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Investigation of methods and equipment for compaction of composite mixtures during their granulation

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Abstract. The article presents the results of a literature analysis of the methods of compaction of materials, analytical and experimental research on the creation of a roller compacting device and the determination of its operation modes, which provides an efficient preliminary compaction of a composite mixture based on technogenic materials.

1. Introduction

The use of secondary material resources (SMR) in the organization of non-waste technologies of production is becoming increasingly widespread in various industries, including in the production of building materials, ferrous metallurgy, road construction etc.

To obtain high-quality products from SMR, the materials in finely fractionated state are pre-agglomerated. For example, in the production of additives to stone mastic asphalt concretes, the used fibrous material is comminuted to dimensions of 10 - 15 mm, after which the granules of size d × h = 5 × 10 mm are obtained [1 - 5].

However, in the process of granulation in traditional equipment (plate, drum and other granulators), it is not always possible to obtain a product of the required quality (in strength, bulk density, etc.).

One of the ways to increase the efficiency of the granulation process is its stepwise (multistage) organization with preliminary compaction of the moldable mixture. The essence of this process is that it proceeds separately in the following sequence: removal of the gaseous phase, formation of a densified structure of particles (or granule formation centers), granule formation in a dynamic or other mode with plastic deformation in the volume of particles and hardening of the surface layer of granules [6 - 8].

2. Analysis of the methods of materials compaction

There are various methods for forming and compacting materials and composite mixtures, the main of which are: isostatic, deformation in confined space, vibratory, pulsed, tip and rolling. A comparative analysis of the main methods of compaction of moldable materials is presented in Table 1 [6, 8, 9].

Table 1. The methods of materials compaction

№	Name	The essence of the method	Advantages	Disadvantages
1	Isostatic compaction	Forming with the use of a liquid or gas under very high pressure and, if necessary, high temperatures under conditions of all-round compression. The method is used to produce large capacity workpieces that have the same density in all directions	The application of pressure on all external surfaces of the pressed material and practically no loss of external friction	The design complexity of installations; large dimensions; periodicity of action; the difficulty of removing air from the molded material; increased energy consumption
2	Compaction using a closed mold	Pressure from one or two punches is applied to the material. Material decreases in volume and becomes a predetermined shape	The possibility of obtaining pressings of certain sizes and with given physical and mechanical properties	Uneven distribution of density in the volume of the pressing due to the appearance of frictional forces
3	Vibratory compaction	Under the influence of vibration, the initial interparticle bonds are destroyed, and the mutual mobility of the particles improves, thereby achieving a significant density of pressings	Allows one to significantly reduce the pressing pressure and increase the density of pressings	The design complexity of installations; periodicity of action; relatively low productivity
4	Pulsed compaction	The compaction is produced by shock waves with an interval of 1 s. At high compaction rates of the powder, the heat released as a result of particle deformation, interparticle and external friction leads to local heating of the contact points of the particles and their sintering	A high degree of compression of the material and its compaction	Periodicity of action; use of explosive substances; increased wear of working parts; high noise
5	Tip compaction	Compaction of the material occurs due to its extrusion through the forming channel (outlet, die), which determines the shape and dimensions of the cross section	The possibility of obtaining pressings of predetermined geometric shapes and sizes	Defectiveness of the structure of the obtained workpieces due to the "delamination" of the material during punching; periodicity of action; the difficulty of removing air from the material; low productivity

6	Rolling compaction	The material passes between two rotating rolls with a smooth surface	High productivity, economy, simplicity of construction and reliability; low operating costs, relatively small dimensions	The main disadvantage of this type of machines is the difficulty in forming adhesively active materials

The process of preliminary compaction, depending on the properties of the molded material and technological necessity, can be organized separately in special devices - prepressors (precompactors) of various designs.

3. Development of roller compactor

One of the technical solutions for the implementation of preliminary compaction (removal of the gaseous phase, formation of a densified particle structure) can be a roller device, the choice of which was made based on the known advantages of the rolling compaction method (Table 1) and a number of the following circumstances:

- the device is simple in manufacture and operation (does not require strict synchronization of the rotational speed of the rolls, ensures a reliable grip of the molded charge);
- allows one to obtain the preset pre-compacting coefficient of charge;
- provides a greater coefficient of use of the working surface of the forming elements.

Analytical research of the processes that occur during compaction of composite mixtures has allowed obtaining equations for the calculation of design and technological parameters of the compacting device [10].

It follows from these equations that the mass flow rate of the composite mixture, taking into account the law of conservation of mass $G_q \geq G_{m.gr,}$ will be:

$$G_q = B \cdot h_B \cdot v_{\min} \cdot \rho_i, \tag{1}$$

where B - width of forming rolls, m; h_B - gap between the forming surfaces of the rolls, m; ρ_i - density of composite mixture, kg / m^3.

