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Experimental Investigation of Fly Ash and Water Content on the Internal Friction of Concrete

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Abstract. This paper presents the experimental results of investigation of the effects of fly ash and water content on damping of concrete. Impulse Excitation Technique has been used to measure damping of concrete at the ages of 3, 7, 14, 28 and 56 days. It was found that the more fly ash is added the higher damping at early ages is. At the age of 3 days due to addition of 10%, 20% and 30% of fly ash, damping of concrete is increased by 12.92%, 34,45% and by 49,49%, respectively. At the age of 7 days the values of internal friction can be increased by 12.92%, 34.45% and by 49,49%, accordingly, and by 12.92%, 34,45% and by 49,49%, at 14 days. The less water is added the less valued of concrete damping are. Reducing water content by 10 and 20 liters per cubic meter, concrete damping can be decreased by 9.2% and by 27.00%, at 7 days by 12.8% and by 23.6%, and at 14 days by 7.4% and 17.5%, respectively. After 14 days the changes of damping become less significant, which is related to concrete microstructural changes due to its hardening.

Introduction

Traditionally, in many sources of engineering literature concrete has always been considered as an elastic material [1, 2]. However, in reality it is not always true. In the previous works [3, 4] authors have discussed viscoelastic properties of concrete. As any viscoelastic material, it has complex Young's Modulus. The real part E', or Storage Modulus, represents its elastic properties, whereas the imaginary part E'' (Loss Modulus) characterizes its viscosity. Fresh concrete mixture is a viscoelastic substance, which has a constantly changing viscosity. During setting and hardening of concrete its elastic properties (E') are increasing and viscosity (E'') is decreasing.

It is important to understand the correlation between viscous and elastic properties of the material. For this purpose, internal friction, or damping, can be considered. There exist several approaches to introduce the definition of internal friction or damping. Blatner et al. [5] have introduced the most general definition as a dissipation of energy in a material, which is different from the term "friction" meaning the resistance against motion. Referring to cyclic loading of the material, authors have defined the specific damping capacity Ψ

$$\Psi = \Delta W / W \quad (1)$$

or the Loss factor $\Delta W / 2\pi W$, and the Quality factor Q

$$Q = 2\pi W / \Delta W \quad (2)$$

Internal friction itself Q^{-1} is introduced as [6]

$$Q^{-1} = \Delta W / 2\pi W \quad (3)$$

Considering a viscoelastic solid under a cyclic applied stress or strain, for sinusoidal varying stress and strain

$$\sigma^* = \sigma_0 e^{i\omega t} \tag{4}$$

$$\varepsilon^* = \varepsilon_0 e^{i(\omega t - \phi)} = (\varepsilon' - i\varepsilon'')e^{i\omega t} \tag{5}$$

respectively, complex modulus can be written as

$$E^*(\omega) = \frac{\sigma^*}{\varepsilon^*} = E(\omega)e^{i\phi(\omega)} = E'(\omega) + iE''(\omega) \tag{6}$$

where, ϕ is the phase lag between stress and strain. In such a situation internals friction can be defined as [5, 6]:

$$Q^{-1} = \frac{\Delta W}{W} = \tan\phi = \frac{E''}{E'} = \frac{\varepsilon''}{\varepsilon'} \tag{7}$$

Moreover, similar formula can be derived when shear stress or strain is applied [7]:

$$G^* = G' + iG'' \tag{8}$$

$$Q^{-1} = \frac{G''}{G'} \tag{9}$$

where, G' is the shear-storage modulus, and G'' is the shear-loss modulus.

Impulse Excitation Technique

Impulse Excitation Technique (IET) is a very convenient method to identify internal friction of a material. It is based on the following concept. A weak impact is applied to a specimen, which is located on a special wire support with specific conditions. The impact causes vibrations of the sample and the signal is recorded by a microphone and transmitted to the PC software RFDA (Resonant Frequency and Damping Analyzer). Software calculates resonant frequencies and corresponding values of damping, as well as the values of Storage Elastic and Shear Moduli. According to the software algorithm, damping is calculated as:

$$Q^{-1} = k/(\pi f_r) \tag{10}$$

The details of IET are given in [8].

