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EXPERIMENTAL RESEARCH OF INTERRELATION BETWEEN ROCK LAYER POROSITY AND DEFORMATION FORCES ON THE FLAT SURFACES OF DISINTEGRATORS

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ЕКСПЕРИМЕНТАЛЬНІ ДОСЛІДЖЕННЯ ВЗАЄМОЗВ'ЯЗКУ ПОРИСТОСТІ ШАРУ ГІРНИЧОЇ МАСИ ТА ЗУСИЛЬ ДЕФОРМУВАННЯ НА ПЛОСКИХ ПОВЕРХНЯХ ДЕЗІНТЕГРАТОРІВ

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ЭКСПЕРИМЕНТАЛЬНЫЕ ИССЛЕДОВАНИЯ ВЗАИМОСВЯЗИ ПОРИСТОСТИ СЛОЯ ГОРНОЙ МАССЫ И УСИЛИЙ ДЕФОРМИРОВАНИЯ НА ПЛОСКИХ ПОВЕРХНОСТЯХ ДЕЗИНТЕГРАТОРОВ

Annotation. Deformation of granite layer with granite fraction less than 0.5 mm was experimentally studied in order to determine normal-pressure distribution on the flat working surfaces of disintegrators. Series of tests with material compression between two plates without lateral restrictions was conducted, and distribution of porosity factor along the radius of deformation zone was determined. Experiment with compression of different quantities of material in the mortar with the punch down to pressures of 40 MPa was carried out in order to calibrate pressure depending on the material porosity. Compression curves were built for different masses of the sample. For the case of material compression without lateral restrictions, regression curve of dependence between material porosity and pressure was built on the base of compression force balance equation. This curve coincides with compression curve for minimal mass of material sample compressed in the mortar. Distribution of normal pressures on the top plate was determined, at that, experimental curve was more flat than the theoretical one. The pressure high concentration in the center of deformation zone and underloading of its periphery were confirmed.

Keywords: disintegrator, deformation zone, loose material, compression curve, pressure distribution.

Introduction. Processing of fine-sized lumpy materials in disintegrators is combined with compressive influence on material layer as a consequence of two (usually) working surfaces rapprochement. Firstly, the layer is compacted with repacking of particles, and, than, their disintegration on smaller pieces is carried out [1]. The effect of "crushing in layer", when the material is put between working surfaces in 3-5 and more layers, is used in disintegrators to enhance the process selectivity and to reduce the flat particles share [2]. That's why, it is important to take into consideration the dependence of the material layer fractional porosity on the compression pressure during designing of disintegrators operating parts.

The dependence is sufficiently non-linear.

The dependence of the of granite fraction minus 0.5 mm layer (height more than 10 mm) fractional porosity on the pressure has been obtained in a mortar with a punch for the range up to 4 MPa [3]. The experimental data are approximated best by equation

$$e = e_{min} + (e_0 - e_{min}) \cdot \exp(-a \cdot p^m), \quad (1)$$

where e_0 - initial fractional porosity; e_{min} - consolidation limit; a & m - coefficients; p - pressure.

The conditions of material deformation in disintegrators differ usually from the case of a mortar and a punch by absence of side restrictions for material. So, the forces of side thrust lead to the particles pushing out to the periphery of deformed zone [4]. The distribution of pressure on the working surfaces for the case of flat deformed zone is obtained based on the regularities of loose material mechanics. It is shown, that there is high pressure concentration in the zone center, while the periphery has sufficiently lower loadings and, therefore, it doesn’t take part in the disintegration process. This conclusion requires for additional experimental justification while having appropriate pressure level on working surfaces, that is actual for designing of rational schemes of operating parts.

The goal of this work is to determine experimental dependences of the material compression pressure distribution on flat surfaces of the deformed zone without side restrictions, taking into consideration the layer porosity change by the pressure.

The idea of this work is to use the compression dependence of material compression in a mortar for obtaining the distribution of normal pressures on flat surfaces of the deformed zone while compressing without side restrictions.

Basic part.

1. Deformation of material between plates without side restrictions.

The source material is crushed granite of fraction -0.5 mm. The modelling of disintegration has been fulfilled by the press unit with maximum force of 30 kN.

The material portion has been filled in the form of a cone on a static horizontal steel plate. After that, an upper steel plate and a dynamometer have been put on it. The material cone has been settled a little, becoming the truncated one (fig 1) with the height of H_0 and the diameters of the upper and the lower bases being equal correspondingly to $D_{1,0}$ and $D_{2,0}$. The fractional porosity e_0 has been calculated.

