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EXPERIMENTAL STUDY OF THE STRESS STATE IN THE RADIAL COMPRESSION OF A POWDER CIRCULAR DISK

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ABSTRACT

Cold compaction process is one of the most important technologies in powder forming manufacturing. The main goals are to obtain a compact characterized by a series of mechanical properties: modulus of elasticity, Poisson's ratio and green strength. In the paper is presented from theoretical and experimental point of view one of method for mechanical properties determinations namely the radial compression of a powder circular disk. The testing results show the granular nature of the compacted material and could be used as references values in practical applications.

Key words: *powder compacting, powder pressing, powder behaviour, powder testing*

1. INTRODUCTION

Cold compaction process is one of the most important technologies in powder forming manufacturing. It consists in the vertical pressing of powder material through the displacement of die and of a set of punches at room temperature.

The main goals are to obtain a compact with the geometrical requirements, without cracks and with a uniform distribution of density.

The density level affects the principal mechanical properties of the compacted material: modulus of elasticity (E), Poisson's ratio (ν) and green strength.

There were developed some methods for characterize the material parameters of the compacted metallic powder: hydrostatic compression, triaxial compression, uniaxial compression. These methods could capture both the hydrostatic and deviatoric response of the powder; namely, one that could capture both the compaction due to mean stresses (pressure) as well as the plastic flow and enhancement of compaction due to deviatoric stresses (shear). The uniaxial compression are performed to determine the variation of density as a function of the applied compaction pressure. Hydrostatic compression experiments are performed to measure the bulk modulus at the pressure of interest. Triaxial compression experiments are used to measure modulus of elasticity (E) and Poisson's ratio (ν) for the corresponding stress state. Knowing the bulk and Young's moduli, and Poisson's ratio, the shear modulus can be calculated.

Another method that is also used for the material properties characterization is the radial compression of a circular disk. A disk is upright placed and subjected with a thrust force. Thus results a complicated tensile state with a positive and a negative main stress, which analytically can be computed. Within the range of the applying load high compression stresses arise, while the maximum tension adjusts itself in the sample center. This test is usually called the Brazilian disc test.

There are a few dates about the level of the mechanical properties for P/M materials, mainly in green state, that is way in the paper is presented a methodology for the principal mechanical properties of the compacted material determination using the Brazilian disc test.

2. THEORETICAL ASPECTS OF THE RADIAL DISK COMPRESSION

A disk in radial compression is characterized by a plane stress state.

It is considered a disk of diameter d (Figure 1) subjected to P_1 and P_2 loads, $P_2=P_1=P$, acting in O_1 and O_2 points, which belongs to the semi planes S_1 and S_2.

In an arbitrary point from the disk boundary, the stresses σ_r^1 and σ_r^2, equals in size, σ_θ and $\tau_{r\theta}$, according to Boussinesq graphical representation, are given by:

$$\sigma_r^{\,1} = \sigma_r^2 = \sigma_\theta = \frac{2P}{\pi d}; \qquad (1)$$
$$\tau_{r\theta} = 0$$

On an arbitrary interior point (Figure 2) from the disk, the radial and circumferential stresses are given by:

$$\sigma_x = -\frac{2P}{\pi}\left[\frac{\cos^3\theta_1}{r_1} + \frac{\cos^3\theta_2}{r_2} - \frac{1}{d}\right]$$
$$\sigma_y = -\frac{2P}{\pi}\left[\frac{\cos\theta_1 \sin^2\theta_1}{r_1} + \frac{\cos\theta_2 \sin^2\theta_2}{r_2} - \frac{1}{d}\right] \quad (2)$$
$$\tau_{xy} = -\frac{2P}{\pi}\left[\frac{\cos^2\theta_1 \sin\theta_1}{r_1} - \frac{\cos^2\theta_2 \sin\theta_2}{r_2}\right]$$

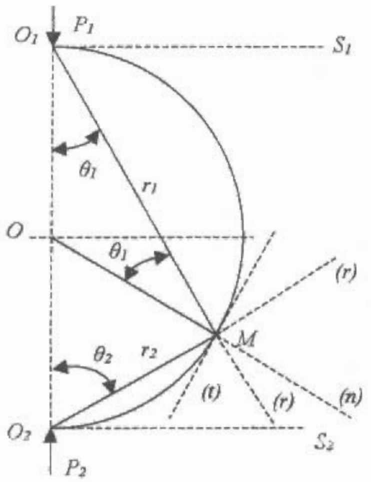

Fig. 1.