Experimental Program

In order to investigate the effect of fly ash content and water content on the concrete damping six batches of concrete have been cast for the experiment (see Table 1). Reference mixture M0 is based on ACI standard with water-to-binder ratio 0.41 and contains no any fly ash. Mixtures M10, M20 and M30 are obtained using the same standard, however, they have 10, 20 and 30 per cent, respectively, of cement replacement by Type F fly ash. They are designed to investigate the effect of fly ash on the internal friction of concrete. Mixtures M0a and M0b have all the components fixed as in the reference mixture, except water. In order to investigate the effect of water content on the concrete damping, the amount of water was reduced till 175.00 kg and 184 kg for mixtures M0a and M0b, accordingly.

For each batch of concrete two types of samples have been cast. The first one is cylindrical in shape, 200 mm in height and 100mm in diameter. It was used to obtain standard concrete characteristics, such as compressive strength, dynamic Young's modulus, etc. Another type of specimens is a block, 160x80x40 mm. It was designed for the internal friction test.

Table 1. Concrete mix proportions.

Concrete batch	Water, kg	Cement, kg	Type F Fly ash, kg	Fine ag., kg	Coarse ag., kg	SP, kg
M0	194.00	473.17	0.00	768.69	932.38	2.20
M10	194.00	425.85	47.32	749.72	932.38	2.20
M20	194.00	378.54	94.63	730.74	932.38	2.20
M30	194.00	331.22	141.95	711.76	932.38	2.20
M0a	174.00	473.17	0.00	768.69	932.38	2.20
M0b	184.00	473.17	0.00	768.69	932.38	2.20

Properties of the Materials

The raw materials for the concrete mixtures are as follows: Cement – type I Ordinary Portland Cement (OPC), produced by Taiwan Cement Corporation (chemical composition see Table 2); water – regular tap water; fine aggregates – river sand (see Table 3); coarse aggregates – gravel (see Table 5); Superplasticizer – Type G superplasticizer, Yu-Lin Brand, produced in Taiwan (pH=4.34, density 1090 kg/m^3, Cl content 44 ppm).

Table 2. Cement chemical composition.

Chemical composition							
Components	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	LOI
%	20.42	4.95	3.09	61.96	3.29	2.4	1.75

Table 3. Physical properties of fine and coarse aggregate.

Properties	Coarse Aggregate	Fine Aggregate
Maximal Coarse Aggregate size, mm	15.0	-
Specific gravity (OD), g/cm^2	2.70	2.63
Fineness modulus	6.58	2.73
Water absorption, %	0.56	1.78

Experimental Setup

Experimental setup for the internal friction test consists of the following components (see Figure 1): PC, RFDA basic software, microphone, a set of steel impactors and a special steel wire support, which is custom made in order to adapt standard RFDA basic device to test concrete blocks [3].

Results and Discussions

All the cylindrical specimens have been tested at the ages of 3, 7, 14 and 28 days. Compressive strength at the age of 28 days for different mix proportions is shown on Fig. 2, whence it could be observed that in the case of increase in the fly ash content from 0 up to 30% the increase in the compressive strength there is an increase of compressive strength. As it was expected, with the reduction of water amount in the mixture, the compressive strength has reached higher values.

Considering Fig. 3, two comparisons could be made. The first one considers mix proportions M0, M10, M20 and M30 and explains the effect of fly ash content on the damping of concrete. At early ages, for instance, at the age of three days, the increase in the fly ash content from 0 to 10, 20 and 30 per cent leads to the increase in the internal friction by 12.92%, 34,45% and by 49,49%, respectively. At the age of 7 days, the augmentation becomes 21,67%, 38,84% and 99,22%, correspondingly. At 14 days, we can observe that the relative values of damping raise at 11.40%, 41.6% and 47.23%.

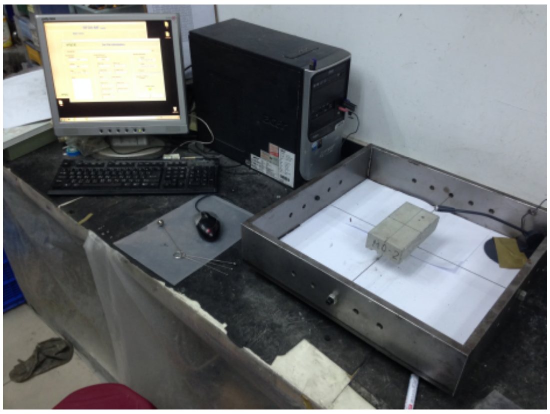

Fig. 1 Experimental setup for the internal friction test.