Futher, the series of tests on the material compression with varied force levels, equal approximately to $P = 5$, 10, 20 и 30 kN, has been carried out. Here, the initial material layer height H_0 has been the same for all the tests.

After the material compression with the set force level, the truncated cone had less height H and also increased base diameters D_1 & D_2 (see fig. 1). It is obvious, that the material porosity after compression is increasing from the center to the periphery. The set of ring splitters of diameters d_i, made of thin metal, has been used in order to determine the dependence of the layer porosity change along the deformed zone radius. Firstly, after the press unit unloading and removing the upper plate with the dynamometer, the splitter of the largest diameter has been put symmetrically relative to axes of the truncated cone and carefully pressed into the material layer to the contact with the lower plate. The material left outside the splitter has been weighed. The splitter has been carefully put off, and the another splitter of less diameter has been set. The operation has been repeated for all the material rings.

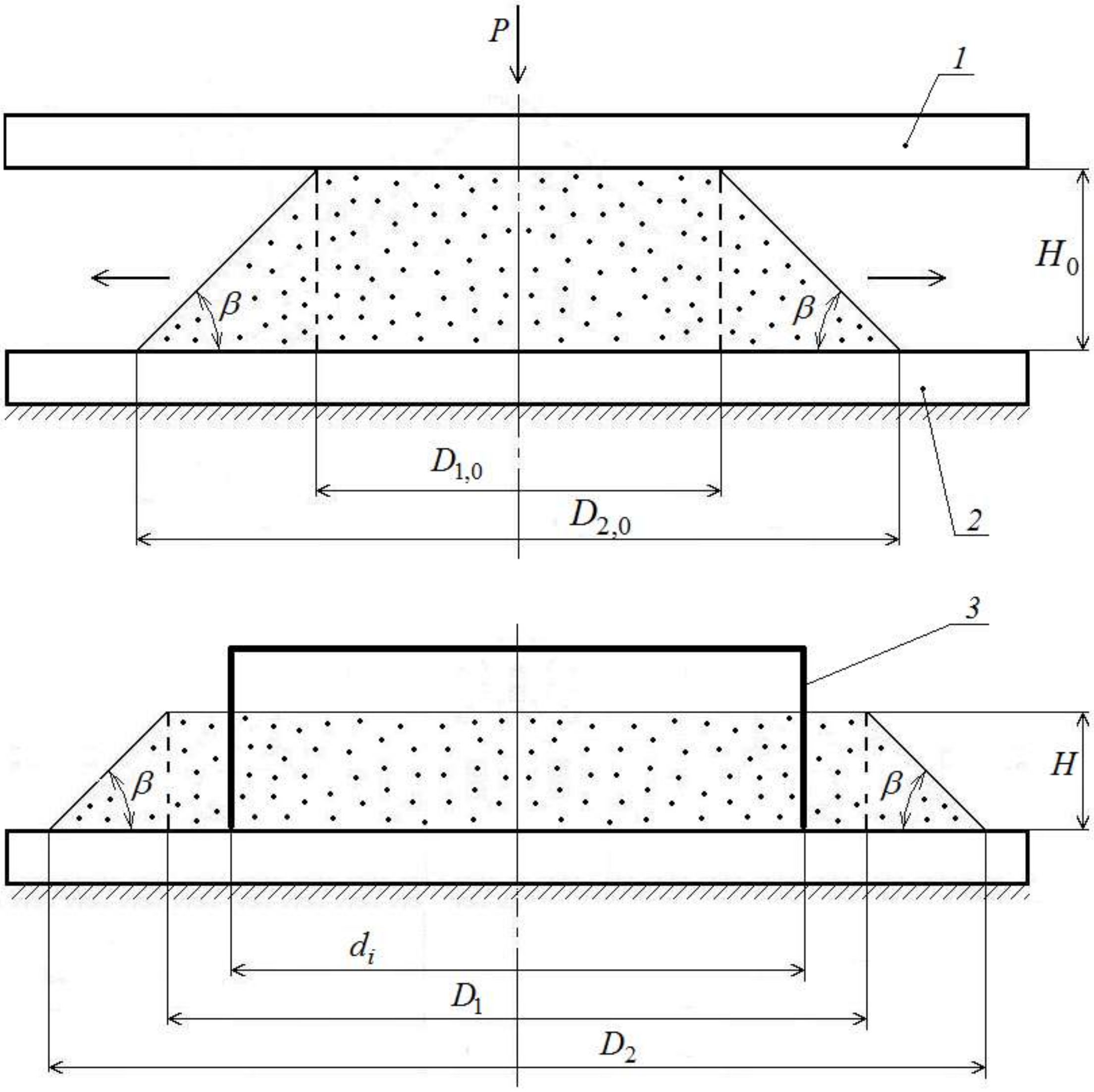

Figure 1 – Scheme of the material compression without side restrictions:
1 – upper plate; *2* – lower plate; *3* – ring splitter

Further, the following parameters have been calculated:

- volume of the material:

$$V_i = \frac{\pi H}{4}\left(d_i - d_{i-1}\right)^2,\ \text{m}^3; \qquad (2)$$

- bulk weight of the material:

$$\gamma_i = \frac{m_i}{V_i},\ \text{kg/m}^3; \qquad (3)$$

and also fractional porosity e_i.

The volume of the last peripheral sector:

$$V_5 = \frac{\pi H}{12}\left(D_1^2 + D_1 \cdot D_2 + D_2^2\right) - \frac{\pi H}{4} d_4^2, \text{ m}^3. \quad (4)$$

The material rings average radiuses have been the calculated coordinates along x axis. Here, the mean radius value is not usable, because the material rings of the same width have different masses. So, the average radiuses have been calculated by formula:

$$r_i = \sqrt{\frac{I_{\rho,i}}{F_i}}, \text{ m}, \quad (5)$$

where $I_{\rho,i}$ - polar inertia moment of i-ring relative to the central axis, which is determined in accordance with the expression

$$I_{\rho,i} = \frac{\pi}{32} \cdot \left(d_i^4 - d_{i-1}^4\right), \text{ m}^4; \quad (6)$$

F_i - area of i-ring, which is find by formula

$$F_i = \frac{\pi}{4} \cdot \left(d_i^2 - d_{i-1}^2\right), \text{ m}^2, \quad (7)$$

