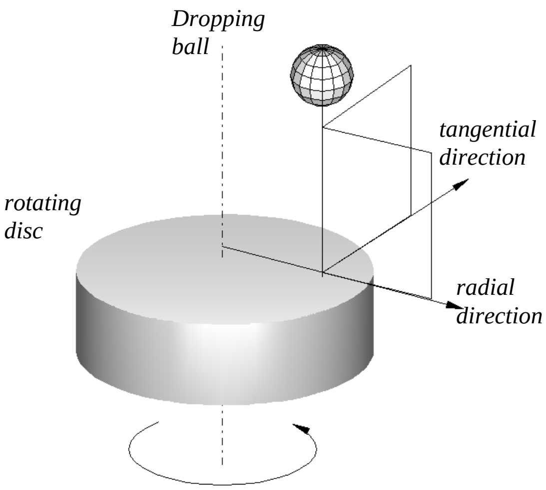

Fig. 1. Experimental set-up principle

The disc is driven in rotation motion using a d.c. engine; the rotation velocity is controlled varying the voltage and measured using a non-contact tachometer.

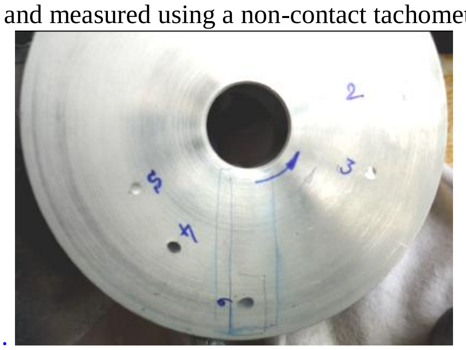

Fig. 2. Post-impact plastic marks on the disc

The velocity of the ball can be precisely controlled by measuring the height from which the sphere is set to fall free. Following the collision, the post-impact plastic indentations can be observed on the surface of the disc, Fig. 2.

Since the plastic imprints shapes and dimensions offer numerous data concerning impact kinematics and impact dynamics, the imprints from the disc's surface were laser scanned for shape and dimensions analysis.

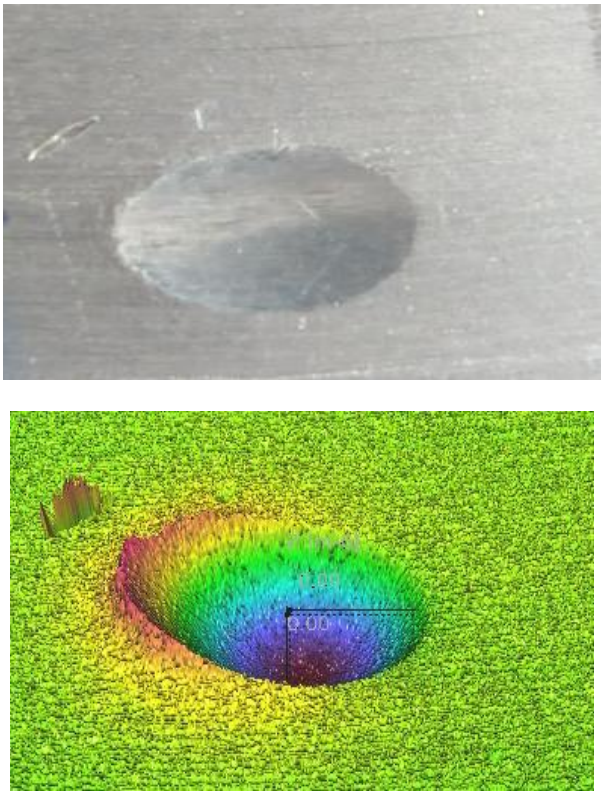

Fig. 3. Photo image and 3D scanned image of a plastic imprint from an aluminium disc

In order to perform the analysis, two indentation profiles, radial and tangential, were defined. The section planes for obtaining these profiles are defined by the vertical direction in the impact point and the vector position radius of this point, and by the impact point vertical direction and the velocity of the point, respectively.

The radial profile of an indentation is presented in Fig. 4.a and the tangential profile is shown in Fig, 4.b.

For comparing several tangential profiles, it was chosen [20] bringing all the profiles with the point A at a common point. To evaluate the profiles of the same indentation, [21] both profiles were brought to the minimum point of imprint in the same point.

Fig. 5 presents the radial and tangential profiles together with the ideal profile of the ball, for the case of a steel ball impacting a steel disc that rotates with a velocity of 4000 rot/min.

