About the Role of Surface Phenomena in the Processes of Processing of the Dispersed Materials

[1]Maxim Vladimirovich Sevost'yanov, [1]Tat'yana Nikolaevna Il'ina,
[1]Vladimir Semenovich Sevost'yanov, [1]Dmitry Aleksandrovich Emel'yanov and
[2]Makhabbat Batyrgaliyevna Amanbayeva
[1]Belgorod State Technological University, Kostyukov Street, 46, 308012 Belgorod, Russia
[2]Abai Kazakh National Pedagogical University, Dostykave 13, 050010 Almaty, Kazakhstan

Abstract: The dispersed materials are widely used in different technologies of processing for the purpose of receipt of bodies and particles of certain sizes, forms, physical-mechanical and other parameters. Surface properties determining the character and strength of binding particles in dispersed systems of different mineralogical and powder composition are of great importance. It has been considered the formation of bonds between the particles of the disperse systems of different composition. It has been determined the influence of mineralogical makeup, dispersibility and specific surface of solid phase of disperse system on autohesion strength of dry and wet mixes. It has been presented the influence of powder on adhesion-autohesion properties of wet raw slurry of cement production. It has been received the dependence of complex parameter of the disperse system, considering the properties of dispersed phase and disperse medium on the size of particles of dispersed phase of different mixes at their wetting and capillary impregnation. Complex researches of surface phenomena in disperse systems can be used to choose a method of processing polydisperse materials including many technogenic for the purpose of their utilization and protection of environment against noxious discharge.

Key words: Agglomeration, adhesion, autohesion, wetting, dispersed materials, specific surface, complex parameter of disperse system

INTRODUCTION

Dispersed materials are the components of disperse systems, consisting of two or more phases with very developed interface between them. In technology of dispersed materials as a rule, these are the systems consisting of solid, liquid and gas phases at different ration between them.

The important properties of solid particles are chemical composition, density, elasto-plastic characteristics, electric conduction, dielectric, magnetic properties, hygroscopic property, solubility, softening temperature.

The following properties are important for individual particles: geometric sizes, form, roughness; surface solidity, plasticity, wettability, solubility, electric conduction of surface layer and films of adsorbate; autohesion capacity ultimate strength of particle contacts at extension and no-load, growth rate of ultimate strength in relation to loading; frictional properties angles of friction and adhesion in single contacts.

All above-stated properties determine in a varying degree the character and intensity of their further processing for the purpose of forming bodies and particles of certain sizes, forms, structure and physical parameters. In technologies of dispersed materials in many industries to obtain the product of required quality as a rule, the processes of mechanoactivation or agglomeration are used. The choice of a method depends on physical and chemical properties of raw powder materials, their dispersibility, requirements for physical and mechanical parameters of the finished productand other factors (Il'ina, 2009). Increasing volume of powder waste in production of constructional materials and products determines the necessity of their utilization by means of mechano activation and compaction. But discrete tasks in technologies of processing polydisperse materials have not been studied enough and need to be solved. It refers to estimate of the role of surface phenomena in disperse systems in choosing rational technology of their processing.

Corresponding Author: Makhabbat Batyrgaliyevna Amanbayeva, Abai Kazakh National Pedagogical University, Dostykave 13, 050010 Almaty, Kazakhstan

MAIN PART

The surface interactions, thermal and physical and chemical transformations can be based on many processes. The surface interaction between disperse particles are conditioned by surface free energy, accumulated in breakage, especially by its mechano activation. Agglomeration in disperse systems may occur without exposure to external forces as so called elemental agglomeration that is effected by transportation, storage, warehousing of polydisperse materials. Formation of agglomerates occurs also in air flows of aspiration systems in suspended fluidized bed by dehydration in drying drums (Il'ina, 2009). At the present time, it has been accumulated meaningful scientific and practical experience in the field of formation of dispersed materials with formation of colloidal capillary-porous bodies.