from where one will have

$$r_i = \frac{1}{2}\sqrt{\frac{d_i^2 + d_{i-1}^2}{2}}, \text{ m}. \quad (8)$$

The last peripheral ring has a complicated form – a truncated cone with a circular cut, so the radius of inertia is corresponded to the expression:

$$r_5 = \frac{\int_0^H r(h) \cdot F(h) dh}{\int_0^H F(h) dh}, \text{ m}, \quad (9)$$

where $r(h)$ - the current radius of inertia for the 5-th ring section at a height h from the lower plate:

$$r(h) = \frac{1}{2}\sqrt{\frac{d(h)^2 + d_4^2}{2}}, \text{ m}; \quad (10)$$

$d(h)$ - the current outside diameter of the 5-th ring section at a height h:

$$d(h) = D_2 - \frac{h}{H}\left(D_2 - D_1\right), \text{ m.} \tag{11}$$

Following the results of calculations, the values determined from expression (9) are almost match the radius of the upper cone base $(0{,}5D_1)$.

2. Material deformation in a mortar with a punch.

For this purpose, the series of tests on compression of investigated granite fraction -0.5 mm has been fulfilled in the mortar of diameter 31.5 mm with a punch. This has allowed, for the force up to 30 kN, to reach the pressure up to 40 MPa, that leads to the granite particles destruction, concerning high concentration of stresses.

The definite material mass from range of 20-143 grams has been filled in the mortar. The tests with slow compression have been conducted for each mass with the force being in range of 2-30 kN. The average fractional porosity has been calculated then. The results of experimental data processing are offered at the figure 2.

The results for each material loading mass have been approximated by dependence (1) using the least squares method. As one can see from the plots, the average fractional porosity rises while increasing the loading mass, having constant final pressure. This effect may be explained as an influence of friction forces on the mortar sides.

3. Pressure values calibration using fractional porosity values and analysis of results.

One may obtain the pressure values from the condition, that the sum of all forces from ring sectors, transmitted to the plate, must be equal to the specified force of working surfaces mutual pressing:

$$\sum_{i=1}^{5} p_i \cdot F_i = P_{sp} = P + G_{pl} + G_{dyn}, \text{ N,} \tag{12}$$

where P - average pressing force by dynamometer indications, N;

G_{pl} – weight of the upper plate;

G_{dyn} – weight of the dynamometer.

