Tribology of particles in acoustic field

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Abstract

This paper analyzes tribological aspects of particle adhesion in presence of acoustic field. It is shown that acoustic field forces create favourable conditions for contact and adhesion between particles.

Keywords: acoustic field, acoustic agglomeration, particle, adhesion.

Introduction

It is considered that stability of the atoms in the crystal lattice is determined by the ratio of attractive and repulsive forces [1–3]. When the particle begins to move with respect to another particle, molecular attractive and repulsive forces can occur between particles. Then conditions for a particle to be in mechanical equilibrium according Tomlinson [3] can be presented as follows: $\sum F_i = \sum F_p + F_N$, where $\sum F_i$ is the component of repulsive forces; $\sum F_p$ is the component of attractive forces; F_N is the normal force. If the acoustic field is acting on the particles, $\sum F_p$ forces are small as compared with the pressure force F_N, microdisplacements of particles results in friction forces that maintain the equilibrium between attractive and pressure forces.

Microdisplacements between particles produce n_k molecular interactions [3]. Moreover, Amonton's law must be satisfied: f = const where f is the friction coefficient. Some authors [3, 4] assume that the number of pairs of interacting molecules n_m depends on an effective contact area between colliding particles. Therefore it is possible to calculate the friction coefficient f and the friction force F_T. However, one problem exists: how to calculate the effective contact area. Author [5] which investigated molecular nature of friction (introduced by Deriagin [1]) also proposed such friction force equation: $F_T = A_r^{10/11}\left(C_{D_1} + C_{D_2} p_{r_i}^{10/11}\right)$, where C_{D1} and C_{D2} are the coefficients depending on a surface roughness, elastic properties and molecular structure of the friction surfaces; p_{r_i} is the effective pressure at the contact spot; A_r is the effective contact area.

However the molecular theory of friction considers molecular interaction forces as sole source of forces. In presence of acoustic field [6-12] impressed pressure forces acts on the particles, it is also known that surfaces of these particles are not ideal. Therefore particle adhesion can have another nature. In this work we shall try to establish the influence of the acoustic forces on particle adhesion.

Object of investigation

Interactions of the SiO_2 particles [13] in presence of an acoustic field were studied. The interaction scheme is presented in Fig. 1.

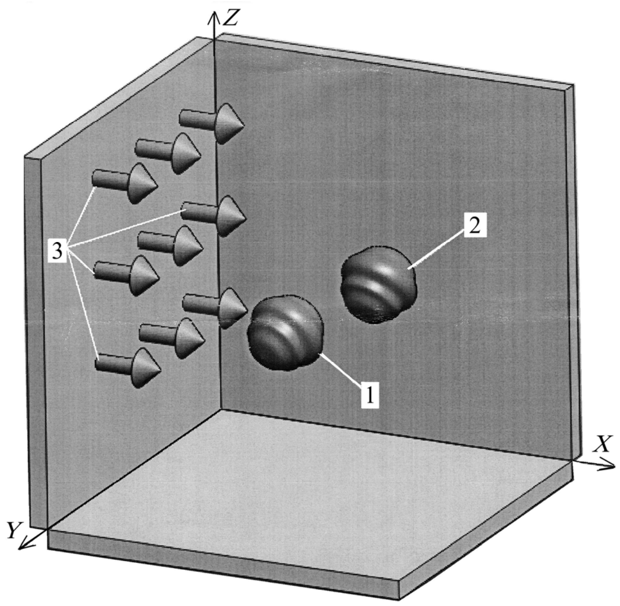


Fig. 1. **Interaction of particles in an acoustic field: 1, 2 – particles; 3 – direction of acoustic field**

Mathematical analysis

Motion of two particles in the air flow acted on by a plane acoustic wave can be described by the following differential equation:

$$m_i \frac{dV_{p_i}}{dt} = 6\pi\mu r_i \left(V_f - V_{p_i}\right) \tag{1}$$

where i = 1, 2; m_i is the mass of the particle; V_{p_i} is the velocity of the particle; t is the time; μ is the dynamic viscosity of the air; r_i is the radius of the particle; V_f is the velocity of air flow.