All disperse systems of kinetic properties of dispersed phase are divided into two classes free disperse in which the dispersed phase is mobile and bond disperse in which one of the phases does not move free as it is structurally immobile. They are referred to capillary-porous bodies with solid dispersion medium in which the particles of dispersion phase cannot move free.

From the point of view of surface phenomena in disperse systems the process of agglomeration can be considered as transfer of the system from free disperse (fluidity) system to bond disperse (granules, briquette and others).

In many cases an agglomerated material consists of fine-dispersed particles of solid components and technological bond, liquid as a rule. Interaction of liquid with the surface of solid body is conditioned by free surface energy or interphase surface tension and from positions of molecular-kinetic theory by uncompensated forces of molecules of the surface layer. Necessary strength can be provided if liquid used as technological binding processes high adhesion in relation to agglomerate solid substance and individual high cohesive strength.

Depending on proportion of solid substance, liquid and gas phases the coalescence of particles is provided by adhesive and cohesive forces in the bridges of technological bond between solid particles or capillary forces. The surface phenomena in disperse systems which adhesion, autohesion and cohesion refer to are based on these interactions.

Autohesion of the particles is a link of contacting particles that prevents their disunity. Adhesion of the particles unlike autohesion means interaction of the particles and solid surface of macroscopic bodies (walls and operative parts of technological apparatuses and the others). Cohesion is a link between molecules (atoms, ions), leading to formation of a single body. By interacting solids cohesion can arise in the points of their direct bonding.

Intensity measure of autohesion is a force necessary for disunity of contacting particles. It is called the force of autohesion.

The intensity of autohesion is different for different materials even at the same conditions, therefore, it has been introduced the notion of autohesion capacity. Autohesion capacity is a comparison characteristic of free flowing material and means the intensity of autohesion, i.e., force which is realized by this material at certain conditions.

The fundamentals of strength of disperse structures also including free flowing material are formulated by Rebinder. These fundamentals come to the following:

- The strength of free flowing materials is defined by the character of contacts between the particles and proportional to contact number per unit of area of material section and average strength of individual contacts
- The contact number is defined by particle size and packaging technique: the denser package, the more contact number per unit of section
- The coarse pores do not only reduce the number of contacts but promote stress concentration in the body which decreases its strength

Thus, the research of autohesion capacity of disperse systems will allow to predict their suitableness for further redivision.

In present work, it has been researched autohesion and adhesion interactions in disperse systems by raw mixes of cement industry. The mixes digger in mineralogical makeup of the components, powder, specific surface area (Table 1 and 2), defined according to known techniques (Butt and Timashov, 1973).

Autohesion and adhesion properties have been determined on the basis of the known methods described in the researches. For each mixture fraction it has been determined the specific surface of the particles and magnitude of adhesive force which allows to reveal the interaction between them. It has been established the increase of bond strength with decrease of particle size (Fig. 1) and increase of specific surface of mixture (Fig. 2).

Table 1: Characteristic of raw materials

No. of mixes	Mix proportion	ρ_{aust} (kg/m³)	ρ_{ns} (kg/m³)	S (m²/kg)	MMC* (%)	$K_{IIPL} = \rho_{aust}/\rho_{ns}$	Plasticity index
1	Chalk+clay	2550	620	1070	29.2	4.11	10.5
2	Limestone+clay	2690	910	590	16.2	2.96	15.5
3	Limestone+slag	2700	890	420	8.6	3.03	9.5
4	Marl	2600	820	1044	30.7	3.17	14.5

