INVESTIGATION OF VIBROPRESSING PROCESS TECHNOLOGY

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Abstract. The vibropressing process tehnology is useful for compacting or packing any dispersed or granulometric materials, can be applied in agriculture. Vibration is widely used in the preparation of concrete and formation of parts from it [1]. The vibropressing technology means a vibrating of a concrete mix in the press form under pressure. The method is high-efficiency, gives the chance to make rigid concrete that provides high durability and frost resistance of products. To achieve a high compaction rate and high strength of the formed product - paving blocks, bricks etc., the vibration must be combined with high pressure. There is extensive literature on the effects of such features as frequency, amplitude and acceleration, and a lot of literature about rheological models of raw concrete. The results depend on material characteristics such as the difference between its initial density after preparation and its maximum packing fraction, the coefficient of friction between the grains, the angularity of particles etc. [2]. In the present work the vibropressing process was experimentally modelled on the dynamic testing machines Instron and Zwick. The form of concrete samples was cilindrical. The vibropressing regime, described by formula $f=f_0+f_A\sin(\omega t)$ was realizing by changing three input parameters – f_0 pressing force (10-50 kN), f_A force amplitude (1-11kN) and frequency (10-50 Hz). The experiments were conducted according to the Mean Square Error Latin hypercube design [3]. The influence of the pressing force, force amplitude and frequency on the vibropressing process [4] and on the strength of samples was investigated.

Keywords: vibropressing process, compacting.

Introduction

The vibropressing technology is generally used for compaction of high-strength concrete blocks such as paving bricks. A large range of block making machines is available on the market from manufacturers like “Poyatos”, “Prensoland”, “Masa-Henke”, “HESS” and many others. They are based on the following principle: the pressure is combined with forced vibrations, and for some models with vibroimpact as well, see QFT8-15 Brick Making Machine [5] for example.

A two-side vibroimpact press was also patented and investigated [6; 7]. The most important characteristics of such blocks are strength and freeze-thaw durability. Both of them increase by increasing the density of the block using the same raw concrete composition – sand, cement, water and chemical additives. Point-mass systems and continuous medium models are used to describe the concrete vibration process. Consolidation by vibration is mostly described as consisting of two stages – the first comprising subsidence or slumping of the concrete, and the second deaeration (removal of entrapped air bubbles). A different model should be used for each stage [8].

The change of viscosity of raw concrete mixture under the influence of vibration is a well known phenomenon. I. Blekhman introduced the name vibrorheology for the field of science that operates with rheological models subject to vibration [9; 10]. Vibrorheological properties of raw concrete are analyzed in [11]. The properties of concrete blocks depend on recipe, chemical and granulometric characteristics of concrete mix components as well as on the dynamic action on the raw material during the forming process – the constant pressure component, amplitude and frequency of forced vibration and length of the forming cycle.

In this study the influence of dynamic parameters on the forming process was analyzed on the basis of mathematical models, identified from natural experiments without application of classical rheological hypotheses. The material testing machines Zwick and Instron 8802 were used instead of a specialized forming machine. A special cylinder-piston construction with the diameter 84.5 mm was built for the experiments. The variable factors were the values of the constant pressure component, the frequency and amplitude of vibration force and the duration of vibration. The same amount of sand and cement was used for all experimental trials.

Experimental design

The experiments were conducted according to the Mean Square Error Latin hypercube design [1] using EDAOpt software. The three variable factors were: constant pressure component, frequency and amplitude of vibration force, see Fig. 1. The intervals of the values of variable factors are dependent on vibrorheological properties of raw concrete and testing machine possibilities. The frequency ω was changing from 10 Hz to 60 Hz, constant pressure component f_0 – from 1 kN to 5 kN and amplitude of vibration force f_A – from 0.1 kN to 1.1 kN.