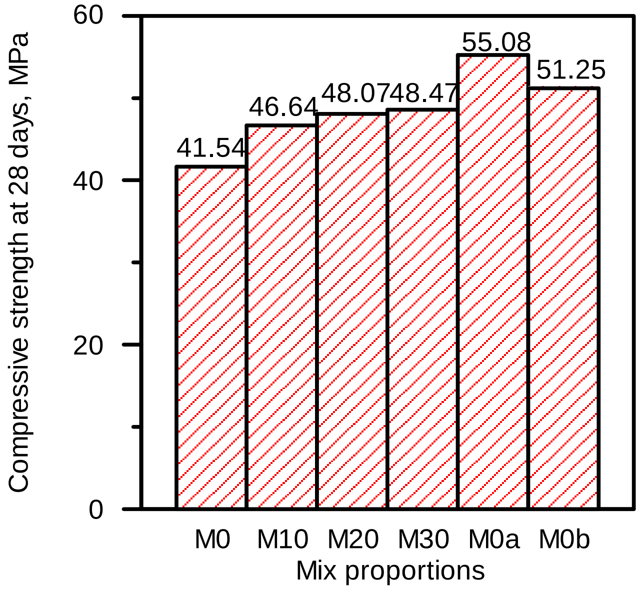

Fig. 2 Compressive strength for different mix proportions at the age of 28 days.

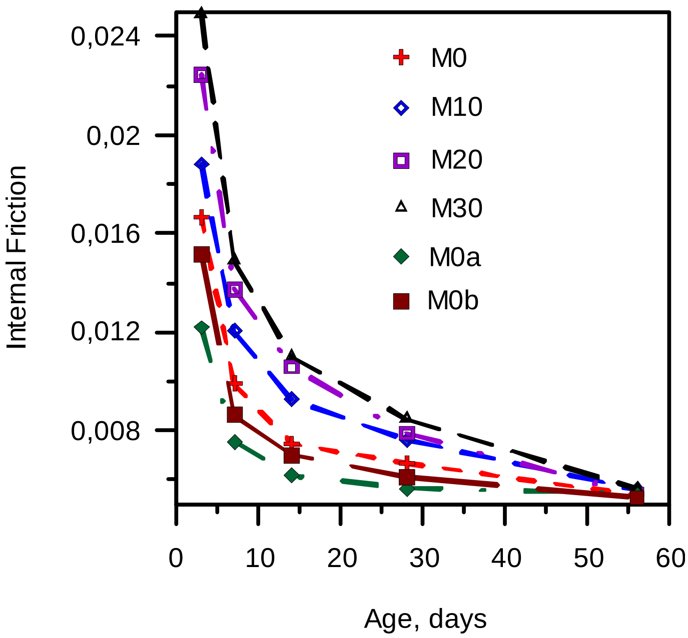

Fig. 3 Effect of fly ash and water content on the internal friction of concrete.

The second comparison shows the effect of water content on the internal friction of concrete, mixtures M0, M0a and M0b should be compared. It is obvious that the less water in the concrete mixture, the smaller value of damping is obtained. At 3 days the decrease in the water content by 10 and 20 liters for 1 cubic meter leads to the decrease in the concrete damping by 9.2% and by 27.00%, respectively, and at 7 days by 12.8% and by 23.6%, respectively. At 14 days the values become 7.4% and 17.5%, accordingly.

It should be also noted that the most significant changes of internal friction occur at the ages earlier that 14 days, after that the process slows down and the changes become less significant. All of these effects could be explained by the microstructural changes in concrete due to its hardening. Raw concrete behaves more viscoelastically, and a hardened one possesses more elastic properties.

Conclusions

Based on the experimental results, the following conclusions can be made:

1) The more fly ash is added the higher damping at early ages is.
2) At the age of 3 days due to the addition of 10%, 20% and 30% of fly ash, the damping of concrete is increased by 12.92%, 34.45% and by 49.49%, respectively.
3) At the age of 7 days the values of internal friction can be increased by 12.92%, 34.45% and by 49.49%, accordingly, and by 12.92%, 34.45% and by 49.49%, at 14 days.
4) The less water is added the less valued of concrete damping are.
5) By reducing the water content by 10 and 20 liters per cubic meter, the concrete damping can be decreased by 9.2% and by 27.00%, at 7 days by 12.8% and by 23.6%, and at 14 days by 7.4% and 17.5%, respectively.
6) After 14 days the changes of damping become less significant, which is related to concrete microstructural changes due to its hardening.

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