

Methods of equipment choice in shotcreting

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Abstract. Shotcrete is widely used in architecture, hydraulic engineering structures, finishing works in tunnels, arc covers and ceilings. The problem of the equipment choice in shotcreting is very important. The main issues influencing the equipment choice are quality improvement and intensification of shotcreting. Main parameters and rational limits of technological characteristic of machines used in solving different problems in shotcreting are described. It is suggested to take into account peculiarities of shotcrete mixing processes and peculiarities of applying these mixtures with compressed air kinetic energy. The described method suggests choosing a mixer with the account of energy capacity, Reynolds number and rotational frequency of the mixing drum. The suggested choice procedure of the equipment nomenclature allows decreasing exploitation costs, increasing the quality of shotcrete and shotcreting in general.

1. Introduction

It is important to choose effective and reliable equipment in concrete work mechanization on construction sites, in buildings' reconstructions and in confined spaces. The important criteria for choosing shotcreting equipment are quality improvement and process intensification.

In spraying the concrete or mixture under pressure onto any surface, a solid layer of shotcrete is formed [1, 2]. In comparison with concrete, shotcrete is stronger, more water resistant, and freeze resistant and is more adhesive with the surface. The main reason for using shotcrete in reconstruction is its interaction with the applied concrete and their consolidation [3]. In order to intensify and improve the quality of shotcreting, one must solve the following tasks: to prepare homogenous mixture by improving the quality of mixing in mixing drums; to make possible shotcreting in confined spaces and at long distances from the technological equipment. The shotcrete-wet mix or the shotcrete-dry mix are commonly used. In shotcrete-dry mix, the shotcrete is conveyed through a hose by compressed air.

The concrete-sand-gravel mix with fractions of 5...6 mm in diameter is used as filler in the shotcrete-wet mix. The single layer thickness in this case is 10...20 mm. Concrete mixtures prepared in mixer drums in advance are used in shotcrete-wet mix, that is why the choice of the technological equipment in different shotcreting technologies has its peculiarities. Shotcrete-wet mix has several advantages: low dusting, possibility to work in confined spaces, minimal safety precautions on the construction site from the ecological point of view; possibility to use the rebound mixture for the second time. The shotcrete-wet mix in comparison the with shotcrete-dry mix allows: reducing



rebound for 5...7 %, encreasing the clearance factor up to 0,75 with the energy consumption reduction by 15...20 % and work with concrete mixtures at longer distances. In shotcrete-wet mix technology, the following types of equipment are used: a concrete-mixer, a shotcreter, a pump, a hose and a nozzle. Transportation by pipelines is especially important as it allows using special equipment, such as concrete pumps.

For continuous and homogenous mixture feeding, different shotcreters are used: *Putzmeister* (*P13DMR*; *P13EMR*; *Aliva-246*; *SSB02*; *SikaPM702*), Russian (*SO-49PBN*, *SO-50PBN*) and Slovak (*MPCS-4*, *MPCS-3*).

Shotcreters' energy consumption is (fig.1) within limits 0.5...2.3 kWt hpm³, where the average parameter is equal to 1.35 kWt hpm³. It should be noted that Putzmeister shotcreter has lower power requirement than those of other manufactures. But, comparing other criteria, including shotcreter price, *SO-49PBN* has more sufficient parameters with power requirement 1.1 kWt hpm³, which is lower than the average value.

The dependence of power requirement with respect to working capacity is shown in fig.1.

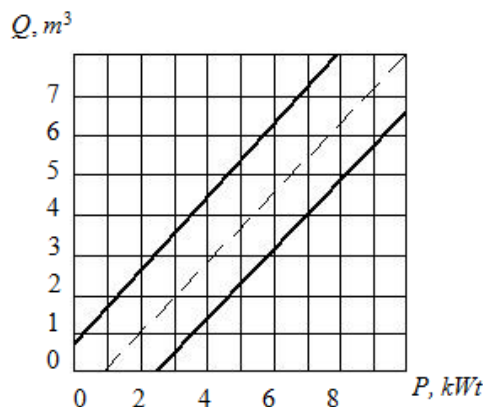


Figure 1. Power requirement with respect to working shotcrete capacity

Shotcreter work regimes, such as pressure in hose, the speed of shot from a nozzle, water-to-cement proportion, distance between the nozzle and the surface of application influence final physico-mechanical and performance characteristics of the shotcrete applied layer.

Shotcrete quality directly depends on mixture homogeneity, which in its turn depends on the concrete mixers work efficiency [4, 5]. To provide homogenous components distribution and receive homogenous mixture in the overall total of mixture, separate concrete mixture particles should receive the desired motion trajectories, which would assure the most number of particles' intersection. Here, the laws of hydrodynamics should be applied to mixed components in concrete mixers [6]. The comparative analysis of constructions and technical and economical parameters of different concrete mixers allowed determining their best properties in preparation of different concrete mixtures with any workability and water-concrete proportions [4, 5].