The velocity of air flow can be calculated as follows:

$$V_f = u_f \cos \omega t \qquad (2)$$

where $u_f = A_f \omega$; A_f is the amplitude of the acoustic field; ω is the angular frequency of the acoustic field.

Substituting Eq. 2 into Eq. 1, we can obtain solution of Eq. 1:

$$x_{p_i} = A_f \frac{6\pi\mu r_i / m_i}{(2\pi f)^2 + \left(\frac{6\pi\mu r_i}{m_i}\right)^2} \times \left(\frac{6\pi\mu r_i}{m_i}\sin(2\pi f t) - 2\pi f \cos(2\pi f t)\right), \qquad (3)$$

where x_{p_i} is the displacement of the particle; f is the frequency of acoustic field; t is the time.

It can be written:

$$m_i = \rho_i V_i, \qquad (4)$$

where ρ_i is the mass of the particle; V_i is the volume of the particle.

It can be adopted that:

$$V_i = \frac{4}{3}\pi r_i^3. \qquad (5)$$

By substituting Eqs. 4 and 5 into Eq. 3 and rearranging we obtained:

$$\frac{x_{p_i}}{A_f} = \frac{4.51\mu / \rho_i r_i^2}{(2\pi f)^2 + \left(\frac{4.51\mu}{\rho_i r_i^2}\right)^2} \times \left(\frac{4.51\mu}{\rho_i r_i^2}\sin(2\pi f t) - 2\pi f \cos(2\pi f t)\right) \qquad (6)$$

x_{p} / A_f

Graphical representation of Eq. 6 is given in Fig. 2.

The acoustic field force which acts on the particle can be obtained by using the following equation [12]:

$$F_a = \frac{10}{3}\frac{\pi^2 r^3 fJ}{c^2}\sin\left(\frac{4\pi f x}{c}\right), \qquad (7)$$

where J is the sound intensity; x is the coordinate; f is the frequency of acoustic field; c is the speed of sound in air.

Graphical representation of Eq. 7 is shown in Fig. 3.

The obtained results show that the frequency and the intensity of the acoustic field have an influence on displacements of particles and collisions between them. The acoustic field force in some cases can act tangentially to the surface. Thus its action can result in the partial removal (microcutting) of fouling layer and increase the contact area between particles. Then adhesive forces begin to act, creating adhesive bonds between particles. Therefore it is necessary to create the acoustic field effect in such a way that both normal and tangential forces would act on the particles. This can be achieved by use of several acoustic field generators arranged both radially and tangentially.