The stresses σ_x, σ_y, τ_{xy} could be expresses as a function of Cartesian coordination, recognize that:

$$r_1 = \sqrt{x^2 + y^2}$$
$$r_2 = \sqrt{(d-x)^2 + y^2}$$
$$\theta_1 = arctg\frac{y}{x} \quad (3)$$
$$\theta_2 = arctg\frac{y}{d-x}$$

3. THE STRESS DISTRIBUTION ON THE MIDDLE DIAMETER OF THE DISK

For $\theta_1 = \theta_2 = 0$, $r_1 = x$, $r_2 = d - x$ (Figure 3) one obtains:

$$\sigma_x{}^0 = -\frac{2P}{\pi}\left[\frac{1}{x} + \frac{1}{d-x} - \frac{1}{d}\right]$$
$$\sigma_y{}^0 = \frac{2P}{\pi d} \quad (4)$$
$$\tau_{xy}{}^0 = 0$$

σ_y^0 is a tension stress and have a constant value, and σ_x^0 is a compression stress and its minimum value is given by:

$$x = \frac{d}{2}$$
$$\sigma_{x\,min}{}^0 = -\frac{6P}{\pi d} \quad (5)$$

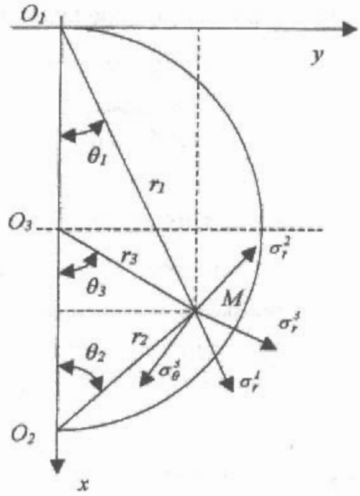

Fig. 2.

An element from the vertical diameter is subjected as it is presented in figure 3c.

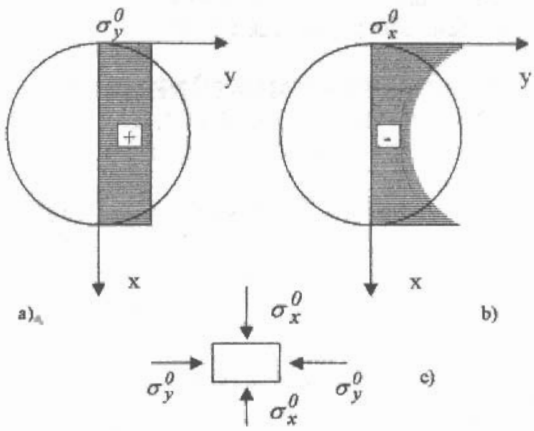

Fig. 3.

In the middle vertical diameter, the specific strain ε_y is given by:

$$\varepsilon_y = \frac{1}{E}\left(\sigma_y{}^0 - \nu\sigma_{x\,min}{}^0\right) \quad (6)$$

or according to relations (4) and (5):

$$\varepsilon_y = \frac{2P}{\pi E d}\left[1+3\nu\right] \tag{7}$$

4. MATERIALS FOR POWDER PRESSING

The material used is D.W.P. powder made by Ductil SA, Buzau, Romania. D.W.P. is a water atomized iron powder for high quality sintered components from medium up to the high density range.

The properties are presented in the tables 1-3.

