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Mechanical Compaction Process Models of Man-Made Materials and Their Instrumentation Software

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Abstract: The article presents an analysis of the problems associated with the growing need for complex processing of man-made materials of various branches of industry by the compaction method in order to produce products that are in demand. The possibilities of molding man-made materials in devices with differentstructural and technological features have been considered. The necessity of the development of machines for molding man-made powdered materials with different physical and mechanical properties have been shown. The features of the compressionprocesses of dispersed materials depending on external influences have been investigated. As a result of the complex analysis mechanical models'basedon Hooke, Newton, Sen-Venana, Culona-Deryagina laws, describing the forming mechanism of molded body have been developed. The proposedmechanical models of various compaction processes allow us to determine priority areasfor structural and technological improvement of the molding equipment for the processes considered by extrusion, granulation and briquetting. The practical output of these developments is thepatenteddesignof the aggregatesfor the implementation of these processes with theregard to the specific characteristics of man-made materials.

Key words: Man-made materials · Granulation · Briquetting · Extrusion · Vibration and centrifugal granulator · The press roller aggregate

INTRODUCTION

At the present stage of the production development the search of technical solutions for elimination environmental problems is extremely important and in this connection it is necessaryand economically advisable to makea complex processing of man-made materials in various branches of industry. An important role is played by low-tonnage production and technological systems that can quickly be reconfigured for producing various kinds of products which are in demand [1]. The most popular are dry building mixtures for various purposes, including heat-insulating mixtures andmaterials using waste products of expanded perlite, fibro fillers of cellulose and paper production [2-3].

The Main Part: When disposing man-made powdered materials it is possible to obtain a wide range of products bycompacting (molding)method. The range of aggregates with different structural and technological features for molding materials: screw, roller (perforatedthe press, the press roller extruders, granulators for pelletizing materials, etc.) are known and widely used [4, 5]. The choice of equipment depends on theproduction technology of the main products of construction industry enterprises [6-8]. Typically, the process of molding material in these machines conform to the general laws presented in the form of compression curves of dependenceof the degree of compaction $E_i$on the molding pressure $\overline{P_i}, E_i = f(\overline{P_i})$

Various powdered materials with predetermined molding humidity (Fig. 1) were chosen as the test materials. The analysis of the received compression curves polydisperse materials allows to establishtheir common pattern.

The intensive removal of the gaseous phase takes places at the first stage (segment AB). This occurs due to

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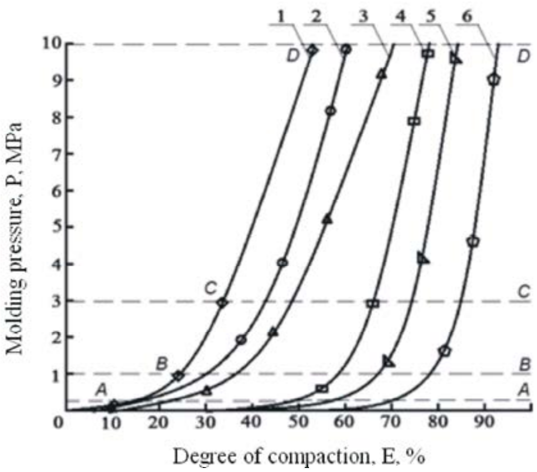

Fig. 1: Compression curvesof dependence of the degree of compaction of polydisperse materials on the molding pressure

1 - expanded perlite, W = 50%; 2 -rotary kiln dust during cement production, W = 12%; 3 -dust discharge of the rotary kiln during lime production, W = 18%; 4 - dust discharge of the rotary kiln during production of expanded clay, W = 17%; 5 - shredded wood production wastes with oil sludge finder C_{osf}= 40%, 6 - finely ground cellulose and paper production wastes, W = 10%.