The value of the minimum compaction rate can be obtained from the following expression:

$$v_{\min} = q / \rho_i, \tag{2}$$

where q - specific mass flow rate of the mixture, kg / m^2 s.

The research of the processes of deformation of powdered materials and their relaxation after stress relief has made it possible to establish an expression for determining the necessary elastic relaxation time of the mixture:

$$\tau_{upr.r.} = (\ln\sigma_0 - \ln\sigma_\tau)\theta / \ln\ell, \tag{3}$$

where σ_0 - initial stress, N / m^2; σ_τ - current stress in the layer of the moldable mixture, N / m^2; θ - the elastic relaxation time of the moldable mixture, c; ℓ - length of contact area between forming rolls, m.

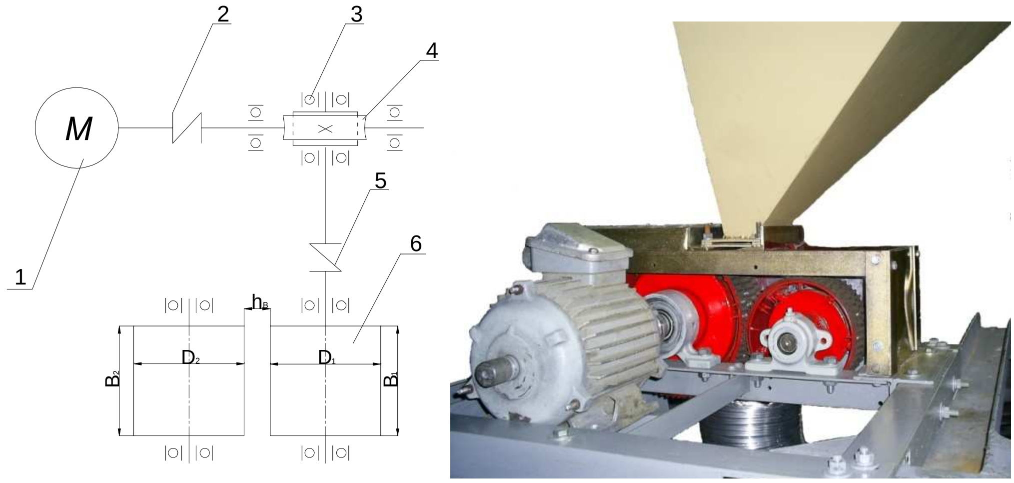
Taking into account the properties of the material of the forming rolls ($E_{f.v}$ is the modulus of elasticity, μ is the Poisson ratio), the radius of the rolls ($R_{f.v}$), expression (4) is obtained to calculate the compaction time and deformation of the mixture at biasing force P, n / m:

$$\tau_{upl.d.} = (2/\pi \cdot n_{f.v.}) \times \sqrt{P(1-\mu^2)/\pi \cdot E_{f.v.} \cdot R_{f.v.}}. \qquad (4)$$

Under condition $\tau_{upr.r.} \leq \tau_{upl.d\,.} \geq \tau_f$ and taking into account the conditions necessary to ensure the elastic relaxation of the mixture, this expression determines the rotation frequency of the forming rolls, $n_{f.v.}$, s^{-1} [10].

After calculating the parameters of the roller compactor, the following technical characteristics of the experimental setup were determined: the speed of the rolls – $n_{f.v.} =$ 90 - 150 rpm; the diameter of rolls – $D_1 = D_2 = 0.25$ m; the width of rolls – $B_1 = B_2 = 0.1$ m; the gap between the rolls – $h_V = 1 - 3$ mm.

The construction scheme and the general view of the roll compacting device is shown in Figure 1.



