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COMMUNICATIONS

EFFECTS OF SAND AND SILICA FUME ON THE VIBRATION DAMPING BEHAVIOR OF CEMENT

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ABSTRACT

The addition of sand to cement paste was found to degrade the vibration damping ability, as shown by decreases in both loss tangent and storage modulus under flexure. However, further addition of silica fume more than restored the vibration damping ability, due to the silica fume causing increases in both loss tangent and storage modulus. Silica fume increased the loss modulus of mortar by as much as three orders of magnitude. © *1998 Elsevier Science Ltd*

Introduction

Concretes with vibration damping ability (or energy dissipation ability) are needed for vibration reduction and hazard mitigation of bridges, buildings and other civil infrastructure systems. As concrete is inherently poor in damping ability, admixtures to enhance this ability are needed. For example, a viscoelastic admixture with an undisclosed composition has been reported to be effective (1), and steel fibers are effective when the frequency is appropriately low (2). A systematic study involving cement pastes has shown that surface-treated silica fume and latex are particularly effective for enhancing the damping capacity (3,4), such that silica fume has the additional ability to greatly enhance the storage modulus. A high damping capacity and a high storage modulus are both desired for vibration reduction. The product of these two quantities is the loss modulus, which is a figure of merit that combines both virtues. Since the study in References 3 and 4 is limited to cement pastes, this paper is aimed at extending the study from cement pastes to mortars, which are a step closer to concretes. Specifically, this paper addresses the effect of sand on the damping capacity and the storage modulus, as this effect is not intuitively obvious and has not been previously reported. Information on the effect of sand is valuable for the design of concrete mixes for vibration reduction applications. Moreover, this paper addresses the effect of silica fume with respect to mortars. As in References 3 and 4, this work conducted testing under dynamic flexure, but the specimens of this work were larger than those of References 3 and 4 in order to extend from cement pastes to mortars. Moreover, the storage modulus values of this work are more

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TABLE 1
Loss tangent (tan δ, ± 0.01).

Mix	0.2 Hz	0.5 Hz	1.0 Hz	2.0 Hz
Plain*	0.016	$<10^{-4}$	$<10^{-4}$	$<10^{-4}$
Sand	$<10^{-4}$	$<10^{-4}$	$<10^{-4}$	$<10^{-4}$
Sand + silica fume	0.021	0.14	0.01	$<10^{-4}$

* No sand, no silica fume.

accurate than those in References 3 and 4 due to the larger aspect ratio of the specimens used in this work.

Experimental Methods

The cement used was Portland cement (Type I) from Lafarge Corp. (Southfield, MI). The fine aggregate used for mortars was natural sand (all passing #4 US sieve, 99.9% SiO_2); the particle size analysis of the sand is shown in Figure 1 of Reference 5; no coarse aggregate was used, and the sand/cement ratio was 1.0. The water/cement ratio was 0.35. A water-reducing agent (TAMOL SN, Rohm and Haas Co., Philadelphia, PA; sodium salt of a condensed naphthalenesulphonic acid) was used in the amount of 2% of cement weight.

The silica fume (Elkem Materials, Inc., Pittsburgh, PA, EMS 965) was used in the amount of 15% by weight of cement. As in Reference 4, surface treatment of silica fume was performed by immersing the silica fume in sulfuric acid (96%) for 2 h, washing with water, filtering and then drying at 150°C for 1–2 days. All silica fume used in this work had been surface treated.

All ingredients were mixed in a Hobart mixer with a flat beater. After pouring into molds, an external vibrator was used to facilitate compaction and decrease the amount of air bubbles. The samples were demolded after 24 h and then cured in a moist room (relative humidity = 100%) for 28 days.

Dynamic mechanical testing (ASTM D4065–94) at controlled frequencies (0.2, 0.5, 1.0 and 2.0 Hz) and room temperatures (20°C) were conducted under flexure using a Perkin-Elmer Corp. Model DMA 7E dynamic mechanical analyzer. Measurements of tan δ and storage modulus were made simultaneously as a function of temperature at various constant frequencies. The heating rate was 2°C/min, which was selected to prevent any artificial damping peaks which may be caused by higher heating rates. The specimens were in the form of beams (68 × 11 × 3.5 mm) under three-point bending, such that the span was 62 mm. The loads used were all large enough so that the amplitude of the specimen deflection was from 6.5 to 9 μm (over the minimum value of 5 μm required by the equipment for accurate results). The loads were set so that each different type of specimen was always tested at its appropriate stress level. Six specimens of each type were tested.

Results and Discussion

Tables 1-3 show the loss tangent, storage modulus, and loss modulus respectively.

The loss tangent was much decreased by the addition of sand, but the further addition of

TABLE 2
Storage modulus (GPa, ± 0.2).

Mix	0.2 Hz	0.5 Hz	1.0 Hz	2.0 Hz
Plain*	13.7	14.48	14.02	14.00
Sand	9.43	11.67	10.32	9.56
Sand + silica fume	13.11	14.34	13.17	13.11

* No sand, no silica fume.

silica fume caused the loss tangent to increase to a level comparable to or exceeding that of cement paste (“plain,” Table 1). The advantage of the mortar with silica fume over cement paste increased as the frequency increased (below 1 Hz). In other words, the positive effect of silica fume overshadowed the negative effect of the sand. The negative effect of the sand is due to the poor damping capacity of sand compared to cement paste (less homogeneous than a sand particle) and the small contribution of the interface between sand and cement paste to the damping capacity. The positive effect of silica fume is due to the large contribution of the interface between silica fume (much smaller in particle size than sand) and cement paste to the damping capacity.

The storage modulus (Table 2) was decreased by the addition of sand, but was restored by the further addition of silica fume. The negative effect of sand is due to the imperfect bond between sand and cement paste. The positive effect of silica fume is due to strong bond between silica fume and cement paste, and the small size of the silica fume particles enhancing the reinforcing ability of the silica fume.

The loss modulus (Table 3) was much decreased by the addition of sand, but was increased to a level above that of cement paste (“plain”) by the further addition of silica fume. At 0.5 Hz, the loss modulus was particularly high, reaching 2 GPa. The high loss modulus reflects the combination of high loss tangent and high storage modulus.

The results of this work suggest that aggregates, whether fine or coarse, degrade the vibration damping ability. Thus, the common aggregate proportions that are designed for high compressive strength may not be desirable for vibration damping. In the presence of aggregates, silica fume is effective for increasing the loss tangent by as much as two orders of magnitude and increasing the loss modulus by as much as three orders of magnitude. In

TABLE 3
Loss modulus (GPa, ± 0.2).

Mix	0.2 Hz	0.5 Hz	1.0 Hz	2.0 Hz
Plain*	0.22	$<$0.001	$<$0.001	$<$0.001
Sand	$<$0.001	$<$0.001	$<$0.001	$<$0.001
Sand + silica fume	0.28	2.00	0.13	$<$0.001

* No sand, no silica fume.

the absence of aggregates, silica fume is also effective, but not as dramatically (3,4), since the loss tangent is already high when aggregates are absent.

Conclusion

The ability to reduce vibration was much decreased by the addition of sand to cement paste, as shown by decreases in both loss tangent and storage modulus under flexure. This ability was more than being restored by the further addition of silica fume, as shown by increase in the loss modulus to values up to 2 GPa (at 0.5 Hz). Silica fume increased the loss modulus of mortar by as much as three orders of magnitude.

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