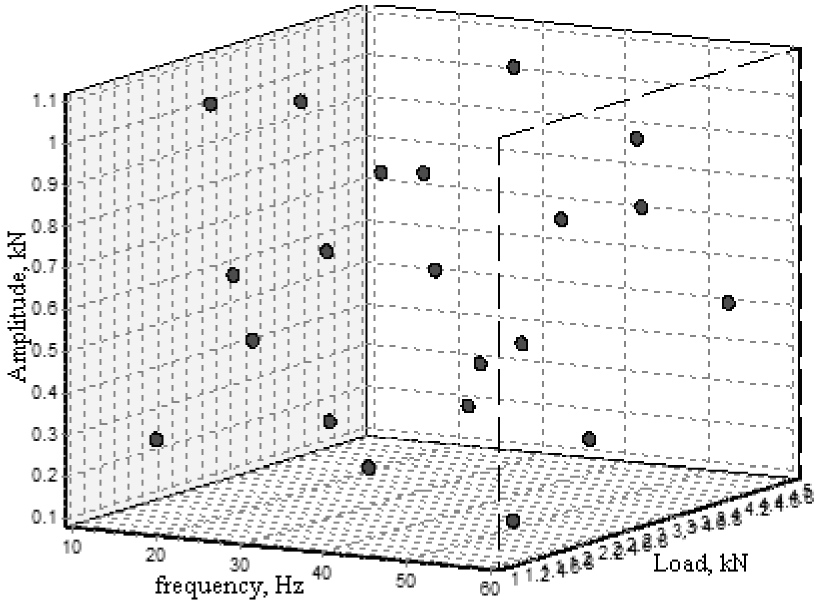

Fig. 1. **Mean Square Error Latin hypercube design**

The dynamics of vibration under pressure are described by the following force function:

$$f = f_0 + f_1 \sin(2\pi\omega t) , \tag{1}$$

where f_0 – constant pressing force;
f_1 – force oscillation amplitude;
ω – frequency in RPM.

At the beginning of the process this pressure cannot be applied since the raw concrete has a low compacting rate and accordingly a low resistance force. Therefore, before applying vibration, the two-stage pressing without oscillations was used, see Figure 2.

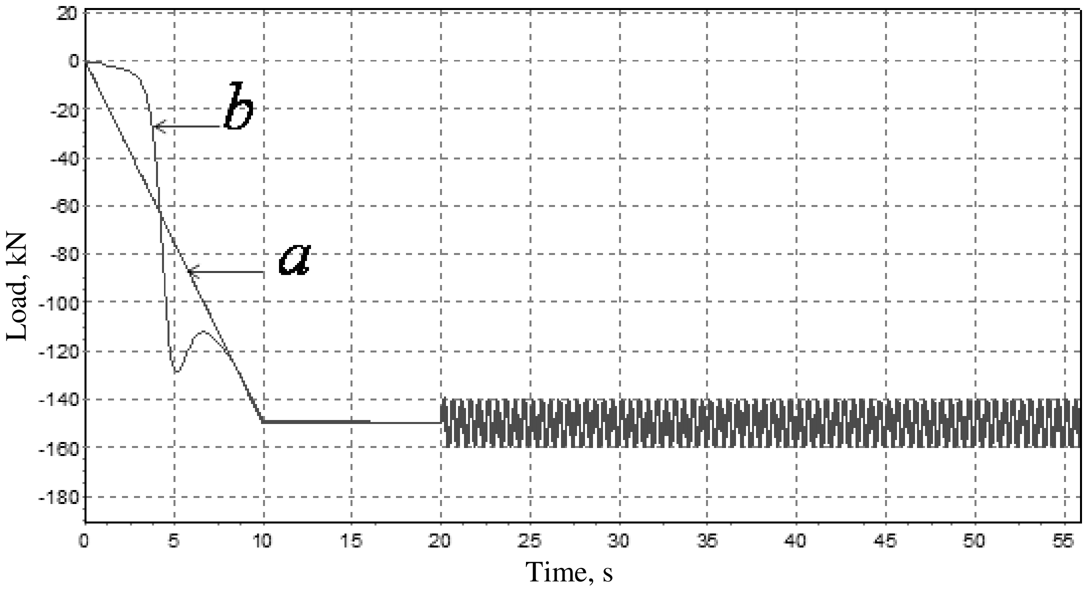

Fig. 2. **Example of required (*a*) and implemented (*b*) vibropressing regimes**

The first pressing stage is different between the required (a) and implemented (b) vibropressing regimes. The crash of the largest particles of the concrete mixture and the air burble movement can effect the implemented vibropressing regime visualisation.

The influences of constant pressing force, vibration force frequency and amplitude on the compacting process was analyzed. The same cement (class 400), sand filling aggregate (0.3-12 mm, moisture 0.2 %) and water-cement mass ratio (W/C) 0.36 were used for all experimental runs.

Concrete cylinder blocks with diameter 84.5 mm and weight 1 kg were compacted, see Figure 3.

