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IMPACT BETWEEN SPHERICAL GLASS PARTICLES AND DIFFERENT TARGET SURFACES

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Abstract. Interaction of spherical glass particles with plane targets of different materials was studied experimentally, using a special Laser Doppler Anemometer measuring technique. Particles striking against a target of duraluminium, copper, annealed steel and ceramic composition plates were investigated. The mathematical model expressing the coefficient of restitution was analysed.

Key words: particle impact, restitution coefficient, Laser Doppler Anemometer.

1. INTRODUCTION

Interaction of solid particles with a target surface is of great interest in many areas. Particle impact causes erosion damage on a surface. This erosion depends on the energy exchange between the erodent particle and the material surface under impact. On the other hand, restitution coefficients describe the kinetic energy exchange between the particle and the surface, and therefore the knowledge of restitution coefficients gives an insight into the behaviour of the particle-wall collision. The process of particle-wall collision is influenced by a number of factors, for example, particle and target material; particle shape and target surface roughness with their variations at impact; different impact conditions. Our efforts focus on the interaction process of particle flow with the surface, using Laser Doppler Anemometer (LDA) methods in the maximum possible range of collision parameters. We aim to propose a theoretical basis allowing for the determination of the restitution coefficient for different target materials.

2. MEASURING METHOD

The interaction of spherical glass particles with the plane surface of different materials was studied experimentally, using a special LDA measuring technique. A centrifugal four-channel device was used to accelerate the particles. Mounted on the base of a coordinate device, it had the capacity of being moved relative to the measuring volume of the LDA. The plate to be investigated was fixed at the corresponding angle onto the bracket of the cover.

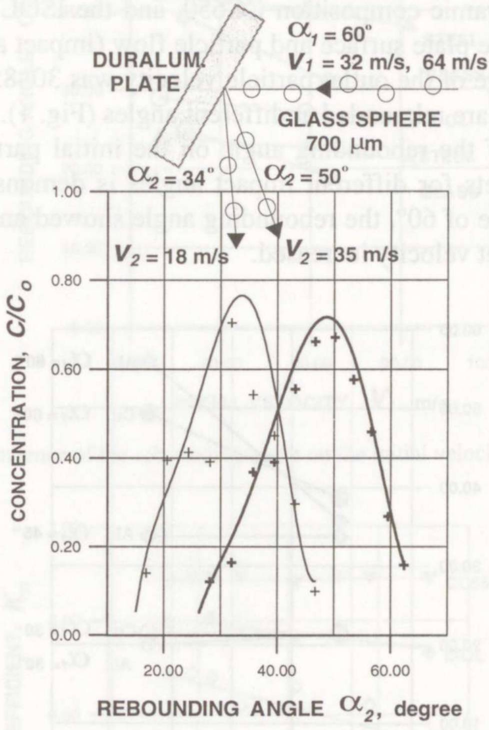

Fig. 1. The angular distribution of rebounding particle concentration (impact angle 60°, C/C_0 normalizes the number of rebounding particles, crossing the volume measured per unit of time and registered by the LDA, the initial velocity $V_1 = 32$ and 64 m/s).

A special one-component LDA was used for measuring the velocities of the striking and rebounding particles. The rebound direction was determined by the point of the maximum particle concentration, obtained by the number of Doppler signals registered by the system in one time unit. This point was found by linear scanning along the direction parallel to the direction of particle outlet at some distance down from the plate in the most probable rebound region. The rebounding particle velocity at this point was determined by angular scanning on the maximum of measuring velocity [1]. The system was tuned for the registration of glass particles with an average size of about 700 µm. Figure 1 shows the geometry of the experiment and an angular distribution of the concentration of rebounding particles in the case of collision with the duraluminium plate at an angle of 60 degrees.

3. EXPERIMENTAL RESULTS

Our study focused on the interaction between spherical glass particles (average size 700 µm) striking against targets of lead, copper, duraluminium, annealed steel, the ceramic composition CC650, and the ISOL insulator plates. The angles between the plate surface and particle flow (impact angles) were 30°, 45°, and 60°. The range of the outlet particle velocity was 30–85 m/s. After wall collision, the particles are rebounded at different angles (Fig. 1).

The dependence of the rebounding angle on the initial particle velocity for soft materials as targets for different impact angles is demonstrated in Fig. 2. Under the impact angle of 60°, the rebounding angle showed an increasing trend when the particle outlet velocity increased.

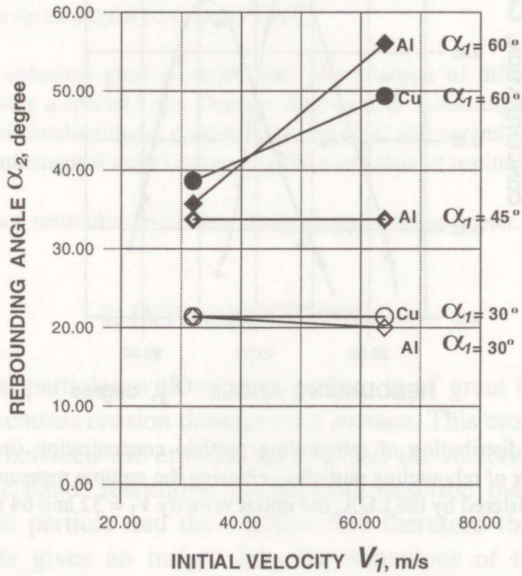

Fig. 2. Dependence of the rebounding angle on the initial velocity for soft materials.