In rotor forced action movement, orbits of concrete components particles have forced nature which are determined by blades. In interaction of the mixture with a flat blade which is parallel to the mixer axial axis, the blade experiences the reaction of the movement. This reaction is mostly determined by frictional force at its lateral surfaces (fig. 2, a).

If the blades are perpendicular to the mixture stream, then the reaction depends on the pressure difference in front of and behind the blades (fig. 2, b).

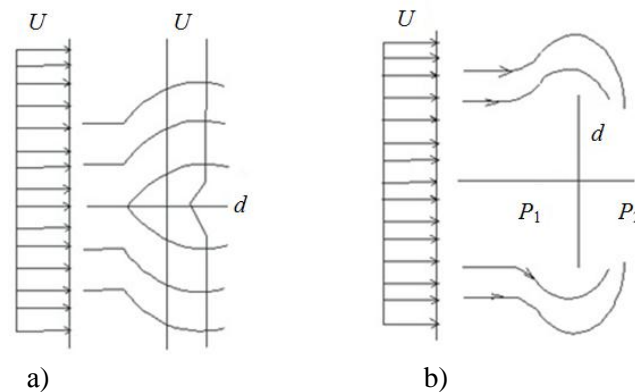


Figure 2. Mixer blade interaction with concrete mixture: a – friction force at the lateral blade surfaces; b – pressure difference in front of P_1 and behind blade P_2 . Here d is blade diameter, U – concrete mixture movement speed

In blade position along the concrete mixture movement vector, the minimal amount of the mixture will be on the blade; the mixture amount will be determined by the boundary layer thickness.

In the blade position normal to the concrete mixture movement vector, the maximal amount of the mixture will be on the blade. The mixture speed is the greatest at moving blades' edges (fig. 3), and turbulence trace takes place behind the blade. There is a dead space on the blade front where the components are not mixed. At the same time, small agglomerate mixture particles are destroyed at the flow boundaries due to friction speed differences. The destruction takes place in the boundary layer.

Concrete mixture movement under rotational action of horizontal shafts blades may be described by Navier-Stokes system of equations and solidity. Here, the mixture is considered to be solid medium with determinable viscosity. In a plane problem, this system of equations is simplified.

In Navier-Stokes equation for total constant viscous stream, flow has three components [3, 7].

In order to choose the most rational equipment and a concrete mixer, rational movement of mixture components in shotcrete production, different concrete mixers, their temporary condition, and patent search were conducted [4, 5, 8-12]. Having studied the experiences of invention, analyzed different mixers constructions for shotcrete production, the authors chose a mixer “*Turbula*” of the Swedish company “*Willy A. Bachofen*”. A six-link mechanism with binary triaxial joint is used in this type of the mixer, where the drum has the function of a central drive shaft.

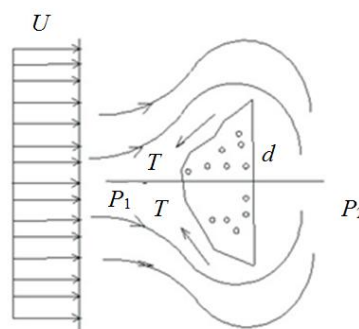


Figure 3. Interaction of the concrete mixture stream with blade material in its flow in normal position to the movement vector

A mixer consists of a stand, a driver and driven shafts fixed in shackle hinge joints on diametric mutually perpendicular axes. Complex binary elliptical movement with angle change provides all degrees of freedom in movement to all mixture particles intensifying and enhancing their mixing. The process of shotcrete components mixing is intensified by increasing the oscillation amplitudes of drum

movements during its turn from one extreme position into another with the simultaneous increase of the turn angle. Kinematic analysis showed that the point moves along a complex trajectory – an ellipse in a plane, a plane gradually moves to some angle of a circle with some radius. The point motion can be conventionally divided into translator motion and relative motion. Depending on geometric drum sizes, one can determine the main parameters of particle movement trajectory and forces acting on a point [13]. The choice of design-technological concrete mixers parameters combinable with shotcrete equipment in shotcreting remains important. Different shotcrete installations have been analyzed and *SO-49 PBN* with productivity 4 m^3 was chosen as the best one. Also two sizes of concrete mixers were chosen with load ratio 500 l and 800 l, with drum cubic capacity 430 l and 750 l, drum radii 0.4 m and 0.8 m and masses 450 kg and 850 kg [14].