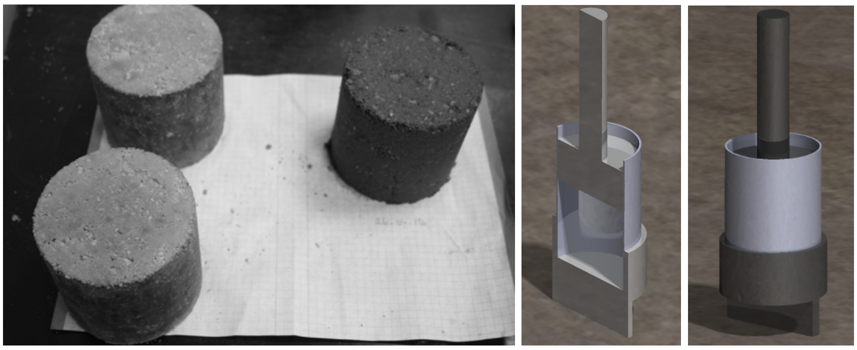

Fig. 3. **Pressing plunger, mold and compacted concrete block specimens**

Computational dynamic analysis

The experiment for three variable factors f_0, f_1, and ω was planned according to the Mean Square Error experimental design [1]. During the experiments, the testing machine was registering the compacting displacement of the plunger.

Fig. 4. shows a typical compacting displacement curve. The approximation with a power function was used in the form

$$\hat{x}(t) = x_0 + R(t - t_0 + \Delta)^p \tag{2}$$

with four parameters x_0, R, Δ and p for curve fitting according to the least-squares method. This approximation gives very accurate approximation of the displacement curves, see Figure 4.

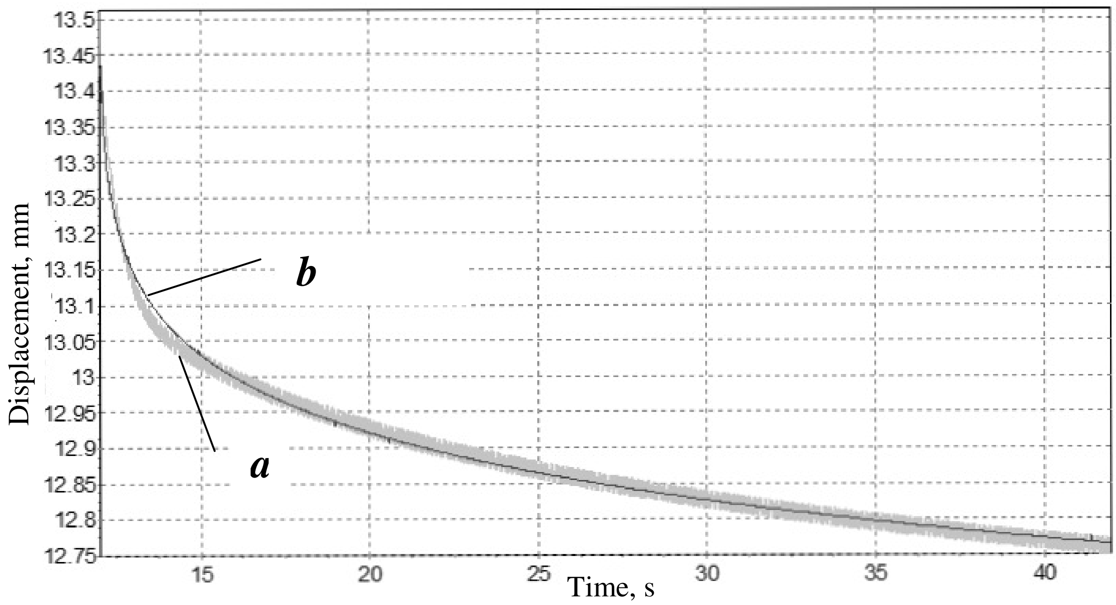

Fig. 4. **Registered (*a*) and approximated (*b*) plunger displacement graph**

Furthermore, quite good approximations for all our experimental runs could be obtained using fixed values of $x_0 = x(t_0)$ and $\Delta = 0.02$, $p = 0.05$ and fitting only one value – coefficient R. By determining the value of R the compacting process can be entirely characterized in the given time interval. So the approximation of the dependence $R = R(f_0, f_1, \omega)$ gives the possibility to analyze and to optimize the vibropressing process [12]. Greater compaction (and density, respectively) gives higher concrete block strength [11; 13; 14]. However, the compaction ratio is limited by the granulometric characteristics of the filler material and cannot be infinitely increased.

Effect of vibropressing process on strength of concrete

At the next step all concrete block specimens were approved by the crash test. The crash test results were registered (kN) and the correlation between three input parameters and the strength of specimens – P was found, see Table 1. The correlation coefficient between f_0 – constant pressing force and P – strength of specimens is 0.24, between f_1 – force oscillation amplitude and P – strength of specimens is 0.42, and the correlation coefficient between ω – frequency and P – strength of specimens is 0.62. That means that the most important effect of vibropressing process is left by frequency.

