Daily strength testing of the Portland cement mortars

E V Tararushkin¹ and T N Shchelokova²

¹Federal State Institution of Higher Education «Russian University of Transport» (RUT - MIIT), 9b9, Obrazcova Street, Moscow, 127994, Russia
²National Research Moscow State University of Civil Engineering, Yaroslavl highway, 26, Moscow, 129337, Russia

E-mail: evgeny.tararushkin@yandex.ru

Abstract. The study of daily tests (1-28 days) for compressive and flexural strength of cement mortars is presented in the article. The mortars were made from ordinary Portland cement, two different classes of cement were considered. Graphs with daily test strengths were obtained from the results of the experiment and the test results were fitted by exponential curves. To estimate the strength rates of mortars, numerical derivatives are calculated from experimental data and the exponential curves are fitted by the obtained values of numerical differentiation. As a result of experimental data processing, it was found that the flexural strength rate decreases to zero on the 12-14th day hardening of mortars, which can be explained by the end of the formation of macroporosity (voids) of the cement paste and the end of the chemical-physical processes of the formation of most contacts between the cement paste and the aggregate (sand grains).

1. Introduction

Today, ordinary Portland cement (OPC) is one of the main hydraulic binders. On its basis, concrete and reinforced concrete structures for buildings and structures are made, including such transport structures as bridges and overpasses. Due to the fact that concrete structures and concrete in reinforced concrete structures predominantly work in compression when an external load is transferred to them, one of the important characteristics of OPC is compressive strength. Basically engineers and researchers are interested in the value of compressive strength on the 28th day under normal hardening conditions. On this day, class of OPC is assigned in accordance with regulatory standards. Also the compressive strength of OPC and other hydraulic binders based on OPC on intermediate days up to 28 days, for example, on days 1, 3, 7, and 14 are of great interest [1-4]. The strength values on this day are important for studying the kinetics of a set of binder strength, which must be taken into account when selecting the composition of concrete, for example, when erecting cast-in-place reinforced concrete structures. In addition to compressive strength, such a mechanical characteristic of OPC as tensile strength is of interest. The tensile strength is an important characteristic when designing reinforced concrete structures from OPC. The character of the destruction of cement mortar during tension is similar to the character of fracture in flexural from the point of view of fracture mechanics. Therefore, the flexural strength of cement mortar is often considered.

The aim of this work is to study the daily kinetics of a set of compressive strength and flexural strength for cement mortars from OPC for 28 days.
2. Materials and methods
Two classes of cement were used for testing: cement of class M600-D0 as per GOST Standard 10178-85 “Portland cement and slag Portland cement. Technical conditions” and cement of class CEM I 42.5 N as per GOST Standard 31108-2016 “Cements for general construction. Technical conditions”. Cement of class M600-D0 is OPC without mineral additives, cement of class CEM I 42.5 N contained 95% of OPC and 5% of the additive in the form of mineral powder.

Cement mortars for each classes of cement were made with polyfraction sand at a ratio of 1:3. Distilled water was used for the manufacture of the mortars. The values of the water-cement ratio (W/C) were determined based on the required spreading of the cone of the mortars and, as a result, amounted to 0.38 and 0.40 for a mortar on cement of class M600-D0 (here in after M1) and a mortar on cement of class CEM I 42.5 N (here in after M2), respectively.

To determine the strength characteristics of the mortars, prism samples 40x40x160mm in size were made. The first 24 hours, samples were stored in steel molds at a temperature of 20°C and a humidity of 100%. On the second day, samples were removed from the molds and curing in distilled water at a temperature of 20°C for 28 days.

Throughout the hardening period, daily tests were carried out to determine the values of compressive strength and flexural strength. Before testing, the samples were wiped to remove water from surface of prism samples. The flexural strength was determined by a three-point scheme. The loading rate was 50 ± 10 N/s. The loading rate of the samples under uniaxial compression was 2400 ± 200 N/s.