Figure 3 shows the same dependence for hard materials. For any angle, the tendency of a decrease in the rebounding angle with an increase in the initial velocity is observed.

Once the velocity components were determined, the restitution coefficients were calculated for different materials and different initial velocities according to the equation $K_n = V_{2n} / V_{1n}$, where V_{1n} is the normal component of particle velocity before impact and V_{2n} is the same normal component after impact. Figure 4 shows the measured values of the restitution coefficient K_n as a function of the normal component of velocity before impact V_{1n}.

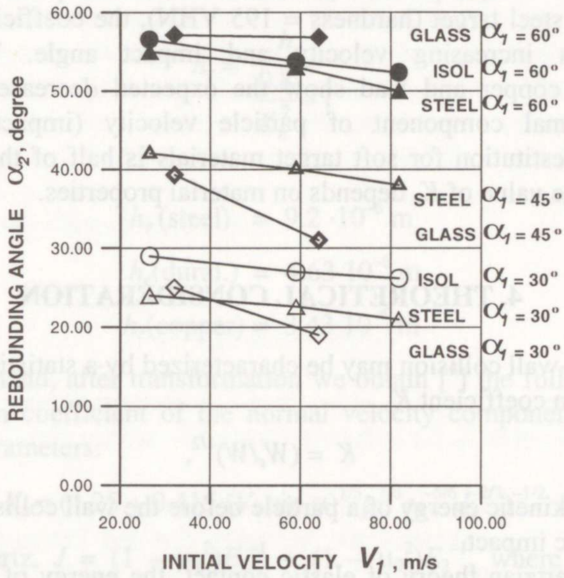

Fig. 3. Dependence of the rebounding angle on the initial velocity for hard materials.

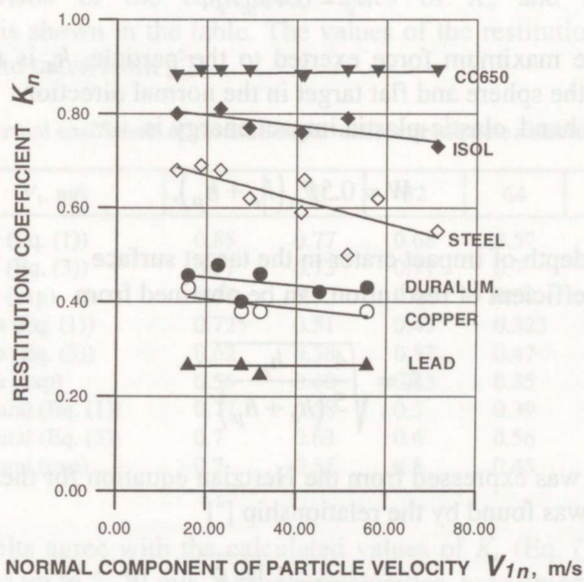

Fig. 4. Measured values of the restitution coefficient K_n, depending on the normal component of particle velocity V_{1n}.

For ceramic plates (hardness > 1800 VHN) as target material, the restitution coefficient proved to be independent of the velocities of the glass spheres and of those of the impact angles. This independence indicates that the interaction between the colliding bodies is fully elastic. The dependence of K_n on particle velocity or impact angle for ISOL-plates (hardness ≥ 867 VHN) is weak. But in the case of the steel target (hardness = 195 VHN), the coefficient of restitution decreases with increasing velocity and impact angle. The results for duraluminium, copper and lead show the expected decrease of K_n with the increasing normal component of particle velocity (impact velocity). The coefficient of restitution for soft target materials is half of that for hard ones. Furthermore, the value of K_n depends on material properties.

4. THEORETICAL CONSIDERATION

The particle-wall collision may be characterized by a statistical determination of the restitution coefficient K

$$K = (W_e/W)^{1/2},$$

where W is the kinetic energy of a particle before the wall collision and W_e is the energy of elastic impact.

From the Hertzian theory of elastic contact, the energy of elastic impact is expressed as

$$W_e = 0.4\,F_m h_e\,,$$

where F_m is the maximum force exerted to the particle, h_e is the total elastic deformation of the sphere and flat target in the normal direction.

On the other hand, elastic-plastic impact energy is

$$W = 0.5 F_m\left(h_e + h_p\right),$$

where h_p is the depth of impact crater in the target surface.