a *b*

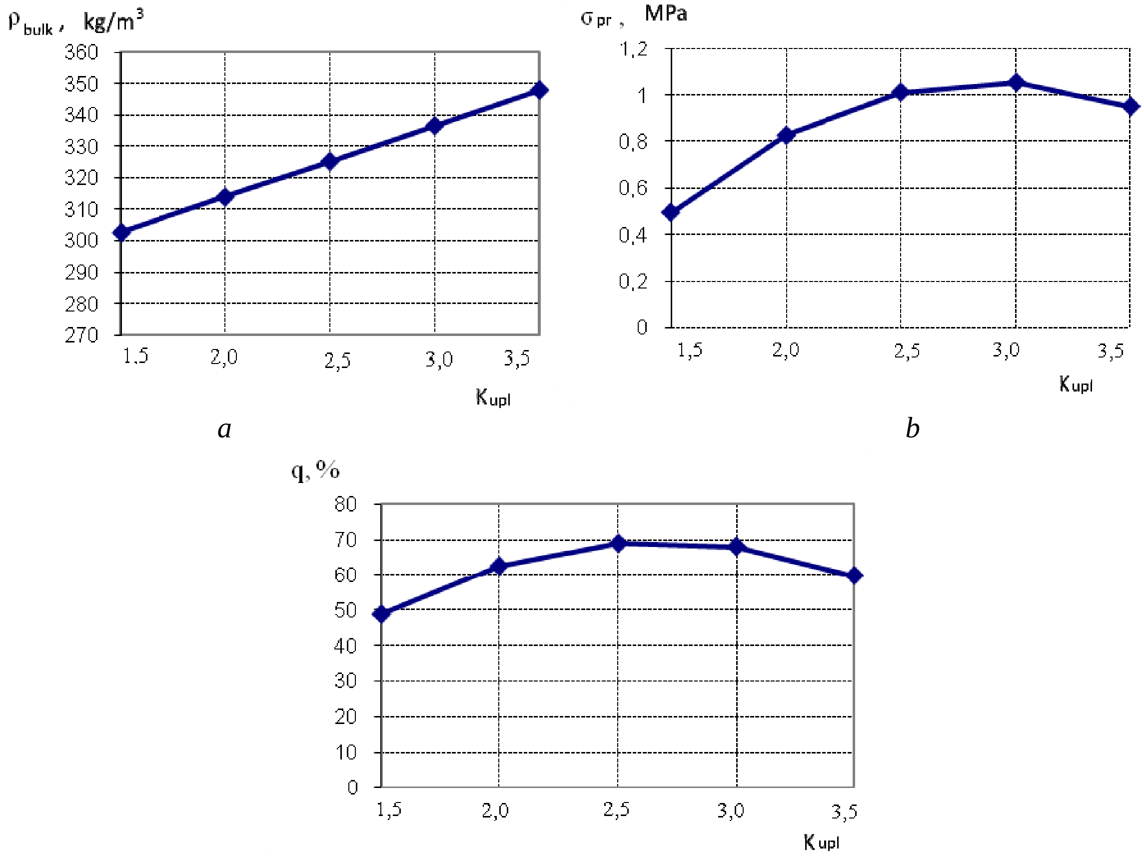
Figure 1. Roller compacting device: a - construction scheme; b - general view; 1 - electric motor; 2, 5 - couplings; 3 - bearings; 4 - worm reducer; 6 - working element (roll).

4. Experimental researches

Research of the effectiveness of the developed technical solution was carried out using technogenic materials. The composition was prepared in the following composition (% by weight on a dry basis): dust of pearlite production (42-47), bentonite (13-17), gypsum (13-17), liquid glass (23-26). Humidity of the charge is W = 50 - 52%. The bulk density of the initial charge moldable is $\rho_0 = 200$ kg/m^3.

The task of experimental researches was to determine the influence of the compaction coefficient ($K_{upl} = \rho_i/\rho_0$, where ρ_i - the density of the composite mixture after the roller device and ρ_0 - density of the initial composite mixture, kg/m^3) on the characteristics of the obtained granules (bulk density of dry granules, $\rho_{bulk.}$, kg/m^3; compressive strength in a cylinder, σ_{pr}, MPa; and the number of conditioning granules (homogeneity of the granulometric composition) of size 5 - 10 mm, q, %). One of the conditions for carrying out the experiment was the subsequent molding of the compacted composite mixture in a vibratory centrifugal granulator.

The results of the research are presented in the form of graphical dependencies (Figure 2).



a *b*

c

Figure 2. Graphical dependencies: a - densities; b - strength; c - number of conditional granules from $K_{upl.}$

Precompaction coefficient (K_{upl} from 1.5 to 3.5) selected for research range values was caused by the fact that at lower values it is not provided with the necessary conditions for the removal of gaseous phase. Increasing compaction coefficient ($K_{upl} > 3.5$) by reducing the gap between the rolls or the frequency of their rotation leads to liquid extrusion that does not have a positive influence on the formation of microgranules. This is due to incompressibility of the liquid phase at maximum compaction.

In addition, an increase in the compaction coefficient ($K_{upl} > 3.5$) leads to an increase in the power consumption of the drive and an increase in the wear of the working surface of the rolls.

As a result of the analysis of the obtained results, it is established that the value of the pre-compaction coefficient should be set in the range of $K_{upl.} = 2.5 - 3.0$ since at these values there are high characteristics of the investigated parameters.

So, obtained from the composite mixture on the basis of technogenic materials, granules have the following characteristics: $\rho_{bulk} \approx 320 - 340$ kg/m^3; $\sigma_{pr} \approx 1.0 - 1.1$ MPa; $q \approx 65 - 70\%$, which satisfies the requirements for an artificial porous filling aggregate (GOST 32496-2013).

5. Conclusion

Thus, this research allows us to approach more soundly to the issue of increasing the efficiency of the process of granulation of composite mixtures and the development of design and technological solutions for its implementation, taking into account the conditions of compaction and the physical and mechanical properties of materials. Application of the developed roller device allows obtaining granules from a composite mixture on the basis of technogenic materials possessing high consumer properties.

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