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A CONSEQUENCE OF POST-IMPACT RADIAL PROFILE SHAPE OF INDENTATION. PART II: A POSSIBLE EXPLANATION

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Abstract—The shape of the radial profile of a rotating disc, is different in the case when a free falling ball collides the disc, presents in the region between the imprint and the periphery of the disc a different shape from the one it has in absence of contact. Accepting, in accordance to Saint-Venant's principle that at distances far enough from the region the load is applied, it doesn't matter the manner of applying the load, under the hypothesis of linear elastic behaviour of material and using a FEA software, the phenomenon is modelled. There were considered the cases of rotating disc without impact, the impact of free falling ball with the resting disc and the impact with the rotating disc and for neither one of the situations the material in the vicinity of the disc periphery reaches the plastic deformation domain.

Keywords—impact, plastic indentation, contact stress

I. Introduction

THE first part of the paper there were presented images of radial and tangential profiles of an indentation obtained when a free falling ball collides the plane face of a rotating cylinder. Comparing the two profiles, the pile-up phenomenon was observed in both sections, a fact perfectly explainable, according to [1] and [2].

A less expected aspect concerns the shape of the profile from radial section. Similarly to the tangential profile, the radial profile presents asymmetry with respect to the axis of contact region but while for the tangential profile, the asymmetry is strictly local, occurring on a length approximately equal to the maximum contact radius, for the radial profile, the asymmetry becomes more pronounced as leaving from the contact centre.

Considering the complex phenomena occurring and the intricate relative motions on the contact area, a quantitative validation is difficult to obtain.

For cases where a series of simplifying hypothesis are accepted, the literature presents analytical or numerical solutions, [3]-[9].

For a better illustration of the considered issues, a new launching of the ball was made, from a height of h=0.89 m, onto an aluminium disc, with diameter Φ=115 mm and thickness 22 mm, rotating with a velocity 400 rot/min. The normal coefficient of restitution is c=0.14 and the radius of impact point is r_c=45 mm. The radial and tangential profiles are presented comparatively in Fig. 1.

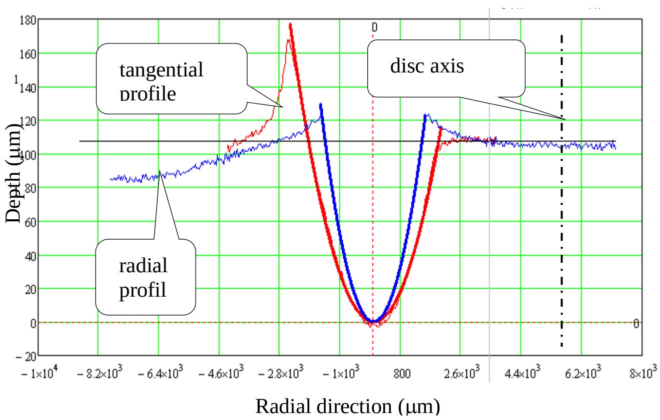

Fig.1. Radial and tangential profiles

From Fig. 1 it can be clearly observed that in the radial profile there is a monotony alteration near the impact region.

II. FEA Modelling of Disc

In the case of lack of spherical imprint, the axial deformations of the rotating disc are given by the relation, [10]:

$$\varepsilon_{zz} = -\nu\frac{\rho_0\omega^2}{8E}\left[2(3+\nu)a^2-(3\nu+2)r^2\right] \qquad (1)$$

where ν is the Poisson coefficient of the disc's material, E is the Young modulus, ω is the angular velocity of the disc, a is the exterior disc radius and ρ_0 is the density of the disc's material.

Considering the axial strain:

$$\varepsilon_{zz} = \frac{h - h_0}{h_0} \tag{2}$$

where h_0 is the initial disc thickness and h is the current thickness, it results that the axial profile of the disc for the operating angular velocity has a parabolic shape, the minimum thickness of the disc being obtained in the centre of the disc.

Starting from this observation, the deformation of the disc was modelled using FEA. To reduce the computation time, there were employed the observation referring to the geometry and loading symmetries: any axial disc section will remain plane and the median central plane of the disc will remain plane, too. Fig. 2.a presents the constraints imposed and the loads applied to the cylindrical sector used in modelling the centrifugal effect upon the disc with central hole.