Here, the pressure is expressed by the fractional porosity, according to (1) and having zero consolidation limit, in such a way:

$$p_i = \left[\frac{1}{a}\ln\frac{e_0}{e_i}\right]^{1/m}, \text{ Pa.} \tag{13}$$

Here, for the 5-th (peripheral) ring sector, the value of the fractional porosity has been averaged concerning different contact areas on the upper and the lower plates. So, the calculated maximum diameter of this sector has been determined in accordance with (8):

$$d_5 = \sqrt{8r_5^{\,2} - d_4^{\,2}}, \text{ m.} \tag{14}$$

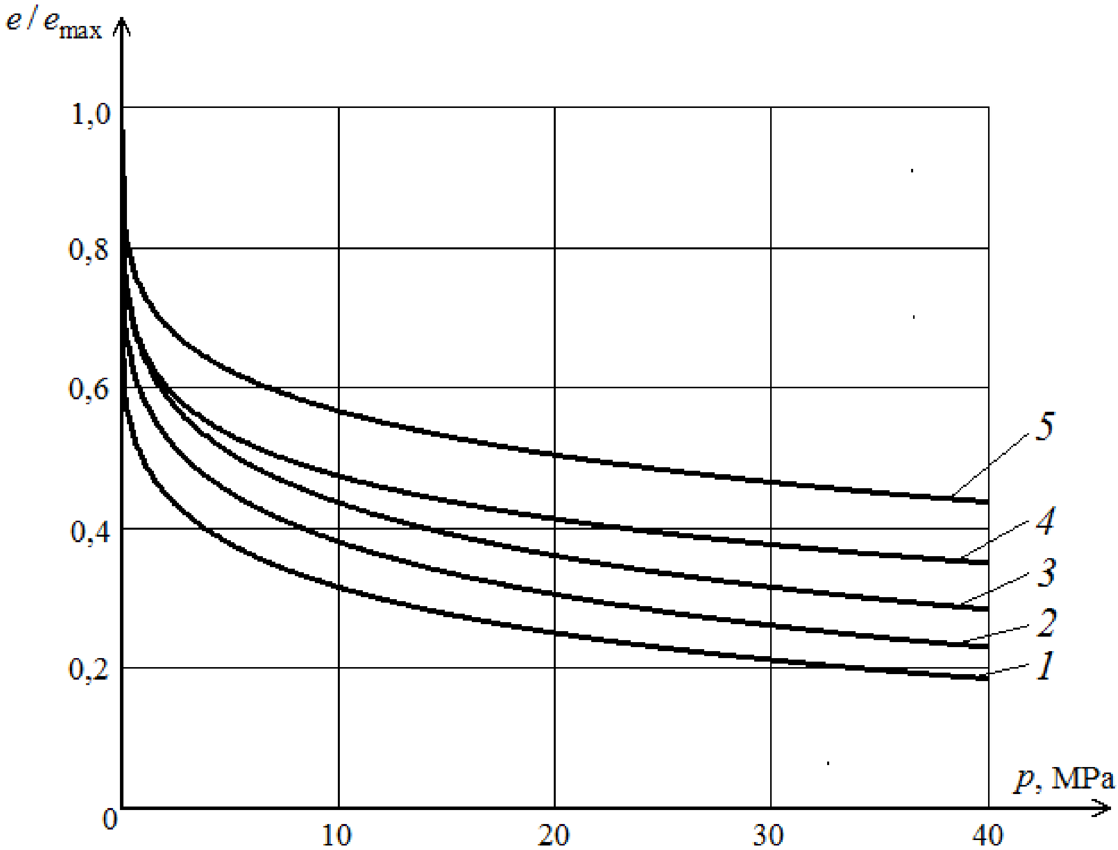

Figure 2 – Dependence of the fractional porosity on the compression pressure in the mortar:
1 – *m* = 20 g; *2* – *m* = 40 g; *3* – *m* = 70 g; *4* – *m* = 100 g; *5* – *m* = 143 g

As a result, there is a system of four equations of type

$$\frac{1}{P_{sp}}\cdot\sum_{i=1}^{5}\left[\frac{1}{a}\ln\frac{e_0}{e_i}\right]^{1/m}\cdot\frac{\pi}{4}\left(d_i^2-d_{i-1}^2\right)=1, \qquad (15)$$

each equation per every value of compression force.