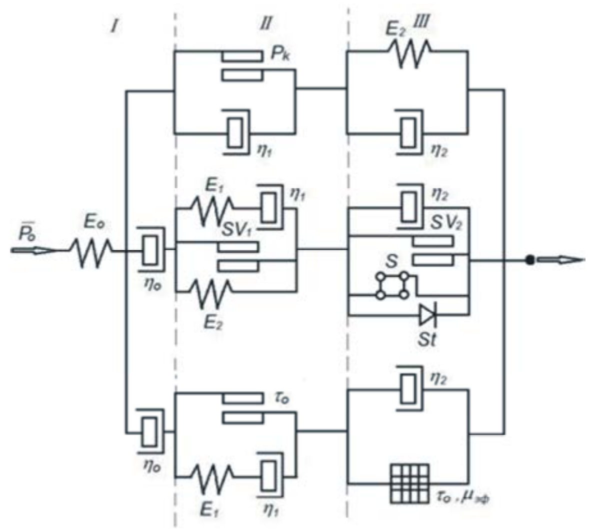

Fig. 2: The mechanical models ofcompaction processes ofman-made materials by different methods

external force on the initial material in loosened state. In the compaction process contact interaction of multi fractional particles overcoming the in terparticle friction takes place. With the growth of external influence on the test batch (segment BC) the visco-elastic-plastic deformation of granular media, which is hampered by the presence of liquid in the pores of the material can be observed. At the third stage (section CD) - plastic deformation changes into the elastic one and the minimal increase of values $\mathring{A}_i$(to 20%) and the significant increase of the pressures used can be observed ($\overline{P_i}$ from 3 to 10 MPa).

Based on the presence of the general laws of the molding process of man-made materials with different physical and mechanical properties and humidity [9], the processes of visco-elastic-plastic deformation of the batchimplemented by various technologicalways of compaction:extrusion, granulation, briquetting and tabletting, etc., can be represented in the form of mechanical models characterizing the specific features of these processes (Fig. 2).

Phasic granule formationas result of visco-elastic-plastic deformation of the batchcan be easilyrepresented by means of the elements of Hooke, Newton, Sen-Venana, models of Maxwell, Kelvin, Bingham and etc. [10, 11].

- Extruding (visco-plastic molding)
- Pelletizing (semi-dry molding)
- Briquetting (semi-dry-dry molding)

In a detailed review of the mechanical models ofcompaction process of man-made materials their universal character, as well as the specific features characterized of each stage of the force impacts on the moldable material have been defined.

Moldable mixture in its initial state is typicallya three-phase system, the particles of which are interconnectedby capillary bridges and compressible air bubbles. Compaction of the mixture occurs at the first stage without any significant efforts and is accompanied by the removal of the gaseous phase, by the convergence of the particles with liquid moving in the contact area of the particles (E_0). At the same time, the influence of the capillary depression and viscosity of the pore fluid (η_o) increases.

At the second stage in the case of visco-plastic molding (extruding) the maximum plastic viscosity η_1 occurs in parallel with the change of dry friction (the body of Sen-VenanaSV_1) modeling the limit strength $\overline{P_k}$. In the case of semi-dry - dry molding (briquetting) elastic deformation of particles is described by the Maxwell model (M=H-N), representing the serial connection of the Hooke (E_1)elastic element and Newton (η_1) viscous body. As it is seen from the data of mechanical models, elastic deformations are more pronounced and prolonged throughout the second molding stage. It is caused by the pressure on the material which is insufficientfor its plastic outflow and resistance to molding (briquetting).

While granule formation (pelleting) a second stage can be represented as a Poynting-Thomson (PT=H/M) combined model with an element of Sen-Venana (PT/SV_1). [12]. The capillary fluid dampens and migrates and into interporousspace, providing interparticle packing and removal of the gaseous phase.

The third stage of molding occurs when increase loads above critical, wherein the differencesof processes are most evident. Thus, when extruding the external compacting effortsare aimed at overcoming plastic viscosity (η_2) of the structured liquid and elastic deformations of the moldable mixture (E_2) solid component.On granulating by pelletingin the field of centrifugal forces at a high degree of freedom of volumetric deformations shear stress arise in the contact zone. These shear stresses are characterized by an element (SV_2) and the viscous component of the coagulation-structured pore fluid (η_2). At the third stageof dynamic granule formation particles reorientation that is taken into account by the nonlinear deformed structural element (S) as occurs. The result of impacts mass transfer between the grains takes place, which resultsin the destruction of the weaker granules as well as their growth and compression(thickening) of the granules. This process is taken into account by the body of St-stopper [13].