Thus, the coefficient of restitution can be obtained from

$$K = \sqrt{\frac{4}{5}\frac{h_e}{\left(h_e + h_p\right)}}\,. \qquad (1)$$

The value of h_e was expressed from the Hertzian equation for the flat-and-sphere contact, and h_p was found by the relationship [2]

$$h_p = V_1 R\,\sqrt{\frac{2}{3}\frac{\rho}{e_0}}\,,$$

where e_0 is the specific energy of impact crater formation, ρ is the density of the particle and R is the radius of sphere. The values of e_0 are discussed in [2].

It has been confirmed [3] that the value of the elastic deformation is constant for materials. At a small velocity ($V_1 < 10$ m/s), plastic deformation is insignificant, and it is possible to determine h_e from Eq. (1)

$$h_e = \frac{h_p}{\frac{0.8}{K_n^2} - 1}. \quad (2)$$

For $V_1 = 32$ m/s

$$h_e(\text{steel}) = 9.2 \cdot 10^{-6} \text{ m}$$

$$h_e(\text{dural.}) = 4.63 \cdot 10^{-6} \text{ m}$$

$$h_e(\text{copper}) = 3.43 \cdot 10^{-6} \text{ m}$$

On the other hand, after transformation we obtain [4] the following equation for the restitution coefficient of the normal velocity component K_n related to other material parameters:

$$K_n = (1.25 + 0.415\,(V_1 \sin\alpha)^{1/3} \rho^{1/6} e_0^{-5/6} J^{-2/3})^{-1/2} \quad (3)$$

According to Hertz, $J = (1 - \mu_1^2)E_1^{-1} + (1 - \mu_2^2)E_2^{-1}$, where μ_1 and μ_2 are Poisson's ratios of impacting particles and target plate material, E_1 and E_2 are elasticity modules of impacting particles and target material, respectively.

The comparison of the calculated values of K_n and those obtained experimentally is shown in the table. The values of the restitution coefficient at low velocity were taken from [5].

Normal coefficient of restitution for different particle velocities

V_1, m/s	5	20	32	64	100
K_nst (Eq. (1))	0.85	0.77	0.68	0.57	0.46
K_nst (Eq. (3))	0.77	0.73	0.71	0.7	0.68
K_nst (exp)	0.77	0.72	0.68	0.58	0.42
$K_n$cu (Eq. (1))	0.725	0.51	0.43	0.323	0.27
$K_n$cu (Eq. (3))	0.62	0.58	0.52	0.47	0.45
$K_n$cu (exp)	0.55	0.48	0.43	0.35	0.3
$K_n$dural (Eq. (1))	0.77	0.58	0.5	0.39	0.32
$K_n$dural (Eq. (3))	0.7	0.63	0.6	0.56	0.5
$K_n$dural (exp)	0.7	0.55	0.5	0.45	

Our test results agree with the calculated values of K_n (Eq. (3)) only at low impact velocities up to 5–20 m/s. At higher velocities, experimental values of K_n fall faster than the theoretical ones. Apparently, this can be explained by two facts:

1) impact craters formed by the particles of higher energy in the target surface are actually spherical, hence the contact model with flat surface is no more applicable;

2) elastic modules of the target material used in the calculations were obtained from tests under static load and may be different at impact.

As can be seen, the values of K_n obtained by the theoretical Eq. (1) are in good agreement with the experimental data at impact velocity > 20 m/s. When plastic deformation is insignificant, the restitution coefficient K_n = 0.89. This result agrees with our experimental data. For steel, it is impossible to neglect plastic deformation and the calculated value of K_n is greater than the experimentally obtained values.

5. CONCLUSIONS

1. The experiments performed by the LDA method confirm that the normal restitution coefficients K_n for soft target materials are smaller than those for hard materials.

2. For hard materials, the dependence of K_n on particle velocity or impact angle is weak. This independence indicates that the interaction between the colliding bodies is rather elastic.

3. The use of nonlinear deformation model in the analytical treatment of the particle impact process yields a good correlation between the calculated and experimental results at low outlet velocities (Eq. (3)).

4. A comparative analysis of the results allows us to conclude that the values of the coefficient of restitution obtained with Eq. (1) are in good agreement with the experimental data.

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SFÄÄRILISTE KLAASOSAKESTE JA METALLPLAADI VAHELISE PÕRKEPROTSESSI UURIMINE

Ilmar KLEIS, Irina HUSSAINOVA ja Igor ŠTŠEGLOV

Kasutades spetsiaalselt osakeste kiirusvektori suuna ja suuruse määramiseks väljatöötatud laser-Doppleri anemomeetrit on uuritud sfääriliste klaasosakeste põrkumist mitmest materjalist metallplaatidelt. Erilist tähelepanu on pööratud põrkenurkade määramisele. On võrreldud eksperimentide käigus ja teoreetiliste arvutuste abil saadud põrketeguri väärtusi. Tulemustest järeldub, et löögikiirustel kuni 20 m/s võib plastseid deformatsioone mitte arvestada. On analüüsitud tulemuste lahknemise võimalikke põhjusi.