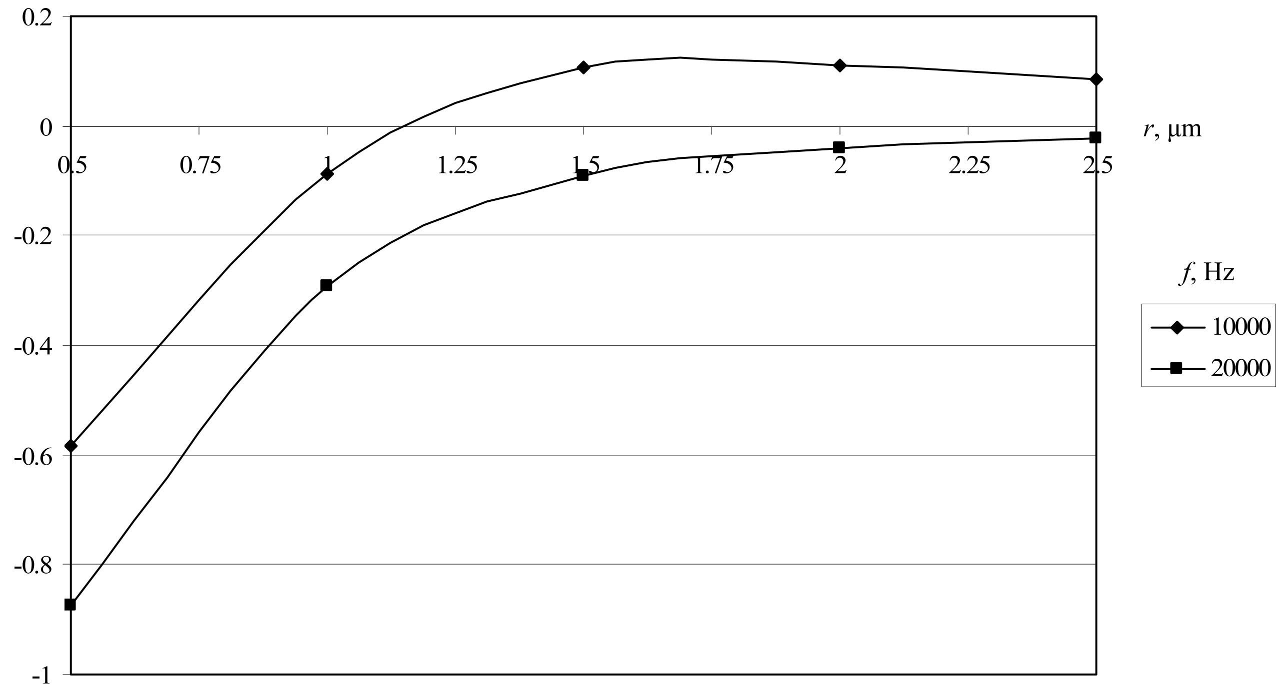
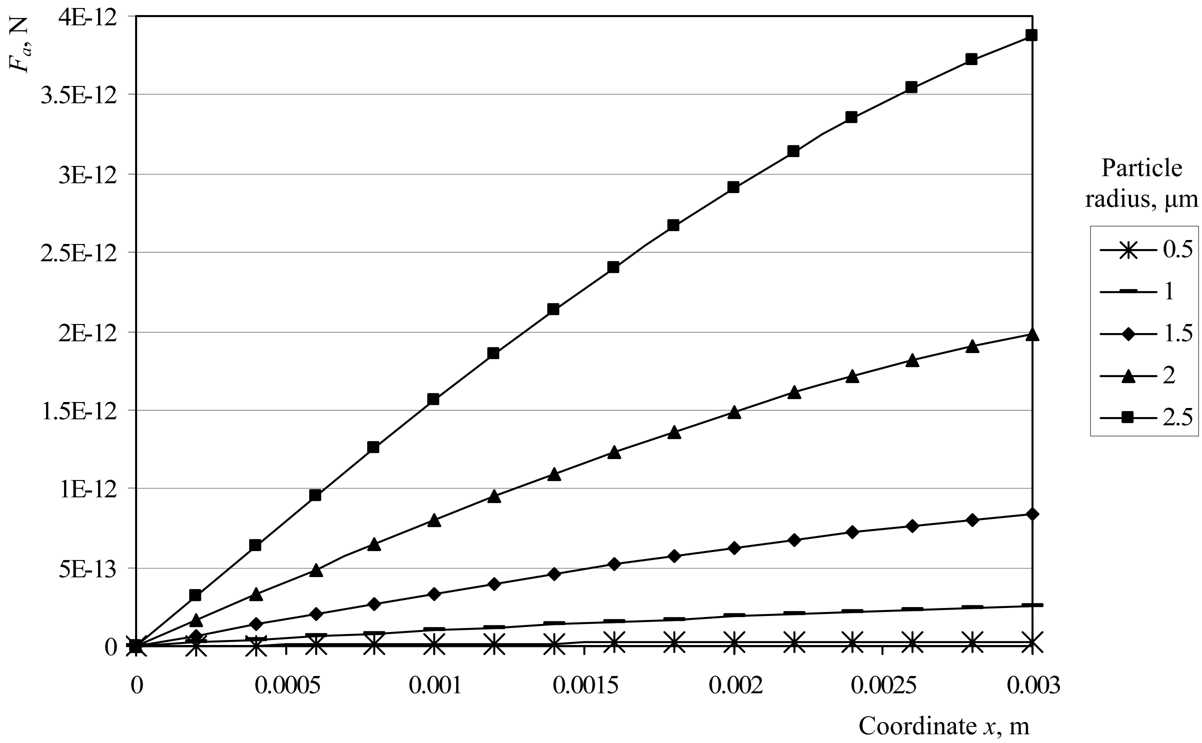
