Mixing process simulation of the initial building materials components using the DEM Solution EDEM system

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Abstract. Quality of building materials, products and constructions depends on the organization of technological process of their production, and it, as a rule, concerns preparatory operations, such as crushing and in a greater degree mixing of initial compound components of the future products and constructions. Production of high-quality building mixtures is one of the most actual tasks of modern building technologies. Today, the mixing of bulk materials has evolved into a special branch of technological knowledge, which is based on mechanical processes, whose goal is to ensure the highest possible degree of alignment of individual components in the mixture. Due to the development of digital technology, modern industry is able to abandon expensive and long field experiments and tests in favor of digital experiments. The results of digital experiments have a high degree of convergence with real experiments, but are carried out many times faster. To model the influence of the material loading method on the heterogeneity factor of the mixture, digital sampling was carried out using EDEM software in a screw type mixer.

1. Introduction

Mixing is one of the most important technological processes, since the quality of finished products and structures in the future depends on the homogeneity of the mixture from the original components. There are several factors that affect the quality of the mixture in the mixing process, such as the condition and concentration of the components of the mixture, the construction of the mixer (the form of the working body, the form of the mixing chamber, options for loading the mixed components), the technological mode of the mixing process.

In any volume of ideally homogeneous mixture from the phenomenological point of view, there should be particles of all components in quantities determined by their given ratio. However, this ideal arrangement of the particles in the mixture volume is not observed in reality. In randomly selected volumes of the mixture there can be a large number of combinations of particles of components, i.e. their distribution in the mixture by chance, which leads to the use of a static approach [1] to estimate the quality of the mixture.

The most common and frequently used criteria for assessing the quality of a mixture [2] is the inhomogeneity factor:
where $\bar{c}$ — the arithmetic mean of the key component concentration in the samples;

$c_i$ — the concentration value of the key component in the i sample;

$n$ — the number of samples to be analyzed.

EDEM is the leading software product on the market to simulate the behaviour of bulk material particles (dry and wet) during various processes. Developed using advanced discrete element modeling (DEM) technology, EDEM quickly and accurately simulates and analyses the behaviour of bulk materials such as rocks, dry powders, coal, soil, pellets, building material components, etc.

2. Materials and methods

2.1. Materials

Screw type mixer (Fig. 1) consists of a conical casing 1, cover 4, ledge 7, drive screw 3, drive ledge 2, screw 5, locking mechanism 6. Screw 5, rotating around its own axis driven by an engine 3 through a pair of conical gears, makes a rotation on a planetary trajectory around the axis of the casing mixer from the drive 2, a pair of gears and ledge 7. The upper end of the screw 5 is connected to the driver 7 by a coupling, freely suspended in the lower section of the mixer housing. Screw and driver drives are mounted on the cover 4 of the mixer casing [1].

Material is loaded through the spigots in the top cover, unloaded through the discharge box. One of the most important components of the mixer is the swivel support of the screw, as it is placed directly in the mass of the bulk material, so its design should provide operation without lubrication and prevent abrasion of the shaft neck by particles of the mixing material [3].

\[
V = \frac{100}{\bar{c}} \sqrt{\frac{\sum_{i=1}^{n} (c_i - \bar{c})^2}{n-1}},
\]  

(1)

![Figure 1. Screw type mixer.](image-url)
As the screw rotates around the axis of the body and its own axis, particles of the material are lifted up by its windings, also some particles are carried away along the walls of the body, and the rest of the particles, located closer to the center and opposite side of the cone from the screw, are lowered down. In this way, three material trajectories are formed in the mixing chamber: upwards along the screw turns, along the wall of the mixing chamber and downwards in the space free from the screw. This results in a quality mixing of the components of the mixture.[4].

2.2. Methods
For researching the parameters of heterogeneity of the mixture, can be using EDEM software, which allows to choose a wide range of physical properties of mixed mate-rials, such as the simulation of any type and shape of material: large lumps or fine powders, dry or wet materials. All this makes it possible to simulate processes and with this help to make conclusions about how different bulk and wet materials will interact with each other as well as with elements of the designed equipment under different technological conditions [5].