At the third stage in the process of briquetting of compacting mixture under the normal stresses friction force (μ_{ef}) develop depending on the nature of dispersed materials and the state of the sliding surfaces (τ_o) is characterized by Culon-Deryagin (*Kl-D*) element. The deformation speedis also dependent on the viscosity of the structured liquid (η_2) which is the same for all types of compaction of dispersed materials by extrusion, pelletizing and semi-dry molding (Fig. 2).

Analysis of the proposed mechanical models of various compaction processes allowsto determine the priorityareas for structural and technological improvement the molding equipment for the processes of extrusion, granulation and briquetting. These include:precompaction of the batch before its molding; the uniform distribution of compacting material on the working surface of the molding elements; phasic process of compacting the material by varying of impactforce; ensure possibility for the implementation of various technological methods of physic-mechanical and physic-chemical impact (classification, vibration exposure, plastic properties improvement, creating favorable conditions for the removal of the gaseous phase and liquid phase migration, aging of moldable mass under pressure, the uniform distribution of stresses in the molded materials, etc.); the possibility of compacting of isotropic and anisotropic man-made materials with different physical and mechanical properties, etc.

In view of the analysis of mechanical models of the various processes of compacting, established general and specific patterns of the considered processes the design of aggregates for extrusion, granulation and briquetting of man-made materials (Fig. 3-5) [14-17] have been developed and patented by us.

In the press roller extruder (Fig. 3) is implemented: a preliminary compressing of batch in a screw pre-compressing and conical sleeve, increasing the plastic properties of the batch due to heating, the possibility of introducing surfactants (SAS); the uniform distribution of the batch across the width of the compressing rollers with vibration exposure, aging compression of the batch under compressed pressure, etc. [14, 15]. Similar technical solutions are implemented in the flat matrix roller press extruder.

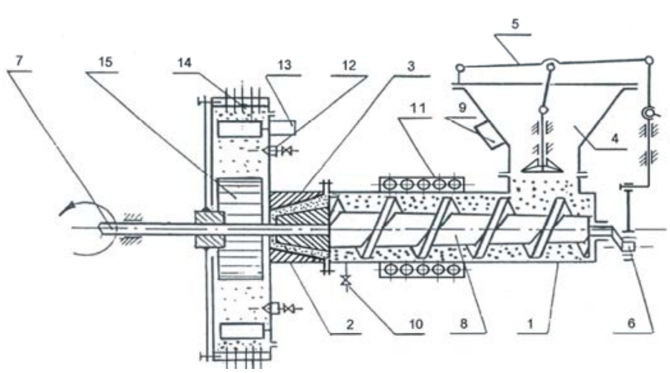

Fig. 3: Rollerpress extruder
1-body with output conical head; 2-sleeve; 3-conical inner surface of the sleeve; 4-hopper; 5-arm compressor; 6-crank, 7-shaft, 8-screw, 9,13,20-high frequency vibrators; 10-connector with valve for heating medium, 11-band of composing insulating elements with heaters;12-nozzle;14-press-matrix; 15-roller presses.

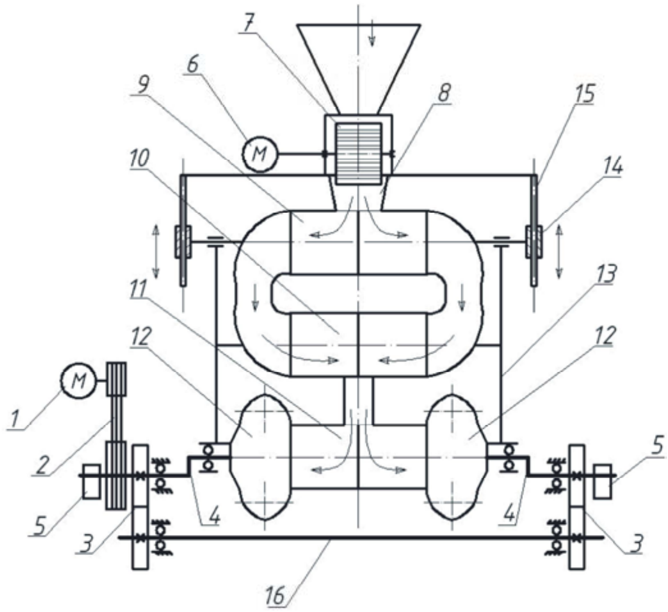

Fig. 4: Vibration-centrifugal granulator
1- the main drive motor; 2 - V-belt transmission; 3 -gear pair; 4-eccentric shaft; 5- balances; 6 -electric drive of precompression device; 7 -elastic compression roll of microgranulation;8-vibration gutter; 9, 10, 11 -drums of granulation material; 12-toroidal chambers; 13-movable frame; 14 -slides; 15-column shears; 16-intermediate shaft

