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TRUE CONTACT AREA BETWEEN WHEAT GRAIN AND A FLAT SURFACE

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S y n o p s i s. The technique of microphotography was used to obtain images of the true contact area between wheat grain and a glass plate. The value of contact area was measured using a TV area meter. The measurements were carried out applying normal contact forces in a range from 0.03 N to 4.3 N. The regression curve was calculated and compared with the Hertz problem solution.

INTRODUCTION

One of the ways towards a mechanical description of the behaviour of granular media is an attempt at statistical generalization of momentary states of individual grains. Such an approach is followed by Kitamura [1] when he formulates a model of the fundamental mechanical phenomena taking place in soil: the processes of shearing, consolidation, and permeability. This model is based on the Markov process theory. The choice of the Markov process is based on its effectiveness when applied to the description of such non-steady physical processes as heat transport and diffusion. A comparison of the results of a triaxial compression experiment with those of a numerical experiment utilizing Kitamura's model leads to the conclusion that the model proposed may be used in the search for a constitutive medium equation [1]. To formulate a model capable of expressing a constitutive equation, however, requires detailed input data concerning the actual material subjected to loading.

Another attempt at describing the relationships between the mechanical properties of a granular medium and its geometrical structure was undertaken by Oda [4]. He found that the mechanical behaviour of material in the process of shearing depends on the initial spatial arrangement of solid particles and associated void called fabric. To describe the fabric Oda introduced two concepts: that of packing, and of the spatial orientation of the long axes of non-spherical grains of the medium. He formulated statistics corresponding to those concepts, and determined the relationships between the mechanical properties and the initial geometrical structure of samples of sand.

In experiments involving direct shearing and triaxial compression carried out at the Institute of Agrophysics, Polish Academy of Sciences, [5], it was shown that there is a strong correlation between the internal friction angle of cereal and rape grain, and the spatial orientation of grains in a sample.

An analysis of the studies mentioned above leads to the conclusions that apart from shearing, as extremely complex, the effect of mutual interaction of the elementary particles of a material depends on its geometrical structure determining the system of the elementary normal and friction forces within the contact areas. In the case of soil, for which the existing models have been designed, it is assumed that elementary particles are non-deformable. This assumption cannot be adopted with respect to agricultural granular materials, and especially to cereal grain. Within the range of loadings that are common in practice cereal grain is subject to significant deformation, which additionally complicates the description of the medium. The mechanical properties of individual grains are also strongly correlated to moisture. With increasing moisture content the susceptibility of grains to deformation increases. An increase in grain moisture content, therefore, results in an increase in the true contact area between grains. On the other hand Kragielski et al. [2] have shown that the friction resistance of metal friction pairs depends on the true contact area.

In studies aimed at describing the frictional properties of agricultural granular materials it was assumed that the basic phenomenon determining the behaviour of a material in the process of shearing is the friction resistance. It also seemed valid to adopt the hypothesis that the orientation and the value of true contact area of the grains of the medium are the most appropriate data for the descirption of the stress - strain relations in an agricultural granular material. The foundation in the search for a model of the medium, therefore, should be the identification of physical phenomena taking place within the elementary contact area. An introduction to those studies were measurements of the relationship of the true contact area to normal force, presented herein.

MATERIAL AND METHOD

The authors measured the true contact area of a single wheat grain with a glass plate. The grain used was of the Panda variety, of a relative grain moisture

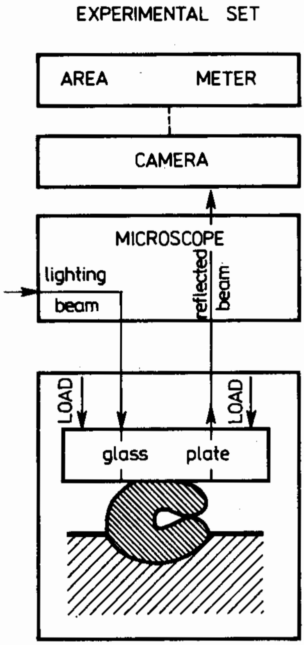

Fig. 1. Schematic diagram of the system for the measurement of the relationship of true contact area to normal force

content of 11% w.b. Grains for the measurements were selected from a sample of a granulation above 3.5 mm. High quality grains of regular shape were chosen. A schematic diagram of the measurement system is presented in Fig. 1. The grain was positioned on the support and embedded in fast setting dental cement; then the support with grain was placed on the measurement microscope table and loaded through a glass plate. The area of grain contact with the glass plate was situated on the side surface of the grain. The area observed was illuminated through the microscope lens, and its magnified image was photographed in the reflected light. The experiment comprised 17 values of normal force loading, within a range from 0.029 N to 4.3 N. The loading cycle and measurements were performed in 20 replications. The photographed image was enlarged, and the contact area was measured using a DT Area Meter. The TV camera of the meter covers, line by line, the image of the object measured. The electronic system adds up the time elapsed while the object is detected. The sum obtained is a measure of the contact area and may be easily determined by means of calibration involving an object of known surface area.

RESULTS

An analytical description of the results obtained was attempted with the help of a regression curve of the form of $S = AN^B$, where: A, B - constants, S - contact area in millimeters square, N - normal force in Newtons. Such a form of the regression curve was a result of the solution of Hertz problem [3].