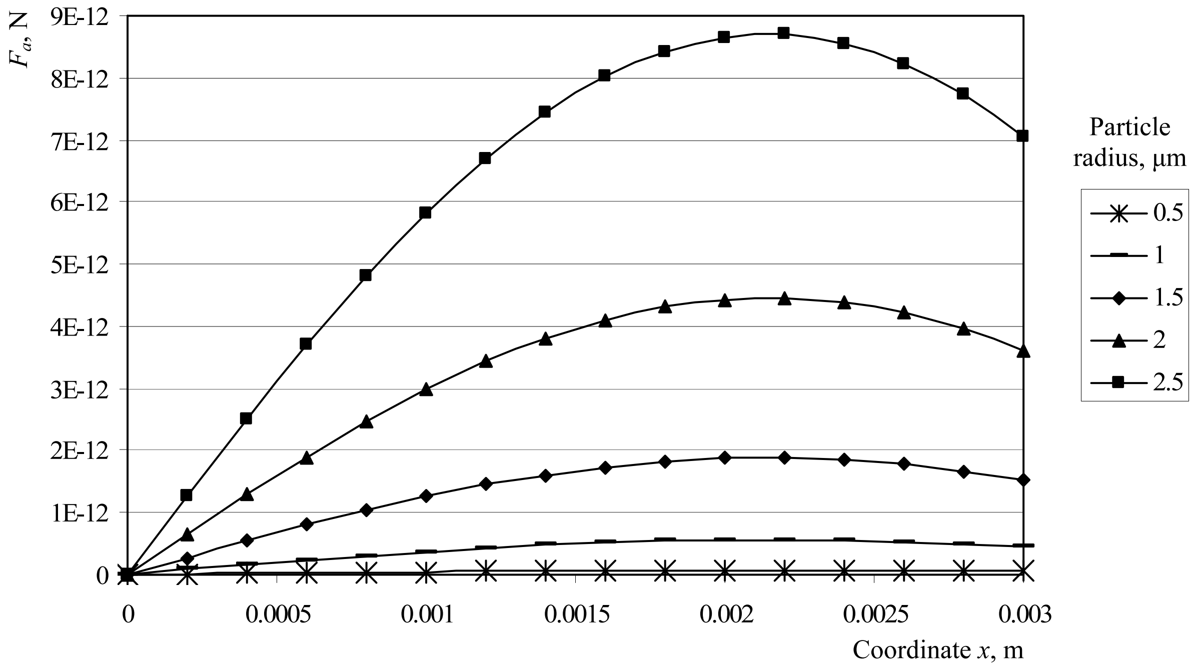