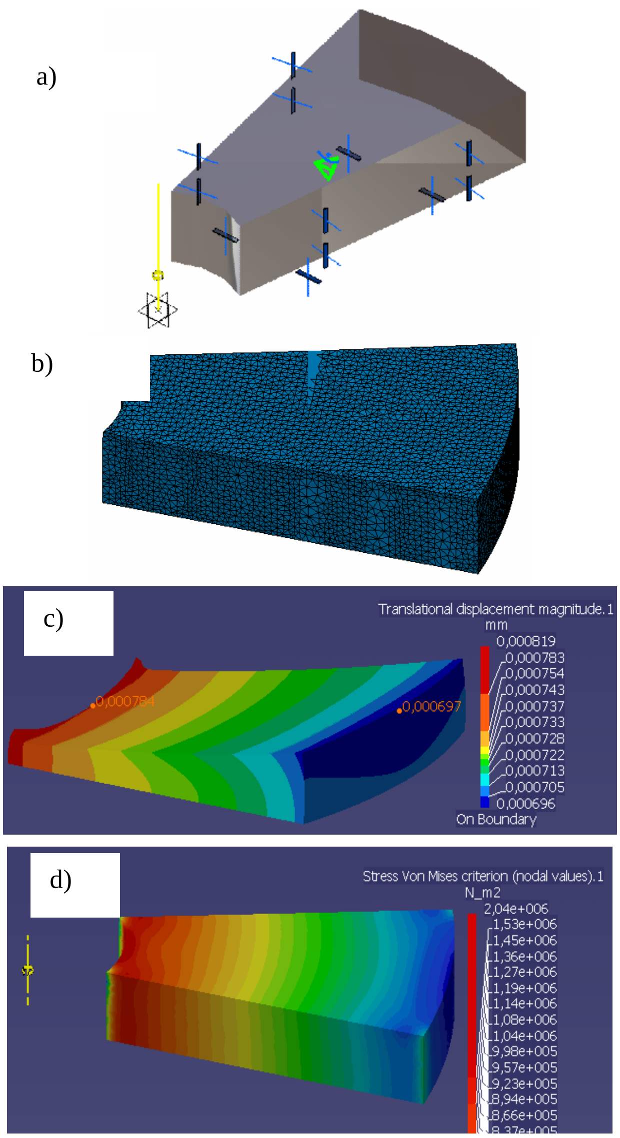

Fig.2. FEA modelling of a disc slice in rotation motion

The mesh was optimized as shown in Fig. 2.b. The values of axial displacements are presented in Fig. 2.c and it can be noticed that in the regions with slope discontinuities, there occur deformations that there are not real. In Fig. 2.d there are presented the values of equivalent von Mises stresses. To be noticed that for the angular velocity 4000 rot/min, the equivalent stress doesn't reach the yield stress value $\sigma_Y = 95\,MPa$.

To obtain the accurate shape of the deformed section, the whole disc should be studied. Therefore, for the complete disc, in order to impede the rotation, and instead of using fictive elastic elements as the used software generally applies, it was preferred the attachment of there angularly equidistant cylindrical spokes, oriented on radial direction, as in Fig. 3.a. The restraint of glide upon their surfaces ensures the totality of required constraints. The influence these spokes upon the stress field is negligible, as noticed in Fig. 3.b, where the axial symmetry is undisturbed. The axial displacements are presented in Fig. 3.c together with the deformed shape of the disc. Except for the vicinity of the central whole, the shape of the deformed axial profile is in complete agreement with (1).

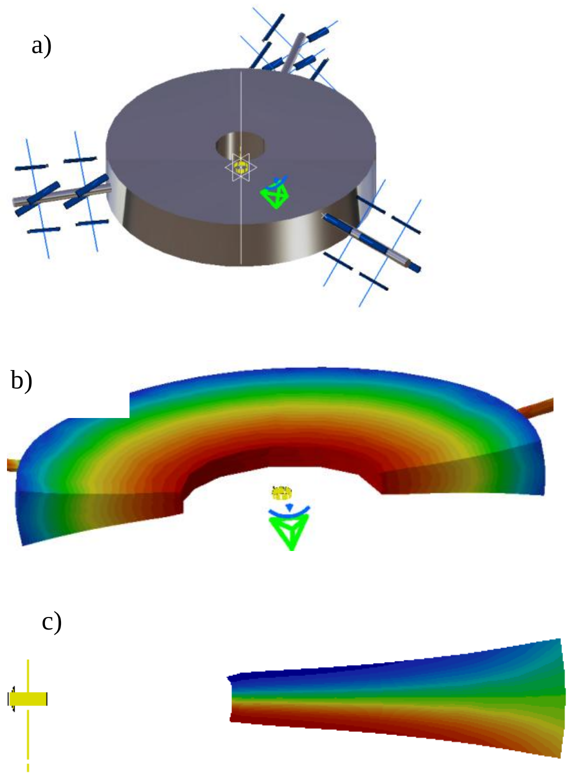

Fig. 3. FEA analysis of a disc in rotation: a) imposed constraints; b) stress field; c) deformed shape