The regression curve obtained had the form of $S = AN^B$, and $A = (5.87 \pm 0.16) \times 10^{-3} \left[\frac{mm^2}{N}\right]$ and $B = 0.825 \pm 0.016$, with a correlation coefficient $R^2 = 99.4\%$. A graph of the course of the curve is presented in Fig. 2. A closer analysis of the graph

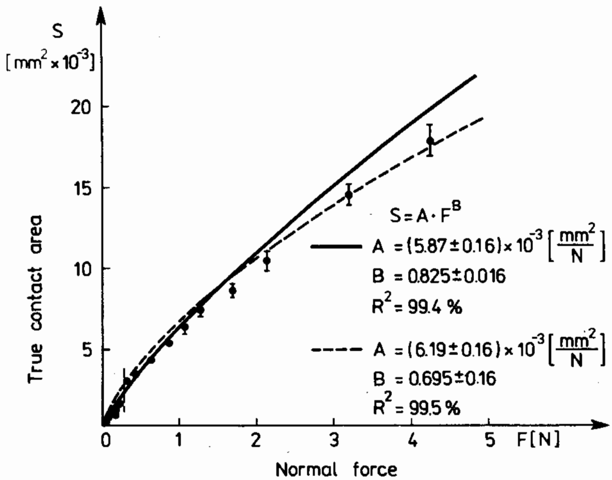

Fig. 2. Relationship of true contact area of wheat grain with a glass plate to normal force

induced the authors to divide the range of normal force applied into two characteristic subranges, and then for a subrange of values above 0.3 N they obtained a regression curve of parameter values $A = (6.19 \pm 0.16) \times 10^{-3} \left[\frac{mm^2}{N}\right]$ and $B = 0.695 \pm 0.16$ and with a correlation coefficient $R^2 = 99{,}5\%$, and for a subrange of normal force values below 0.3 N - a regression curve of parameter values $A = (5.79 \pm 0.055) \times 10^{-3} \left[\frac{mm^2}{N}\right]$ and $B = 0.837 \pm 0.020$ with a correlation coefficient $R^2 = 99.7\%$. The varying values of the exponent obtained for the $S = AN^B$ formula may indicate the existence of varied mechanisms of grain deformation in the two subranges.

In the range of higher loadings the course of the relationship is practically in conformance to the prediction of Hertz formulae, and it also coincides with the results of studies by Kragielski [2] who specifies an exponent value of 0.667 for a case of elastic contact between a rough surfaced sphere and an optically smooth surface. The initial fragment of the course of the relationship requires further studies to determine the exact reason for the deviation from the Hertz theory prediction. We can only point out here that Kragielski [2] obtained in his study an exponent value of 0.82 for the contact of surfaces of more complex roughness characteristics. We can also suppose that at the initial stage of the formation of the true contact area a significant role may be played by cutin - a wax-like substance covering the surface of grains. The significant role of cutin in the formation of the contact area would also be of importance for sliding contact, and therefore for friction resistance and mechanical processes in grain mass.

CONCLUSIONS

1. The method presented permits a quantitative determination of the contact area of grain with a flat glass surface.

2. The experimental relationship obtained is best described, within the whole range of normal forces, by a curve $S = AF^B$, where $A = (5.87 \pm 0.16) \times 10^{-3} \left[\frac{mm^2}{N}\right]$; $B = 0.825 \pm 0.016$; $R^2 = 99.4\%$.

3. Within a range of normal forces above 0.3 N the authors obtained a regression curve of $S = 6.16 \cdot F^{0.695}$, which is fully in conformance with Hertz formula $S = A \cdot F^{2/3}$.

4. Within a range of normal forces below 0.3 N the authors obtained an exponent value of B = 0.837, i.e. much higher than in the range of higher force values, which seems to indicate the existence of different mechanisms of grain deformation in the two loading ranges.

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RZECZYWISTA POWIERZCHNIA KONTAKTU MIĘDZY ZIARNEM PSZENICY I PŁASKĄ POWIERZCHNIĄ

S t r e s z c z e n i e

Zastosowano technikę fotografii mikroskopowej do uzyskania obrazu rzeczywistej powierzchni kontaktu między ziarnem pszenicy i płytką szklaną. Wielkość powierzchni kontaktu wyznaczano przy pomocy analizatora obrazu.

Pomiary przeprowadzano stosując nacisk normalny między ziarnem pszenicy i płytą w zakresie od 0,03 N do 4,3 N. Wyznaczono krzywą regresji i porównano ją z rozwiązaniem problemu Hertza.

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ДЕЙСТВИТЕЛЬНАЯ ПЛОЩАДЬ КОНТАКТА МЕЖДУ ПШЕНИЧНЫМ ЗЕРНОМ И ПЛОСКОЙ ПОВЕРХНОСТЬЮ

Р е з ю м е

Применили технику микроскопической фотографии для получения действительной картины площади контакта между пшеничным зерном и стеклянной пластинкой. Величину площади контакта определяли при помощи анализатора картины.

Измерения проводили, применяя нормальный нажим между пшеничным зерном и пластинкой в диапазоне 0,03-4,3 N. Определили кривую регрессии и сравнили ее с решением проблемы Герца.