Table 1

	Chemical analysis [%]					
D.W.P. 200	C	S	P	Mn	Si	H_2 loss
	≤ 0,02	≤ 0,015	≤ 0,015	≤ 0,15	≤ 0,05	≤ 0,2

Table 2

	Distribution of particles size					
D.W.P. 200	>315	>200	>160	>100	>63	<63
	-	≤ 2	5-15	25-45	25-40	20-55

Table 3

Apparent density, g/cm³	Flow time, s/50g	Green Density, g/cm³		Green strength, MPa	
		400 MPa	600 MPa	6,5 g/cm³	7,0 g/cm³
2,5-2,7	<33	6,5	6,95	18	30

The disks used in experiments had 90 mm diameter and a height of 14 mm (Figure 4). They were pressed using a special device on a 400 t hydraulic press. The press force was 150 t.

5. STRAIN STATE MEASUREMENT METHOD IN THE RADIAL COMPRESSION OF THE DISK

For measuring the stress state in the radial compression of the disk was used the resistance strain gage method that is the most cost effective method of calculating stress from a measured strain.

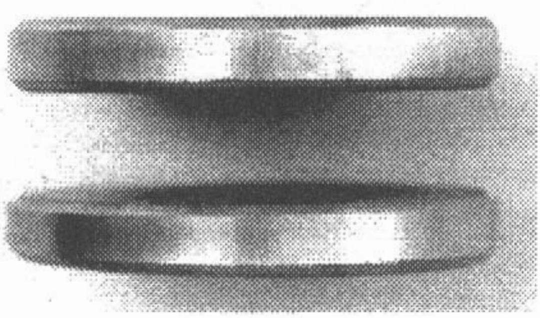

Fig. 4.

The strain gages were mounted according to the schemes presented in figure 5.

The strain gages type Hottinger had been mounted on the both faces of the disks to compensate for the possible differences.

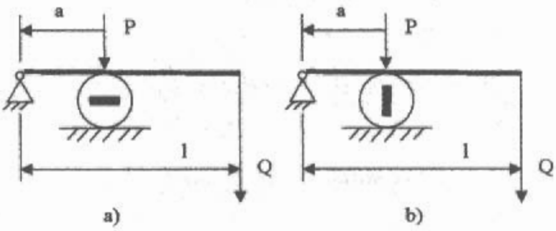

Fig. 5.

In figure 6 is presented the experimental device for stresses measurement.

In table 4 are presented the results of strain gage measurements.

Table 4

Q [daN]	Scheme a)			Scheme b)		
	TER 1	TER 2	M	TER 1	TER 2	M
0	0	0	0	0	0	0
10,300	26	61	43,5	-150	-20	-85
20,457	56	116	86	-330	-40	-185
30,477	90	168	129	-430	-140	-285
40,794	128	216	172	-485	-275	-380
51,271	174	259	216,5	-600	-380	-490
M - average						

Based on the values presented in table 4, it results:

$$\varepsilon_x^{(b)} = -98 \cdot 10^{-6};$$

$$\varepsilon_y^{(a)} = 43{,}3 \cdot 10^{-6} \tag{8}$$

The index (a) and (b) are in accordance with the schemes from figure 5.

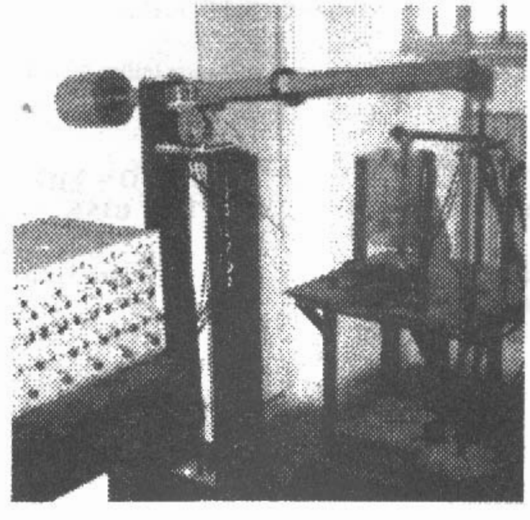

Fig. 6.