Considering the effect of impact between the free falling ball and disc, it has a strictly local character, where the plastic imprint perturbs the stress field. Thus, subsequent to the ball-plane collision, the plastic imprint behaves as a stress concentrator. A disc with a spherical cavity on the surface, in rotation motion, was modelled and the equivalent von Mises stresses are presented in Fig. 4. The concentrator effect of the crater is strictly local. As example, in the case of a circular hole in an elastic plane uniformly stretched at infinity, the stress concentration factor, denoted SCF, is 3, according to Rekach, [11]. Alaci [12] shows that the concentrator effect diminishes rapidly, and at a distance of 3 radii with respect to the centre of the hole, the stress concentrator coefficient, is only 1.02. This observation is valid for spatial situations too. For a spherical cavity situated in an elastic space, [13], SCF is:

$$\mathbf{SCF} = \frac{3(9-5\nu)}{2(7-5\nu)} \qquad (3)$$

and for steel, ν=0.3, takes the value 2.045. In fig. 4 is presented the concentrator effect produced upon a disc by a spherical cavity at the surface.

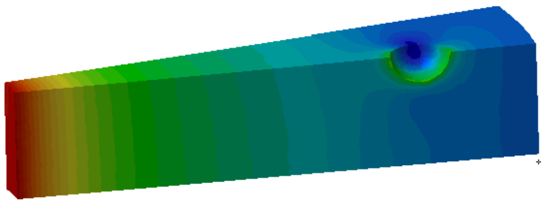

Fig. 4. Stress concentrator effect of a spherical indentation

Therefore, one can affirm that the presence of spherical indentation is not responsible of the alteration of radial profile from the vicinity of disc's periphery.

III. Ball-Immobile Disc Impact

A dilemma occurring in modelling the impact ball-fixed disc is the evaluation of maximum normal load. One possible solution could be to evaluate this normal force using the relation given by Timoshenko, [14], for the impact of two elastic metallic balls. Considering the fact that the impact with the aluminium disc is closer to a plastic impact, [15], the maximum force is estimated based on the viscoelastic model proposed by Flores, [16].

Fig. 5 presents the loading-unloading curves for the elastic impact and for the dumped viscoelastic impact.

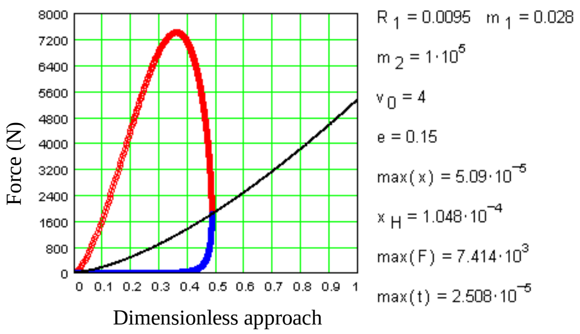

Fig. 5. Loading curves for elastic and dumped impact (loop)

One can observe that for a loading force value F=10000 N, both impact cases are estimated. The von Mises stress field with values greater than the yield stress σ_Y is presented in Fig. 5.a, and it can be noticed that yield is present only at the boundary of ball-disc contact.

The normal stress σ_z is presented in Fig. 5.b, and the axial displacement u_z is shown in Fig. 5.c.

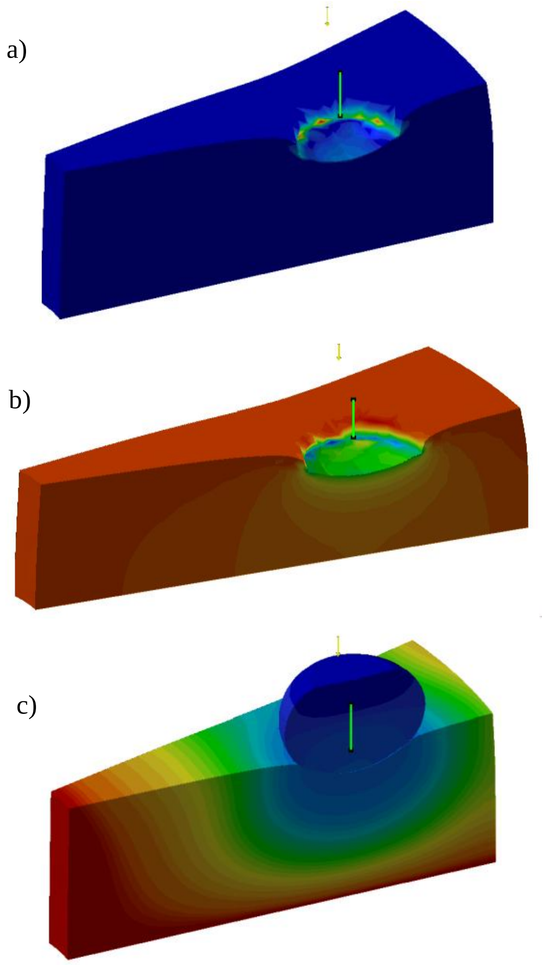

Fig. 5. Motionless disc case:
a) the equivalent von Mises stress; b) normal stress σ_z; c) axial deformations