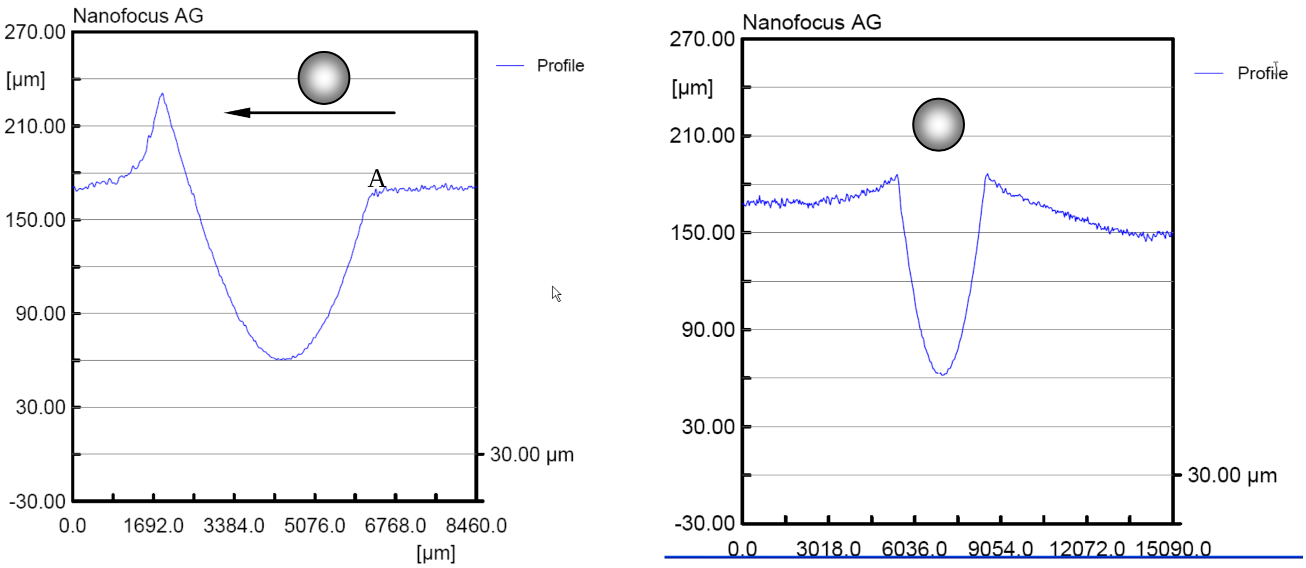

Fig. 4. Tangential and radial profiles of indentation on aluminium disc

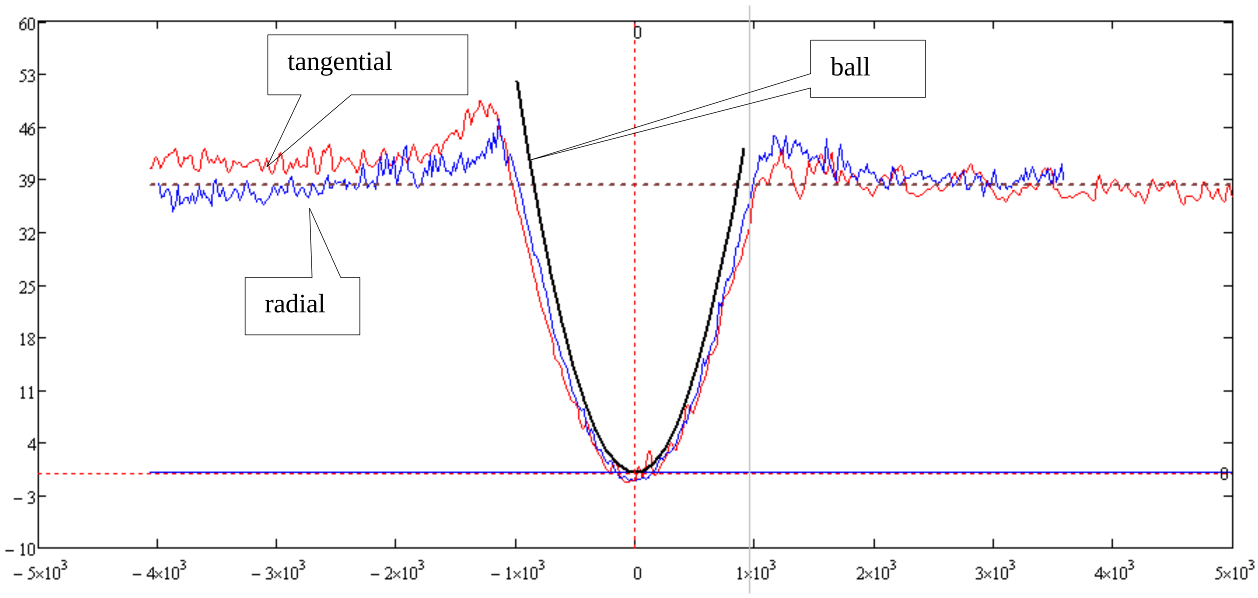

Fig. 5. Comparison between radial and tangential profiles

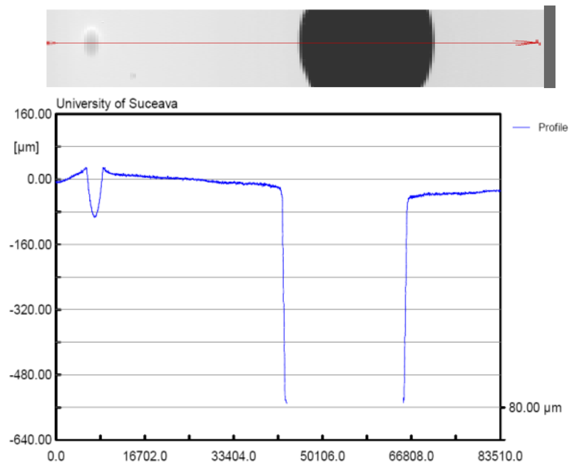

Fig. 6. Axial section through the disc

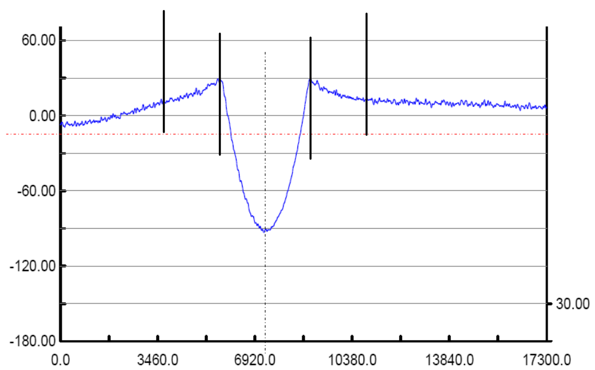

Fig.7. Detail from radial section

From Fig. 5 it can be observed that tangential profile is strongly asymmetric and presents the pile-up phenomenon. By tracing the medium horizontal for the tangential profile region in front of the imprint one can observe that with the exception of a reduced zone, comparable with the imprint's radius, the two profiles are practically identical.

The same conclusion results more clearly by analysing the profiles from the imprints on the aluminium disc. It is observable that for the tangential profile, in the contact initiating region, the pile-up phenomenon is absent while in the exit region it is strongly present. For the radial profile, the indentation presents a very good symmetry while outside the imprint, the asymmetry is obvious. From Fig. 4.a, it cannot be mentioned on which side if the figure the axis of the disc is situated.

The test was repeated, and an orientation scratch on the disc surface was made. A new scanning operation leads to the conclusion that *the lower region from the outside radial profile is situated towards disc's periphery*. To remove any possibility of the presence of parallelism deviation between the face of the disc with the indentation and the opposite one, the positioning face for laser scanner examination, the entire surface of the disc was analysed.

From Fig. 6 it is confirmed that there is no deviation, but there is a change in the slope of the radial profile of the indentation in the impact zone.

Fig. 7 presents a detail where it was traced the medium horizontal to the disc's surface and the axis of the imprint. The obvious observation is that the portion of the radial profile placed peripheral with respect to the imprint is situated below the undeformed surface and one can state that the region where the impact influence is noticed has reduced dimensions – a size order of one imprint radius.

III. CONCLUSIONS

The paper presents the shape and dimensions of indentations resulting from the impact of a free-falling ball bearing and the frontal surface of a metallic disc that rotates around a vertical axis. The analysis of the profile in radial section, that contains the axis of the disc and the impact point, shows that the region from the profile involved in contact divides the profile in two zones: a central one, where the remnant deformations are situated strictly in the vicinity of contact region and a second zone, peripheral, where there can be remarked both a pile-up local deformation but also a more extended deformation, characterized by an inclination of the whole profile.

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