*MMC: Molecular Moisture-holding Capacity

Table 2: Breakup and mineralogical makeup of raw mixes

| Fraction size (mcm)	Content of mix fractions (%)	Mineralogical makeup						
		Carbonate fragments	Organic substances	Quartz	Calcite	Muscovite	Glauconite	Iron hydrooxides
Chalky slime								
100-250	1.7	1.58	0.04	0.06	-	-	-	0.02
50-100	7.0	6.13	0.21	0.09	-	0.02	-	0.23
10-50	14.5	10.81	0.23	1.88	-	-	-	0.98
5-10	17.3	-	0.44	-	16.38	-	0.60	0.48
Sum 5-250	40.5	18.52	0.92	2.03	16.38	0.02	0.60	1.71
Limestone slime								
100-250	3.4	2.82	-	0.50	-	-	-	0.03
50-100	10.2	-	-	0.51	9.40	0.03	0.03	0.14
10-50	35.4	-	-	1.10	32.11	-	0.08	1.94
5-10	14.5	-	-	-	14.50	-	-	-
Sum 5-250	63.5	2.82	-	2.11	56.01	0.03	0.11	2.11
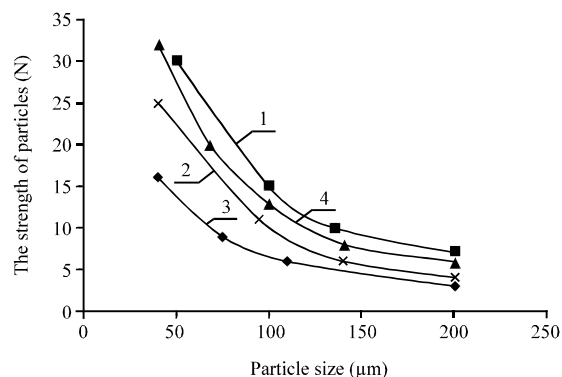
Fig. 1: Autohesion strength of contacting particles of different size of raw mixes; 1: chalk+clay; 2: limestone+clay; 3: limestone+slag; 4: marl
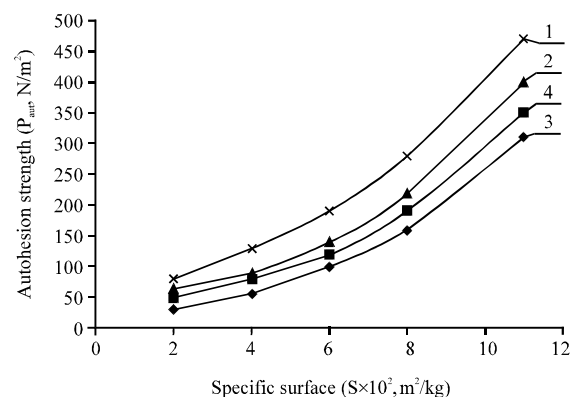

Fig. 2: Dependence of autohesion strength P_{aut}, H/m² of dry mixes on specific surfaces, m²/kg; 1: chalk+clay; 2: limestone+clay; 3: limestone+slag; 4: marl
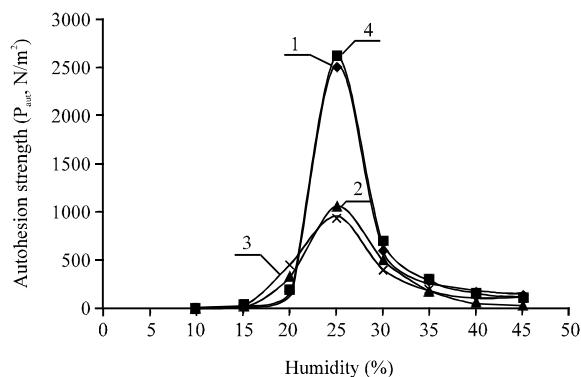

Fig. 3: Influence of humidity of raw mixes on autohesion strength of layer; 1: chalk+clay; 2: limestone+clay; 3: limestone+sludge; 4: marl

As Fig. 1 and 2 show maximum strength is characteristic for chalky-clayey mix. Limestone-sludgy mix with minimal specific surface of particles is characterized by low values of autohesion strength.