IV. Ball-Rotating Disc Impact

The same dependencies were studied for the case of a ball in impact with the rotating disc, Fig. 6. One can observe that the corresponding variations from Figs. 5 and 6 are identical, fact perfectly rational when the value of centrifugal force acting on the ball is compared to the normal load:

$$\mathbf{F_{centrif} = 220N << 10000N = F_{impact}} \qquad (4)$$

An evocative image is presented in Fig. 7, where there are represented the level lines for the equivalent von Mises stresses which obey the condition:

$$\sigma_{Miss} \le 0.2\sigma_Y, \quad \sigma_Y = 9.5 \cdot 10^7\,\mathrm{Pa} \qquad (5)$$

where σ_Y is the yield stress value for aluminium.

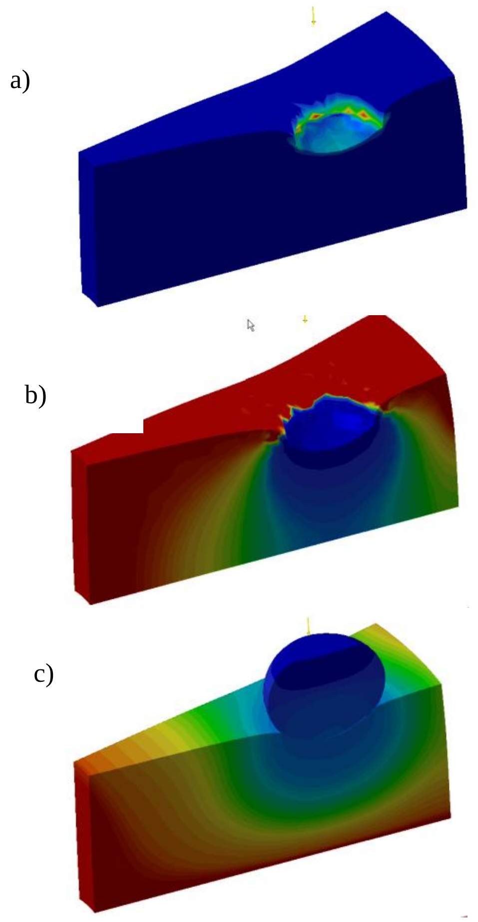

Fig. 6. Case of rotating disc: a) the equivalent von Mises stress; b) normal stress σ_z; c) axial deformations

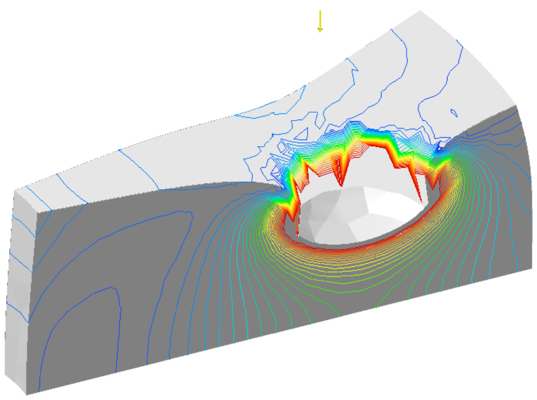

Fig. 7. The equivalent von Mises stresses, smaller than $0.2\sigma_Y$

Fig. 7 proves the fact that in the vicinity region of disc periphery the equivalent stresses are less important than the yield stress values. Considering subsequently the Saint-Venant's principle, after removing the load, the material should revert to the initial shape. In a recent work, [4] it is shown that in the case of impact between a deformable ball and a rigid plane, the augmentation of normal force conducts to a significant expansion of the plastic affected region. Assuming the centrifugal force as a tangential load, the Brizmer model [4] may possibly be applied to the impact of rotating disc.

V. CONCLUSIONS

The paper analyses the radial and tangential profiles of indentations produced by a bearing ball falling free on a rotating disc. Assuming the hypothesis of theory of elasticity that the impact effects appear strictly locally, in the region of disc periphery, discordance occurs between the shapes of disc's profile in the cases without and with impact indentation. Using finite element analysis software, under the hypothesis of linear elastic behaviour of material, the ball-disc impact was studied but a clear explanation of the deviation from the predicted shape was not completed.

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