Table 1

Correlation coefficient between three variable parameters, f_0, f_1, ω and P – strength of concrete specimens

f_{0i}, kN	-1<0.24<1	P_i, kN
f_{1i}, kN	-1<0.42<1	P_i, kN
ω_i, Hz	-1<0.62<1	P_i, kN

The EDAOpt software (Experimental Design, Approximation and Optimization software) was used for analysis of the experiments. EDAOpt is created at the Riga Technical University. The linear model was used. The EDAOpt software gives the results of the effect of three input parameters of the vibropressing process on the strength of concrete, see Figure 5.

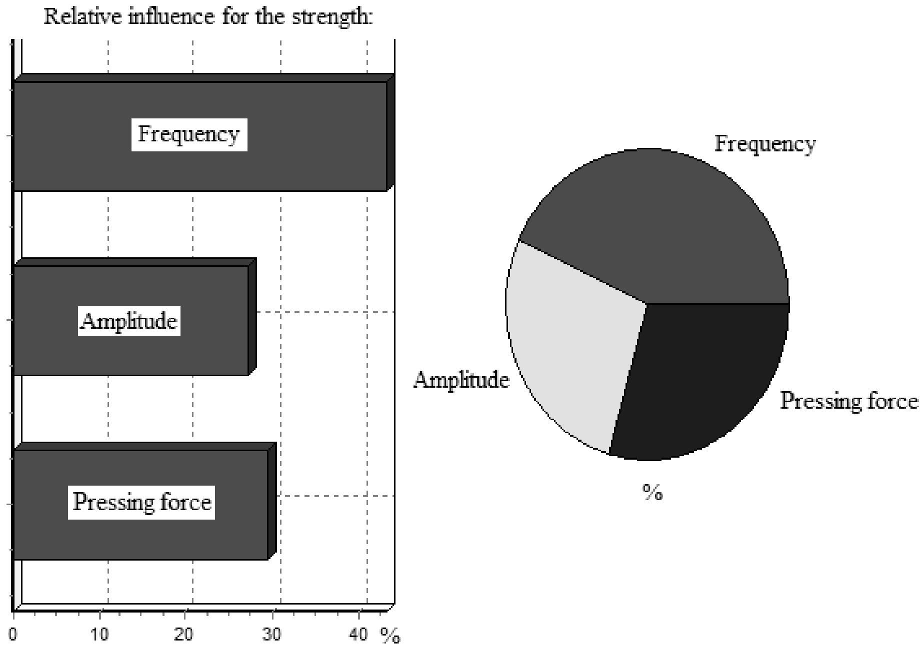

Fig. 5. **Effect of vibropressing process on strength of concrete**

The worthiest dates of experiments results were eliminated, founding maximal relative error by EDAOpt software, see Figure 6.

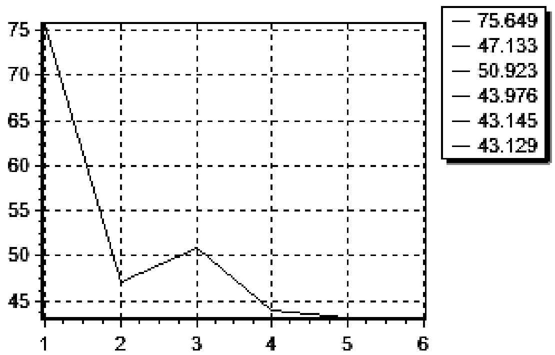

Fig. 6. **Maximal relative error**

The elimination of the two first worthiest results of experiments gives the maximal relative error fall from ~76 % to the ~47 %. All another eliminations research the value of relative maximal error about 43 %.

Conclusions

Greater compaction (and density, respectively) gives higher concrete block strength. However, the compaction ratio is limited by the granulometric characteristics of the filler material and cannot be infinitely increased. The correlation analysis between the input parameters and the strength of samples showed the prevalence of the pressing frequency as the most important factor.

The computational analysis shows the effect of the three input variable parameters on the strength of concrete. The biggest influence on the strength of concrete has frequency – about 42 %.

The vibropressing process tehnology is useful for compacting or packing any dispersed or granulometric materials, can be applied in agriculture.

The future work should concentrate on the building of more accurate models for concrete strength dependency on vibropressing parameters, using robust nonparametrical approximations, as well as the multiobjective optimization of the vibropressing process.

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