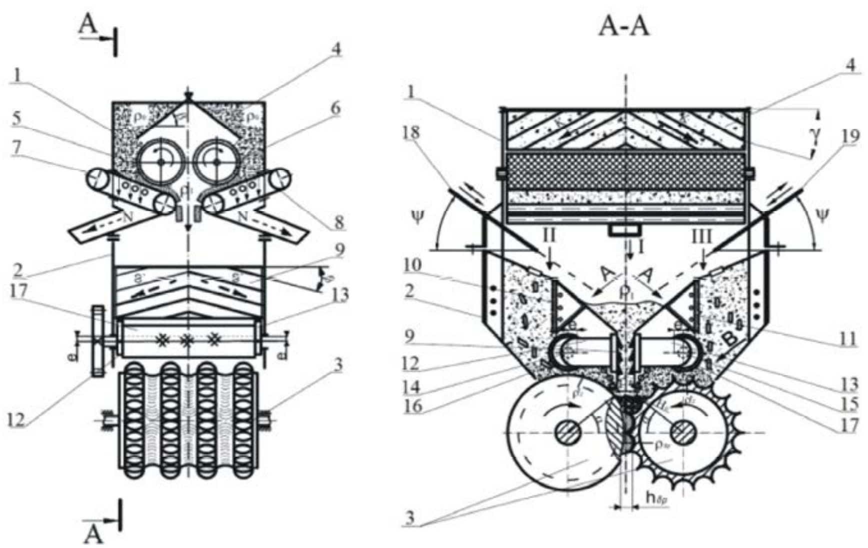

Fig. 5: Roller press aggregate for briquetting of man-made materials with different physical and mechanical properties
1 - the upper block of the hopper; 2 -the lower block of compressionjaw; 3 -press rollers;
4 - distribution plates; 5,6-elastic compression rollers; 7, 8-endless moving belts; 9-compressionjaw; 10, 11-hollow chambers; 12, 13-eccentrics; 14, 15- drive shafts; 16, 17 - freely rotating rollers; 18,19-gate devices

In the vibration-centrifugal granulator (VCG, Fig. 4) the principle of phasic molding of granulated materials is implemented: on the first stage –de-aeration of theoriginal composition mixture by means of precompaction in the roller device and microgranulation of the batch; at the second stage - the compression and classification microgranules; at the third stage - the granule formation of the materials inthe waterfall-cascade and cascade modes of moldedbatch processing;at the fourth stage - spherical shaping of granules and hardening of the surface layer in the toroidal chambers [16].

The above given general regularities of molding processes of visco-plastic and powdered mass (compression curves, mechanical models, Fig. 1, 2) are performed in a roller press aggregate (RPA, Fig. 5) equipped with a device foruniform distributionof the batch on the working surface of the moldingelements and precompression of the charge with the possibility of wide variation of precompaction material factor [17].

Conclusion: General regularities of compression processes ofdispersed materialspresented at three stages have been defined. It is shown that atthe first stageof processesof semy-dry and dry molding the gaseous phase is removed withformation of the agglomerates (microgranules) and it is described by Maxwell model. Its further compression depending on the nature of the external forces is representedby different mechanical models, whose distinctionis especially evident at the third stage. General regularities are revealed and specific features of the processes of extrusion, pelletizing and briquetting can be used in the development of devices and technologypowdered materials compaction.

CONCLUSIONS

The complex analysis of the basic regularities of compression processes of man-made materials with different physical and mechanical characteristics, thedeveloped mechanical models of the processes of extrusion, granulation and briquetting allowed to develop a patenteddesign of aggregates for the carrying out of these processes with regardthe specific characteristics of man-made materials.

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