It makes sense to obtain the regressive dependence of the fractional porosity on the value of pressure at the working surface as the same to the expression (1). Finally, the real values of force are in good correspondence with specified forces, calculated by the regression equation and determined from equation (12) as sums of ring sectors forces (table 1).

Table 1 – Real and calculated deformation forces

Test number	1	2	3	4
Real force, kN	5,02	9,63	19,5	29,4
Calculated force, kN	5,47	7,93	22,0	26,3
Deviation, %	+9,0	-17,7	+12,6	-10,5

The analysis shows, that obtained regressive curve (fig. 3) has good coincidence qualitatively and quantitatively with the data for pressing in the mortar of granite mass 20 g, having minimal influence of effect of the material friction with the mortar sides.

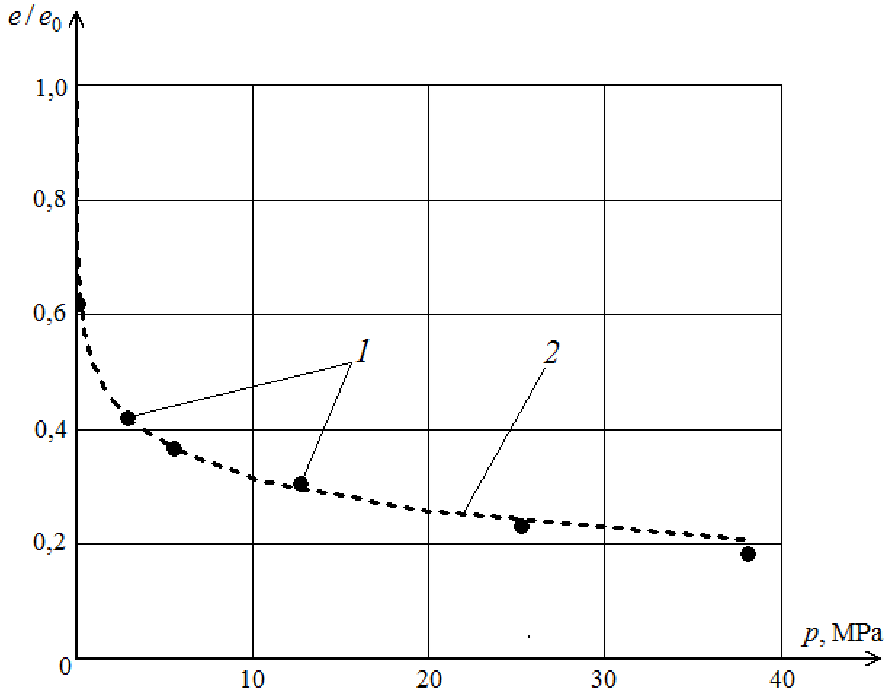

Figure 3 – Comparison of data on the material compression in the mortar (*1*) and between plates (*2*)

Additionally, the curves of pressure distribution in the radial direction of the deformed zone at the upper plate are determined based on the regression equation (fig. 4).