Having determined the energy consumption of the mixers and compared the mixtures according to other technical-economic characteristics of *SO-49 PBN* type, a mixer with drum cubic capacity of 800 l, ready mixture 750 l were chosen. In order to determine mixer capacity with drum cubic capacity 800 l, the mixture and its components should be chosen and the Reynolds number should be determined. Concrete type C30 was chosen according to technical characteristics of the mixer.

According to tests, the concrete of the required strength 29.8 MPa was produced with water and freeze resistance W12 and F300 correspondingly. A newly prepared concrete mixture was workable and dense. Reynolds number is an important characteristic for viscous mixtures. When Reynolds number exceeds the threshold value, lamellose flow turns into turbulent. In general it is expressed by the relation of momentum forces to mixture viscosity and determined according to the dependence:

$$\text{Re} = \frac{Vd\rho}{\eta}, \quad (1)$$

where velocity is 0.332 mps at $n = 0.29$ rotps; n - frequency of rotation of revolving drum mixer bowl equal to 0.29 rotps; d is typical geometric drum size, equal to 1.9 m; ρ is material density, equal to 1800 kgpm^2 ; η is dynamic viscosity of the moving flow, 0.28 Paps.

Then Re will be:

$$\text{Re} = \frac{0.332 \cdot 1.9 \cdot 1800}{0.28} = 4061.$$

The dependence of frequency change of drum rotation on Reynolds number can be estimated according to the dependence:

$$n(\text{Re}) = \frac{2\eta\text{Re}}{d^2\rho}, \quad (2)$$

Fig. 4 shows the dependence of Re number on frequency of drum rotation.

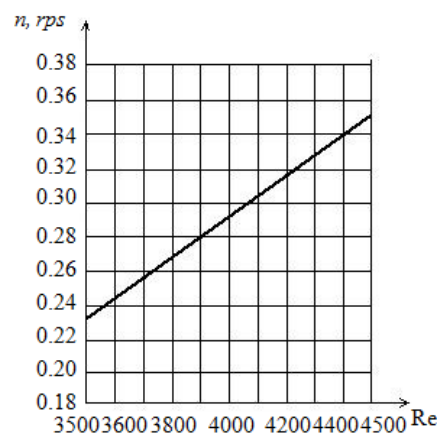


Figure 4. Reynolds number dependence on frequency of drum rotation

One can analytically estimate the dependence of drum diameter changes on Reynolds number (fig. 5) according to:

$$d = \sqrt{\frac{2\eta Re}{n\rho}}, \quad (3)$$

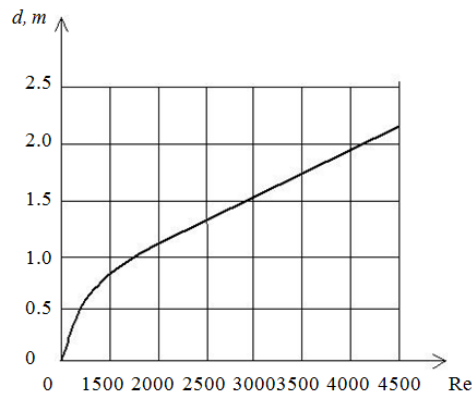


Figure 5. Reynolds number dependence on drum diameter

In order to determine the dependence of the mixer drum diameter on the engine power consumption, let us determine the following dependence (fig. 6):

$$P(d) = P_1(d) + P_2(d), \quad (4)$$

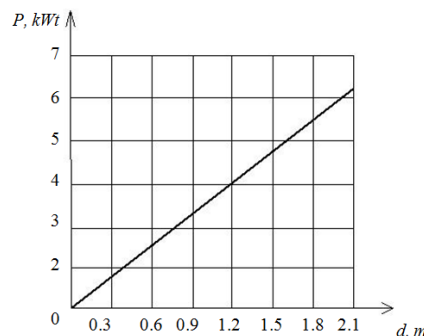


Figure 6. Mixer drums diameter–power dependence

The dependence of the mixer drum diameter on the engine power consumption will be:

$$P(n) = F_m \frac{d}{2} \frac{n}{1000} + \frac{(F_m + F_t)f\omega}{1000}, \quad (5)$$

It is known that if $Re < 2300$, then the mode is lamellose, if $2300 < Re < 4000$ (sometimes 10000 are shown), then the mode is neutral, if $4000 < Re$, the operational mode is turbulent.

As in this case, Re is > 4000 , the mode is turbulent ($Re = 4061$).

In the studied concrete mixer, the mixing is done with turbulent movement of particles, so the quality of mixing in this mode is better than in lamellose; hence, the quality of shotcrete is significantly higher.

2. Conclusions.

As a result, a special shotcrete mixer with low energy consumption is chosen.

This method of equipment chosen for shotcreting provides high quality of shotcrete production and application, reliable equipment choice and best equipment characteristics for shotcreting with energy consumption reduction for 15...17 %.

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