Autohesion properties of disperse systems, except factors stated above, depend on humidity of mix which is especially important for raw sludge of cement industry.

The research results, presented in Fig. 3, show extremal dependence of discontinuous strength of layer on humidity that is exhibited in range of values 20-30%.

Maximum values of autohesion strength are characteristic for fine-dispersed clayey mixes (chalk+clayandmarl). Lower values, practically two times of layer strength are characteristic for dense crystalline particles of limestone particles. With increase of humidity of sludge from 30%, the discontinuous strength for the whole mix increases and makes up 18-20 Pa with humidity 90%.

The decrease of discontinuous strength of sludge with the increase of its humidity is explained by the increased film of water around the particle and determined by the bond strength of sheet of water. This assumption is confirmed experimentally, the strength of water sheet makes up 18.1 Pa which practically corresponds to the strength of sludge by 90% humidity.

Humidity change range of industrial waste is characterized by values 32-48% as a result of this autohesion interactions change from 400-50 Pa. It should be noted higher values of autohesion strength for mixes chalk-clay (1) and marl (4) which is explained by similar mineralogical makeup of mixes and their high capacity to dispersing in water medium.

Disconnected strength of sludge determines conditions of its homogenizing and transportation in the system of hydrotran sport and also capacity for granulation in the chain zone of the «cold» end of the rotary kiln by firing clinker.

The conducted researches have showed that optimal compacting pressure relevant to maximum tearing strength of layer exists for all fractions of dry raw mixes.

The zone of extremum for homogeneous mixtures with greater specific surface is shifted to the area of low pressure which allows to state optimal conditions of pressing for different mixes of fractional composition. For example, pressing mixes containing chalk, clay and limestoneis reasonable with lower pressures than coarsely dispersed limestone-cindery mixtures. It has been revealed the influence of disperse composition of humid sludge on its adhesion-autohesion properties:

- In the range of humidity 48-52% adhesive force of both cretaceous and limestone sludge exceeds adhesive forces in layer
- With humidity of sludge 30-34% adhesive force of fractions 40-60 mcm lesser than the layer of particles 300-500 mcm in size
- By addition to the sludge of fine dust collected in electrostatic precipitator of the rotary kiln of cement making in numerical terms of 5-15% with humidity of mixture of 34-48%, the autohesion strength of the layer of cretaceous sludge increases 20-28% of limestone -48-66%
- It has been established that to decrease autohesion of the layer of the sludge it is necessary to add to it fine-grained hydrophobic materials and to increase hydrophilic

The researches to be conducted before show that the dust burden from the «cold» end of the rotary kiln for clinker burning depends on autohesion properties of dry component of raw sludge. To decrease dust burden and to reduce environmental damaging discharges it has been offered to change the properties of sludge by means of adding water-soluble polymers to it: latex, lignosulphonate industrial, sodium-carboxymethylcellulose and others.

Introduction of optimum admixtures to the sludge at the stage of its preparation leads to the increase of autohesion strength of dust collecting at the stage of sludge drying and to the decrease of dust burden from the«cold»end of the kilnto 15-25%. Besides, it is strengthened the adhesion of sludge to chain curtain in the zone of drying with granules meant for further thermal processing with production of clinker. Adding plasticizing agents to the sludge is conductive to the decrease of humidity of the sludge 1-2% which leads to increase in productivity of the kiln and reduce fuel rate.

Adhesion, cohesion, wetting and liquid spreading are the result of intermolecular interactions in and between the phases. Therefore, the study of the process of wetting in disperse systems represents an interest.

Wetting is a surface phenomenon consisting in interaction of liquid with solid body in the presence of the simultaneous contact of three immiscible phases, one of which is gas (air). The degree of wetting is characterized quantitatively by quantity of cosine of contact angle (wetting angle) or simply by contact angle.