3. Results
Graphs of the dependence of the strength of the OPC on the time were performed according to the results of experimental tests. Figure 1 shows daily graphs of the dependence of compressive strength for two types of mortars. As seen, the graphs describe the logarithmic law of the set of strength of mortars, which is known for composite materials from OPC. At the same time, at some points, for example, on the graph for M1 mortar, there are strength drops (23-24th days), which is due to the bias of the measurement method. Figure 2 shows graphs of the dependence of flexural strength for two types of cement mortars. The flexural strength graphs also describe the logarithmic law, but at the same time, the graphs show no obvious increase in strength after 12-14th days. For example, the flexural strength value on 13th day for a mortar of M1 is more than on 28th day.

![Figure 1. Experimental compressive strength data.](image-url)
For a more visual view, the absence of an increase in flexural strengths in figures 3 and 4 shows curves of experimental mean values of compressive and flexural strengths for two types of mortars. The curve was fitted by an exponential function, of the following form:

\[ f = ae^{bx} + ce^{dx} \]  

(1)

where \( a, b, c, d \) are coefficients.

It can be seen from the figures 3 and 4 that the flexural strength graphs have almost horizontal sections of curves, starting from 12-14th days and to 28th days. On the curves for the compressive strengths of horizontal sections is not observed, thus, the increase in compressive strengths is observed throughout the whole period of hardening of the mortars for 28th days.

Figure 2. Experimental flexural strength data.

Figure 3. Mean experimental values and fitted strength curves for M1 mortar.

Figure 4. Mean experimental values and fitted strength curves for M2 mortar.
To determine the compressive and flexural strengths rates of the mortars, the finite differences of the experimental mean values were calculated. To analyze the results, the curves were also fitted by formula (1) for the corresponding values of numerical differentiation. The curves of the strength rates and the values of numerical differentiation are shown in figures 5 and 6.

Figures 5 and 6 show for both mortars a strong difference between the compressive strength rate and flexural strength rate. Namely, the compressive strength rate don’t to decreases to zero during the whole period of hardening of mortars, in contrast to the curves of the flexural strength rate, for which the rate decreases to zero by 12-14th days, which indicates the absence of an increase in flexural strength after this hardening period. The absence of an increase in flexural strength is also confirmed by nearly equal values of the apparent fracture toughness during concrete tensile tests at the age of 14th and 28th days [5].

Basically, the crack path during flexural failure for heterogeneous materials such as cement composite materials passes through the weakest points. Such weak points in cement composite materials can be contact zones between sand grains and hydration products of OPC, as well as bonds between hydration products of OPC, for example, between layers of hydroxides (C-S-H) in a cement [6, 7]. The flexural strength of cement composites is also affected by their porosity, especially macroporosity (voids) [8], that is, voids in cement can act as macrodefects that reduce the strength of the cement paste. Thus, the flexural strength of cement mortar is exerted by a combination of the above factors. At the same time, the bonds between C-S-H layers will have the least effect on the absence of flexural strength of mortar because the number of C-S-H products increases by 28th days and further, and hence the number of bonds between the C-S-H layers will increase. Thus, the absence of an increase in flexural strength after 12-14th days can be explained by the end of the formation of the macroporosity of the

Figure 5. The strength rates for the M1 mortar.

Figure 6. The strength rates for the M2 mortar.
cement paste and the end of the chemical-physical processes of the formation of most contacts between the cement paste and the sand grains.

4. Conclusion
As a result of the studies, daily (1-28 days) values of compressive and flexural strengths of cement mortars on OPC were obtained. Two types of cement mortars were considered: from OPC of class M600-D0 OPC and from OPC of class CEM I 42.5 N. Processing of the experimental results and subsequent analysis showed that the flexural strength rate decreases to zero by about 12-14th days. This decrease to zero in of the flexural strength rate can be explained by the end of the formation of the macroporosity (voids) of the cement paste and by the end of the chemical-physical processes of the formation of most contacts between the cement paste and the aggregate (sand grains).

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