Fig. 2. **Dimensionless parameter x_p/A_f as function of quartz sand particle radius r: ρ = 1201 kg/m^3; μ = 17.8×10^{-6} Pa/s; t = 2 s**



a



b

Fig. 3. **Acoustic field force F_a as function of coordinate x and radius of the particle: a – f = 10 kHz, J = 100000 W/m^2; b) – f = 20 kHz, J = 100000 W/m^2**

Experimental investigation

Photo of experimental stand is presented in Fig. 4. Two acoustic field generators were mounted inside the stand.

1-5 µm SiO_2 particles were used for investigations. The microscope image of the particles is shown in Fig. 5. Microscope images of aggregated particles after the action of the acoustic field are presented in Fig. 6 and 7.

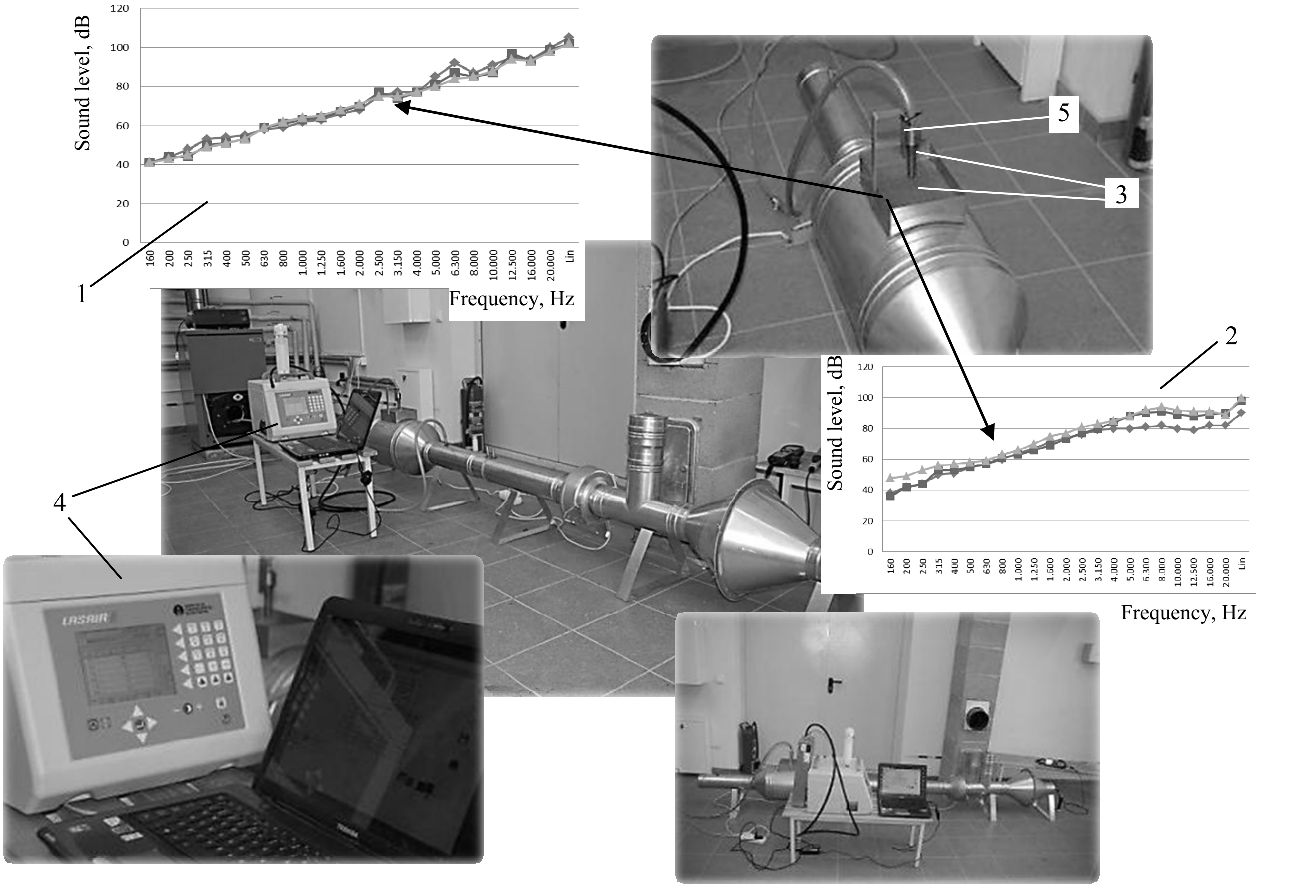


Fig. 4. **Experimental stand: 1, 2 – characteristics of acoustic field generators; 3 – acoustic field generator mounting places; 4 – particle detecting and counting system "Lasair II"; 5 – integrated analyzer**