6. DETERMINATION OF E AND υ VALUES

The stresses are given by:

$$\sigma_x^{(a)} = \sigma_x^{(b)} = -\alpha P \ ; \qquad \sigma_y^{(a)} = \sigma_y^{(b)} = \beta P \ , \tag{9}$$

where:

$$\alpha = \frac{6}{\pi d} \quad \beta = \frac{2}{\pi d} \tag{10}$$

The strain measured by TER[(a)] in the case presented in figure 5.a is given by:

$$\varepsilon_y^{(a)} = \frac{1}{E}\left(\sigma_y^{(a)} - \nu\sigma_x^{(a)}\right) \tag{11}$$

In the second case (figure 5.b), the strain measured by TER[(b)] is given by:

$$\varepsilon_x^{(b)} = \frac{1}{E}\left(\sigma_x^{(b)} - \sigma_y^{(b)}\right) \tag{12}$$

Substituting (9) and (10) in (11) and (12) one obtains:

$$\varepsilon_y^{(a)} = \frac{P}{E}(\beta + \nu\alpha); \qquad \varepsilon_x^{(b)} = -\frac{P}{E}(\alpha + \nu\beta) \tag{13}$$

The relations (13) could be written as:

$$E\varepsilon_y^{(a)} - \alpha P \nu = \beta P; \qquad E\varepsilon_x^{(b)} + P\beta\nu = -\alpha P \tag{14}$$

The system from (14) led to:

$$E = P\frac{\beta^2 - \alpha^2}{\beta\varepsilon_y^{(a)} + \alpha\varepsilon_x^{(b)}} \tag{15}$$

$$\nu = \frac{\alpha\varepsilon_y^{(a)} + \beta\varepsilon_x^{(b)}}{\alpha\varepsilon_x^{(b)} + \beta\varepsilon_y^{(a)}} \tag{16}$$

Substituting the values of α and β from (10) in (15) and (16) one obtains:

$$E = -5{,}093\frac{1}{\varepsilon_y^{(a)} + 3\varepsilon_x^{(b)}} \cdot \frac{P}{hd} \tag{17}$$

$$\nu = -\frac{\frac{6}{\pi d}\cdot\varepsilon_y^{(a)} + \frac{2}{\pi d}\cdot\varepsilon_x^{(b)}}{\frac{6}{\pi d}\cdot\varepsilon_x^{(b)} + \frac{2}{\pi d}\cdot\varepsilon_y^{(a)}} = -\frac{3\varepsilon_y^{(a)} + \varepsilon_x^{(b)}}{3\varepsilon_x^{(b)} + \varepsilon_y^{(a)}} \tag{18}$$

Finally, substituting the values from (8), results:

$$E = -5{,}093\frac{82[daN]}{1{,}4[cm]\cdot 9[cm]}\cdot\frac{10^6}{43{,}3 + 3(-98)} = 0{,}132\cdot 10^6\,\frac{daN}{cm^2}$$

$$\nu = -\frac{3\cdot 43{,}3 + (-98)}{3(-98) + 43{,}3} = 0{,}122$$

7. DETERMINATION OF THE MATERIAL TENSILE STRENGTH

For material tensile strength determination it was used the method of radial compression disk. The usual solution to load the sample to establish the tensile strength is to measure the force needed to crush the sample diametrically compressed between two plates. In this case, the fractures appeared in the diametric plane of compression, where the stresses are uniform stretching stresses on a normal to the compression plane.

The fracture of material produced at a force of 1250 daN.

The strength stress is given by:

$$\sigma_r = \frac{2P}{\pi dh} \tag{19}$$

It results:

$$\sigma_r = \frac{1250}{\pi\cdot 9\cdot 1{,}4} = 31{,}5943\left[\frac{daN}{cm^2}\right]$$

8. CONCLUSIONS

Tensile tests on green powder are generally difficult to carry out. Due to the granular nature of the material it is hard to fix the sample at the two ends and to apply any loads. The solution to establish the material properties is to measure the strains and the force needed to deform a sample diametrically compressed between two plates till this is crushed.