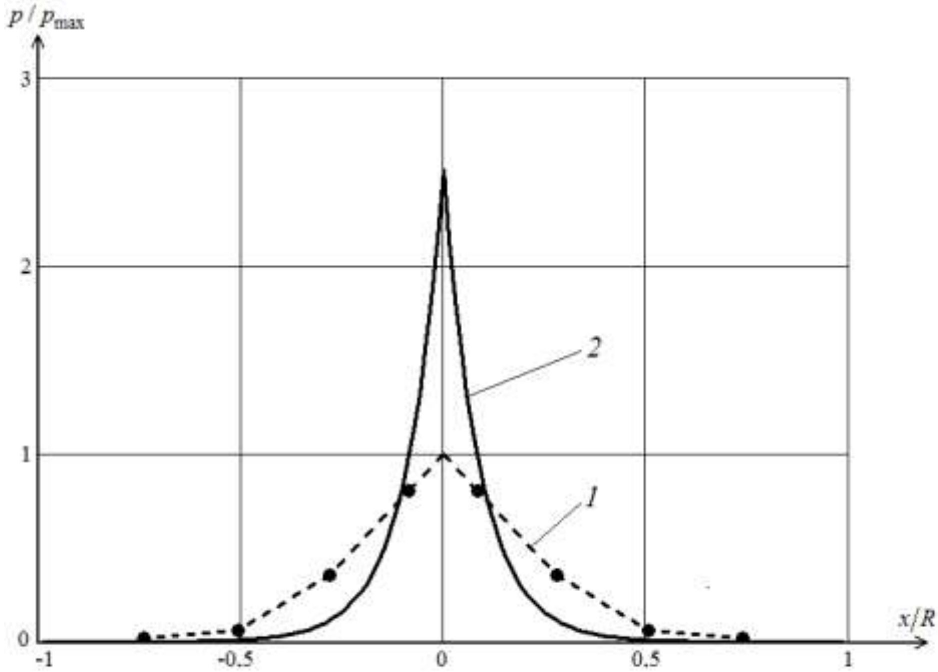

Figure 4 – Distribution of normal pressure at the upper cone base:
1 – experiment; *2* – theory [4]

Comparison with the data [4] for the case of the material layer slow deformation shows, that the gradient of pressure increase from the disk periphery to its center is lower, than the theoretical one. So, it requires the necessity to supplement the process basic mathematical model, but, nevertheless, high irregularity of the pressure distribution has been confirmed, see the data in table 2.

Table 2 – Intensity of the normal pressure distribution

Share of the deformed zone, central circle area, %	1	10	25-28	50-55
Share of the total force, %	10-15	70-72	87-90	97-98
p / p_{cp}	10,5	7,0	3,3	1,9

Conclusions

1. The possibility to model the mining mass deformation processes between the flat surfaces of disintegrators, based on the data of material compression in a mortar with a punch, is shown.

2. The series of experimental dependences of the fractional porosity of granite fraction less than 0.5 mm on the compression pressure in a mortar is determined in a range up to 40 MPa.

3. The regression dependence of the granite layer fractional porosity change on the pressure, for the case of its compression between two plates without side restrictions, is obtained.

4. Good coincidence of the experimental results on the compression in a mortar and free compression between plates is shown.

5. The obtained experimental curve of the pressure distribution along the radius of the deformed zone upper base is more flat, that is claimed by theory, but the distribution is also very irregular.

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Анотація. Виконані експериментальні дослідження деформації шару граніту фракції менше 0,5 мм з метою отримання розподілу нормального тиску на плоских робочих поверхнях дезінтеграторів. Проведено серію дослідів із стискання матеріалу між двома плитами без бокових обмежень та встановлено розподіл коефіцієнта пористості матеріалу вздовж радіуса зони деформування. Для тарування тиску в залежності від пористості, проведено експеримент із стискання різних кількостей матеріалу в ступці із пуансоном до тиску 40 МПа. Отримано набір компресійних кривих для різних мас навішування. Для випадку стискання матеріалу без бокових обмежень, з рівняння балансу зусилля стискання отримано регресійну криву залежності коефіцієнта пористості від тиску, яка добре співпадає із компресійною кривою при стисканні в ступці навішування матеріалу мінімальної маси. Отримано розподіл нормального тиску на поверхні верхньої плити, при цьому експериментальна крива є більш пологою, ніж теоретична. Підтверджено високу концентрацію тиску в центрі зони деформування та недовантаженість її периферії.

Ключові слова: дезінтегратор, зона деформування, сипкий матеріал, компресійна крива, розподіл тиску.

Аннотация. Выполнены экспериментальные исследования деформации слоя гранита фракции менее 0,5 мм с целью получения распределения нормальных давлений на плоских рабочих поверхностях дезинтеграторов. Проведена серия опытов по сжатию материала между двумя плитами без боковых ограничений и установлено распределение коэффициента пористости материала вдоль радиуса зоны деформирования. Для тарировки давления в зависимости от пористости, проведен эксперимент по сжатию разных количеств материала в ступке с пуансоном до давлений 40 МПа. Получен набор компрессионных кривых для разных масс навески. Для случая сжатия материала без боковых ограничений, из уравнений баланса усилия сжатия получена регрессионная кривая зависимости коэффициента пористости от давления, которая хорошо совпадает с компрессионной кривой при сжатии в ступке навески материала минимальной массы. Получено распределение нормальных давлений на поверхности верхней плиты, при этом экспериментальная кривая более пологая, чем теоретическая. Подтверждена высокая концентрация давлений в центре зоны деформирования и недогруженность ее периферии.

Ключевые слова: дезинтегратор, зона деформирования, сыпучий материал, компрессионная кривая, распределение давлений.

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