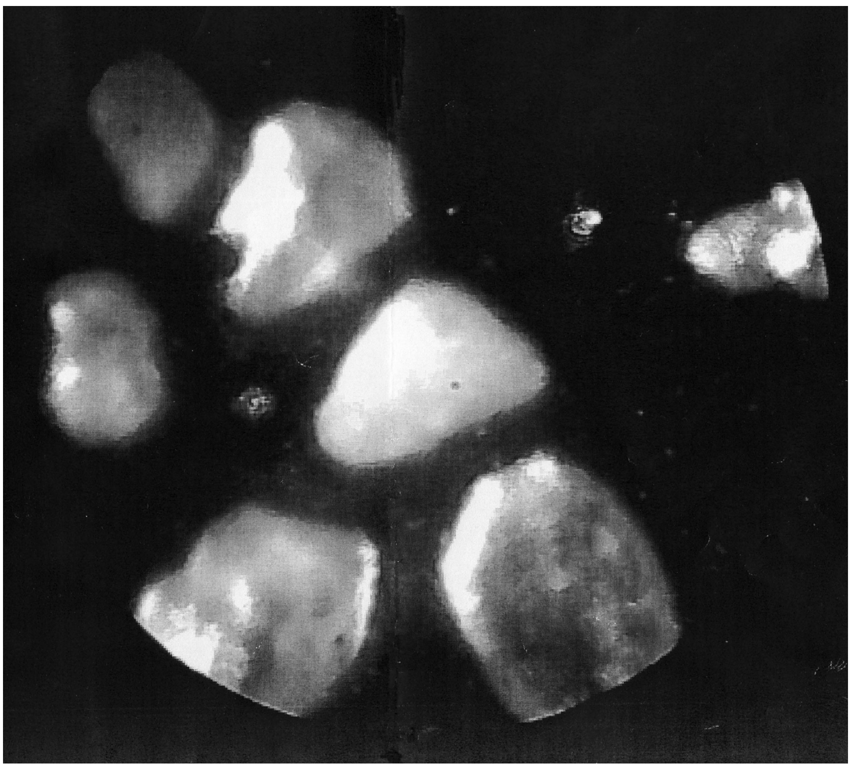


Fig. 5. **Microscope image of SiO_2 particles before the acoustic field was applied**