Wetting is quantitatively characterized by cosine of contact angle, i.e. is determined by relation of work of adhesion to work of cohesion for wetting liquid:

$$W_{adh}/W_{kg} = 1 + \cos\theta/2 \qquad (1)$$

This equation tells that to enhance wetting it is necessary to increase work of adhesion or to reduce work of cohesion (surface tension) of liquid for example by SAS adding, temperature change. The liquid is better to wet which has less surface tension or work of cohesion.

There exist different methods to determine the wetting angle. The simplest is putting drops of liquid onto the studied surface and determining the contact angle by means of the projector. In studying polydisperse systems this method is not applicable, all the more, surface roughness increases the angle of wetting (Frolov, 1982).

In the present work the surface interactions in the disperse system were determined taking into account the rate of dip of powder layer based on the equation (Zimon, 1974):

$$h^2/t = r/c^2 \cdot \sigma_{jew} \cos\theta/4\eta \qquad (2)$$

Where:

r/c^2 = Structure constant, characterizing the property of the analyzed system and depending on the size, packing density and particle shape (m)

h = Distance (m) covered by the liquid in layer per time (t, sec)

σ_{liq} = Surface tension of liquid at the boundary with air (T/m)

η = Dynamic fluid viscosity (Pa·s)

θ = Limiting wetting angle (grade)

As Eq. 2 tells, velocity of travel of liquid in the layer depends on the liquid and structure of composition of porous material. This phenomenon is widely known as the phenomenon of capillary impregnation that is the basis of many natural processes and mechanisms. In terms of the law of fluid motion in capillaries and basing on (Deryagin ,1946) Eq. 2 can be represented in the form:

$$h^2 = K_{KP} \cdot t \qquad (3)$$

Capillary impregnation coefficient has the properties of complex character reflecting the properties and character of interaction of all phases of disperse system.

Capillary impregnation is sufficiently accurate physical model of granulation of dispersed materials which was first substantiated and experimentally proved by Vityugin. According to the researches of the workers of Vityugin V.M. school the velocity of the process of granule formation and the strength of granulated material depend on relation and character of interaction of solid and liquid phases of lump-forming material which is characterized by the constant of capillary impregnation.

Introduction into this model of numerical values of volume concentration of the solid phase in the disperse system allows to quantitatively determine by means of the constant the capacity of the material not only for aggregatedness but for granulatedness as well, i.e., capacity to form humid conglomerates of either strength but the capacity to compact with increasing of size and strength of external centrifugal and gravitational forces (Lotov *et al.*, 2006).

In the present work according to the results of impregnation kinetics of different materials (Fig. 4) it has been obtained the dependence of coefficient of proportionality of Eq. 3 on fractional composition of raw mixes.

As seen from Fig. 4, it is observed an extreme dependence with maximum in the range of particle sizes 80-160 mcm for all materials.
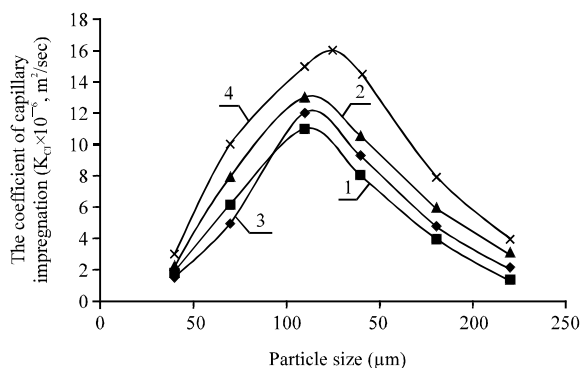

Fig. 4: Dependence of coefficient of capillary impregnation of mixes on particle size (mcm); 1: chalk+clay; 2: limestone+clay; 3: limestone+sludge; 4: marl

For the layer of particles <80 and >160 mcm impregnation coefficient reduces. And for the particles of 20-40 mcm it is observed near coefficients $(1.5\text{-}2.5)\cdot 10^{-6}$ m²/sec irrespective of mix proportion. It can be explained by closer packing of particles and reduction in wetting and infiltration rate.