The discrete element method (DEM) is a numerical method used to simulate the mo-tion of partic-les interacting with each other through a collision. In fact, EDEM simu-lates the dynamics of each particle individually and numerically integrates their ac-celerations, which depend on the sum of all forces, including contact and gravitation-al forces. The position of each particle is captured and their interactions are evaluat-ed at each time step. Then all forces acting on each particle are calculated and New-ton's second law is used to determine accelerations to find the particle's speed and position at each moment of time, this process is repeated until the end of the simula-tion [6-8]. Therefore, the dis-crete element method (DEM) is a reliable and high-performance tool to simulate various processes with bulk and wet materials, in par-ticular, this method is widely used to simulate the processes occurring in different types of mixers [7,8] to obtain quality building materials, products and structures.

3. Results
3.1. Coefficient of inhomogeneity
With the help of EDEM software in the Analyst application, sampling for digital estimation of the in-homogeneity factor in the area of the mixing chamber centre (Figures 2, 3) and radial sampling for different loading options for the initial components of the mixtures (Figures 5, 6) - horizontal (Figures 2, 5) and vertical (Figures 3, 6) - for further theoretical calculations of determining the particle beha-vior of the mixed material has been simulated.

In the Analyst module, using the "Setup Selection" section, four "Total Mass Sensor" material groups have been created, which show the weight of the entire load that is part of this group, as well as the weight of each component of the mixture that is in the group volume. The groups are located in the centre of the mixing chamber circle and rise up the centre axis of the chamber. Based on the results of modeling with the help of Maple analytic package, in time steps 5, 9, 13 and 17 sec the digital coefficient of heterogeneity according to formula (1) was calculated for the received samples (Table 1).
Based on the results of the calculations, a graph of the change in the numerical heterogeneity coefficient (Fig. 4) from the mixing time is plotted. All lines characterizing the change of the coefficient values have a decreasing sinusoidal character. This is explained by the fact that when moving the shaft around the axis of the cone body and its axis, at a certain period of rotation, the screw, capturing the material, raises it up, then under the surfaces of the coils formed voids, which are filled with the material as from the upper layer, as well as related sector.
Figure 4: Graph of the digital heterogeneity factor of the central sample:
1 - horizontal loading of material, 2 - vertical loading of material.

Modeling of obtaining digital radial samples by known methods at mixing with horizontal (Fig. 5) and vertical loading (Fig. 6) camera material is made. Then the numerical heterogeneity coefficients are calculated (Table 2), and a graph is drawn (Fig. 7).

Figure 5: Horizontal loading of material.
Figure 6: Vertical loading of material.

Table 2. Homogeneity factor of radial sample.

| Sec. | Horizontal loading, Vc, % | Vertical Loading, Vc, % |
|------|---------------------------|-------------------------|
| 5    | 23                        | 4                       |
| 9    | 23                        | 23                      |
| 13   | 7                         | 16                      |
| 17   | 12                        | 7                       |

Figure 7: Diagram of the digital heterogeneity factor of the radial sample: 1 - horizontal material loading, 2 - vertical material loading.

4. Discussion
The analysis of the graph showed that, as with the central sample, all lines are sinusoidal, which is associated with the nature of movement due to particles of conicity of the chamber and the impact of the working body on the material. At the same time the lines characterizing mixing at horizontal loading have the most intensively decreasing character, than at vertical loading. Thus, the particles on layers move the most intensively at horizontal loading.
5. Summary
The combined analysis of the results of modeling of mixing process and further selection of central and radial electronic samples, calculation of heterogeneity coefficients for each loading variant at several time steps showed that the most intensive mixing process and the lowest values of heterogeneity coefficient of the finished product are achieved exactly at horizontal location of raw materials in the mixing chamber of vertical screw mixer. This is due to the fact that the main part of the mixing cycle is the transportation of material up the screw, due to which the material from the bottom layer is introduced into the upper, and the upper layer particles fill the voids from the raised material. In this process, the particles of the mixture are moved radially by the screw movement around the axis of the housing, which intensifies the movement of the particles in the load cross section.

Thus, using the proposed tools, it is possible to simulate the processes of mixing the original components in the mixing equipment with horizontal chambers for further production of building materials of products and constructions.

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