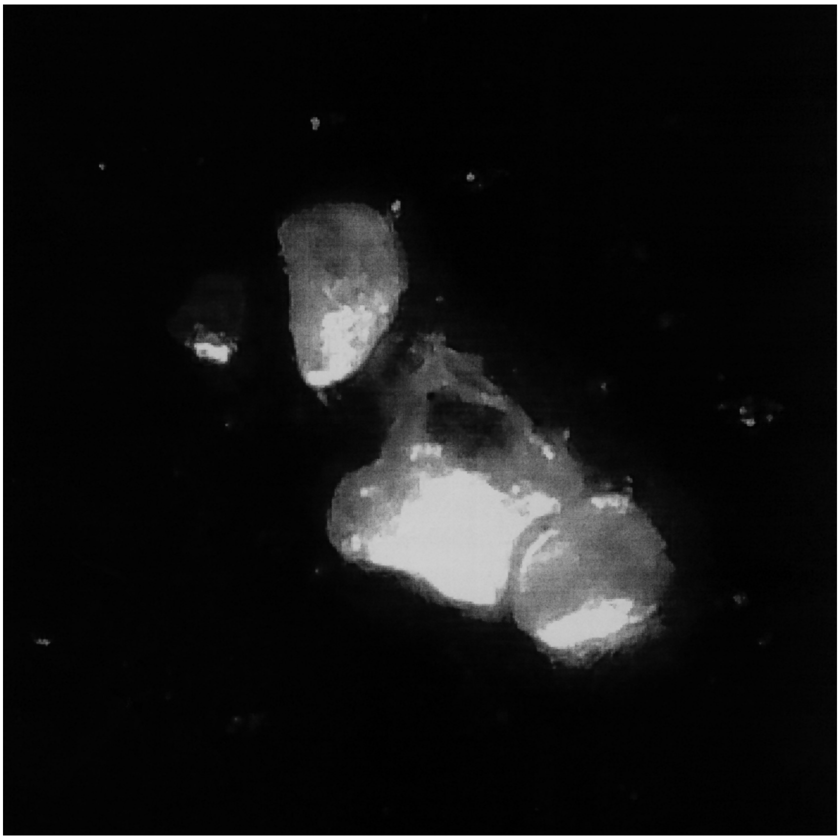


Fig. 6. **SiO_2 aggregated particles after the action of acoustic field**

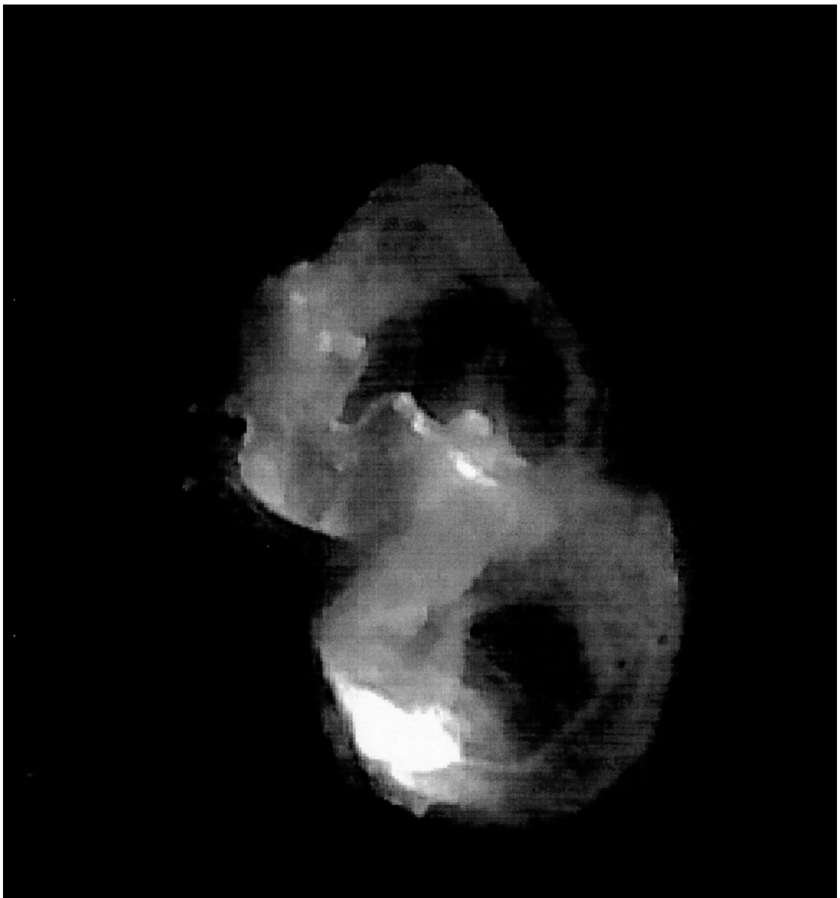


Fig. 7. **SiO_2 particles adhesion caused by the action of acoustic field**

Conclusions

1. The obtained results show that interactions and adhesion between coarser particles can be sufficiently increased if particles are acted on by audio-frequency acoustic field.

2. From the experimental results it is evident that tangential interactions take place between particles.

3. It is purposeful to arrange acoustic sources in such a way that both normal and tangential forces would act on the particles.

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Dalelių tribologija akustiniame lauke

Reziumė

Straipsnyje nagrinėjami dalelių sukibimo akustiniame lauke tribologiniai aspektai. Parodyta, kad akustinio lauko jėgos sudaro palankias sąlygas dalelių kontaktui ir sukibimui.

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