For particles >200 mcm it can be noted more scattered results $(1.5\text{-}5.0)\cdot 10^{-6}$ m²/sec and cretaceous-clayey mixtures have also lesser values. The latter can be explained by lessening the role of capillary phenomena at the expense of pore upsizing and by changing the properties of liquid component that can represent clay suspension with more viscosity and surface tension coefficient than water.

As follows from Eq. 2 and 3, the coefficient of capillary impregnation can be presented as complex parameter, regarding the character of composition of the structure K_{str} and parameter A:

$$K_{KP} = K_{cmp} \cdot A \qquad (4)$$

The complex of parameters a can be conditionally regarded to be adhesion characteristic that has dimension of velocity (m/sec) and indirectly characterizes penetration of bonding material into the pores of disperse material. So, by the results of layer impregnation of the disperse material it has been worked out the bonding materials requirements for agglomeration (securing) of surface layer of polydisperse materials (Il'ina, 2010).

Dimension K_{KP} is m²/sec can be expressed as m³/m·sec. Physical meaning of impregnation coefficient can be presented as gradient of fluid flow rate in the layer, depending on specific surface of the material, its porosity,

wetting angle, viscosity and surface tension coefficient of liquid and other factors. In the research by Lotov *et al.* (2006), it has been presented the methods of porosity analysis of the layer depending on the coefficient of capillary impregnation of materials with different specific surface.

Thus, the processes of material processing are closely connected with the complex of surface phenomena in disperse systems that is conditioned by the nature of material, its dispersibility, physico-chemical properties of liquid phase and other factors.

Methodological ground of working the process of agglomeration, represented in the work (Sevostyanov *et al.*, 2014) can be supplemented by detailed research in the field of surface interactions under external forces.

SUMMARY

Basing on experimental study of surface phenomena in the systems of different mineralogical and disperse composition it has been determined the influence of sizes and specific surface of the particles of solid phase on the bond strength of dry mixes. For wet mixes, it has been obtained extreme dependence of autohesion strength of the layer in the range of humidity 20-30% with maximum values for marlitic and cretaceous-argillaceous mixes.

By studying kinetics of wetting of disperse materials of different mineralogical and fractional composition it has been obtained the dependence of capillary impregnation coefficient on particle size that has an extreme character in the range 80-160 mcm. It has been suggested considering this coefficient as complex parameter of the disperse system, taking into consideration porous structure of the dispersed phase (K_{str}) and adhesion properties of disperse medium (A).

CONCLUSION

The presented in the article analytical and experimental dependences of effect of surface phenomena (adhesion, autohesion and cohesion) indisperse systems can be used to choose and develop the apparatuses for the processes of processing disperse materials of different mineralogical makeup and humidity including technogenic materials for the purpose of their utilization and environmental protection against deleterious effect of industrial wastes.

ACKNOWLEDGEMENT

REFERENCES

Deryagin, B.V., 1946. Determination of specific surface of bodies by capillary impregnation rate. Colloidal J., 2: 27-30.

Il'ina, O.N., 2009. The Processes of Agglomeration in the Dispersed Materials Technology: Monograph. BGTU Press, Belgorod, Russia, Pages: 229.

Il'ina, O.N., 2010. Methods of agglomeration of surface layer of polydisperse materials. Chem. Oil Gas Eng. Ind., 4: 3-7.

Lotov, V.A., V.V. Gurin and A.I. Popov, 2006. Basics of Management of Structure Formation Processes in Wet Disperse Systems. Kuzbas University Press, Kuzbas, Russia, Pages: 295.

Sevostyanov, M.V., T.N. Il'ina, V.S. Sevostyanov and D.A. Emel'anov, 2014. Methodological principles of agglomeration processes improvement in technologies of disperse materials processing. Res. J. Appl. Sci., 9: 738-744.