Modulus of elasticity (*E*), Poisson's ratio (ν) and green strength could be measured using the above method. The small values of the material mechanical properties had a direct connection with the granular nature of the compressed powder. Between the particles exist only a mechanical locking which is mainly dependent upon the material nature and upon the applied force. The results could be used as references values in practical applications.

REFERENCES

[1] Khoei, A.R., Barkhshiani, A., Mofid, M., *An endrochronic plasticity model for numerical simulation of industrial powder compaction process*, Commun. Numer. Meth. Enging. 2003, 19, pp. 521-534

[2] Zohdi, T.I., Kachanov, M., Sevostianov, I., *On perfectly plastic flow in porous material*, Int. Journal of Plasticity, 18(2002), pp. 1649-1659

[3] Oyane, M., Shima, S., *Consideration of basic equations and their application in the forming of metal powders and porous metals*, Journal of Mecahnical Working Technology, 1(1978), pp. 325-341
Mc. Graw-Hill, 1985, ISBN 0-07-036285-8

[4] Wang, W., *Numerical modeling of compaction of particulate systems*, Master of Science Thesis, University of Florida, 1999

[5] Chenot, J.L., Bay, F., Fourment, L., *Finite element simulation of metal powder forming*, Int. Journal for Numerical Methods in Engineering, 1990, 30, pp. 1649-1674

[6] Perez-Foquet, A., Rodriguez-Ferrare, A., Huerta, A., *Efficient and accurate approach for powder compaction problems*, Computational Mechanics, 2003

[7] P. Mosbah, I. Cameron, D.T. Gethin and R.W. Lewis: *Modelling and characterisation of pharmaceutical powders*, University of Wales Swansea, June 2000.

[8] Voinea, R., S.A. - *Introducere in mecanica solidului cu aplicatii in inginerie*, Editura Academiei, 1989

[9] Mocanu, D.R., s.a.- *Analiza experimentala a tensiunilor*, Editura Tehnica, 1977

[10] Nicoara, D. - *Bazele cercetarii experimentale*, Universitatea Dunarea de Jos din Galati, 1993

STUDIUL EXPERIMENTAL AL STĂRII DE TENSIUNI LA COMPRIMAREA RADIALA A UNUI DISC DIN PULBERI

Rezumat

Presarea la rece a pulberilor este una din principalele metode formare a materialelor de această natură. În urma presării rezultă un semifabricat care poate fi caracterizat prin prisma proprietăţilor lui şi anume: modulul de elasticitate, coeficientul lui Poisson şi rezistenţa la rupere. În lucrare se prezintă din punct de vedere teoretic şi experimental una din metodele de determinare a acestor proprietaţi şi anume comprimarea radială a unui disc din pulbere. Rezultatele măsurătorilor dovedesc natura granulară a materialului şi pot fi folosite ca valori de referinţă în aplicaţiile practice.

EXPERIMENTELLE STUDIE DES DRUCK-ZUSTANDES IN DER RADIALKOMPRESSION EINER PUDER-RUNDSCHREIBEN SCHEIBE

Zusammenfassung

Kalter Verdichtungprozeß ist eine der wichtigsten Technologien im Puder, das Herstellung bildet. Die Hauptziele sind, einen Vertrag zu erreichen, der durch eine Reihe Eigenschaften gekennzeichnet wird: Elastizitätsmodul , Poisson's Verhältnis und grüne Stärke. Im Papier wird von theoretischem und experimentellem Gesichtspunkt einer der Methode für Eigenschaften Ermittlungen nämlich die Radialkompression einer Puderrundschreibenscheibe dargestellt. Die Testergebnisse zeigen die granulierte Natur des verbundenen Materials und konnten als Bezugswerte in den praktischen Anwendungen verwendet werden.