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VIBRATION DAMPING ADMIXTURES FOR CEMENT

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ABSTRACT

The loss and storage moduli, and tan δ, of cement pastes were measured at 25-150°C and 0.2-2.0 Hz. The addition of latex or methylcellulose increases all three quantities, though latex is more effective in increasing tan δ, while methylcellulose is more effective in increasing the storage modulus. The addition of silica fume also increases all three quantities. The addition of short fibers increases all three quantities if the mix contains no other additive; it increases only tan δ and loss modulus if the mix contains methylcellulose; it decreases all three quantities if the mix contains either latex or (methylcellulose + silica fume). For energy dissipation applications, a mix with latex is recommended at >1.5 Hz, whereas a mix with methylcellulose + silica fume is recommended at <1.5 Hz; the use of fibers is not recommended.

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]. A systematic study of the effects of various admixtures of known compositions on the damping ability is needed in order to advance this technology. Furthermore, since the damping ability depends not only on the composition, but also on the frequency and the temperature, evaluation of the damping ability as a function of these parameters is necessary. This paper provides a systematic study that satisfies the needs mentioned above, though the study is limited to cement pastes. The admixtures used in this study include polymers (latex, methylcellulose, silica fume) and short fibers (carbon, polyethylene). The objective is to provide recommendations for damping admixtures for room temperature and elevated temperature use and to compare the damping ability of various mixes in terms of the loss modulus as well as the loss tangent (tan δ). The loss modulus (the product of tan δ and the storage modulus) is the material property that best reflects the energy dissipation ability. A high loss tangent alone is insufficient. No previous report has been made on the loss modulus of cementitious materials.

TABLE 1
Amounts of Water and Water Reducing Agent (WR) for Each Mix

	Water/cement ratio	WR/cement ratio
Plain	0.45	0
+ L	0.23	0
+ fibers	0.40	0
+ L + fibers	0.23	0
+ M	0.32	1%
+ M + SF	0.35	3%
+ M + fibers	0.32	1%
+ M + SF + fibers	0.35	3%

Note: L = latex; M = methylcellulose; SF = silica fume

Experimental Methods

Dynamic mechanical testing (ASTM D4065-94) at controlled frequencies (0.20, 1.00 and 2.00 Hz) and temperatures (25-150°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 (24 × 8 × 3 mm) under three-point bending, such that the span was 20 mm. The loads used were all large enough so that the amplitude of the specimen deflection was always 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.

Cement paste made from Portland cement (Type I) from Lafarge Corp. (Southfield, MI) was used for the cementitious material. The admixtures used include (i) latex, a styrene butadiene polymer emulsion (Dow Chemical Co., Midland, MI, 460NA) with the polymer making up about 48% of the emulsion and with styrene and butadiene in the weight ratio 66:34, such that the latex (20% by weight of cement) was used along with an antifoam (Dow Corning Corp., Midland, MI, #2410, 0.5% by weight of latex), (ii) methylcellulose (Dow Chemical Corp., A15-LV, 0.4% by weight of cement), which was used along with a defoamer (Colloids Inc., Marietta, GA, Colloids 1010, 0.13 vol.%), (iii) silica fume (Elken Materials Inc., Pittsburgh, PA, 15% by weight of cement), (iv) carbon fibers, which were isotropic pitch based and unsized, as obtained from Ashland Petroleum Co. (Ashland, KY), with length = 5 mm and diameter = 10 μm, and (v) polyethylene fibers (Allied Signal, Inc., Petersburg, VA, Spectra 900, high modulus type) with length = 5 mm and diameter = 38 μm. Both types of fibers were separately used in the amount of 0.5% by weight of cement; this amount corresponded to a fiber volume fraction of 0.53%. The water reducing agent was a sodium salt of a condensed naphthalenesulfonic acid (TAMOL SN, Rohm and Haas Company, Philadelphia, PA) used in amounts as shown in Table 1 for the various mixes. Table 1 also shows the water/cement ratio for each mix. The amounts in Table 1 were chosen in order to maintain the slump at around 170 mm. No aggregate (whether fine or coarse) was used.

TABLE 2

Loss Modulus (GPa, ± 0.02) of Various Cement Pastes at Various Temperatures and Frequencies.
The Highest Value for Each Combination of Temperature and Frequency is Shown in Bold Type

		30°C			60°C			90°C			100°C			150°C	
	0.2 Hz	1.0 Hz	2.0 Hz	0.2 Hz	1.0 Hz	2.0 Hz	0.2 Hz	1.0 Hz	2.0 Hz	0.2 Hz	1.0 Hz	2.0 Hz	0.2 Hz	1.0 Hz	2.0 Hz
1: Plain	0.067	0.000	0.000	0.085	0.000	0.000	0.099	0.000	0.000	0.099	0.000	0.000	0.103	0.000	0.000
2: +L	0.336	0.167	**0.107**	0.293	0.133	**0.058**	0.251	0.141	**0.037**	0.236	0.133	**0.033**	0.242	0.132	0.037
3: +carbon fibers	0.352	0.167	0.000	0.374	0.165	0.000	0.427	0.155	0.000	0.464	0.156	0.000	0.496	0.157	0.000
4: +poly-ethylene fibers	0.154	0.049	0.000	0.154	0.069	0.000	0.151	0.074	0.000	0.142	0.077	0.000	0.123	0.072	0.000
5: +L+ carbon fibers	0.100	0.056	0.023	0.094	0.048	0.012	0.097	0.049	0.014	0.101	0.048	0.016	0.106	0.050	0.017
6: +M	0.301	0.025	0.000	0.338	0.038	0.000	0.310	0.037	0.000	0.303	0.051	0.000	0.297	0.068	0.000
7: +M+SF	**0.651**	**0.242**	0.000	**0.604**	**0.276**	0.000	**0.678**	**0.307**	0.000	**0.637**	**0.367**	0.000	**0.642**	**0.354**	0.000
8: +M+ carbon fibers	0.280	0.052	0.015	0.304	0.073	0.018	0.309	0.091	0.022	0.314	0.070	0.018	0.316	0.094	**0.047**
9: +M+SF + carbon fibers	0.177	0.046	0.011	0.173	0.063	0.010	0.194	0.052	0.003	0.195	0.051	0.010	0.210	0.057	0.014

Note: L = latex; M = methylcellulose; SF = silica fume

A Hobart mixer with a flat beater was used for mixing. For the case of cement pastes containing latex, the latex, antifoam and fibers (if applicable) were first mixed by hand for about 1 min. Then this mixture, cement and water were mixed in the Hobart mixer for 5 min. For the case of pastes containing methylcellulose, methylcellulose was dissolved in water and then fibers (if applicable) and the defoamer were added and stirred by hand for about 2 min. Then this mixture, cement and water were mixed in the Hobart mixer for 5 min. After pouring the mix into oiled molds, an external vibrator was used to decrease the amount of air bubbles. The specimens were demolded after 1 day and then allowed to cure at room temperature in air (relative humidity = 30%) for 28 days. Mechanical testing was performed at 28 days.

Results and Discussion

Tables 2-4 show the loss modulus, storage modulus and loss tangent respectively of various cement pastes at 28 days for various combinations of temperatures and frequencies. Among the nine mixes studied, (i) the loss tangent (Table 4) is highest for mix No. 2 (with latex) for most combinations of temperature and frequency, (ii) the loss modulus (Table 2) is highest for mix No. 7 (with methylcellulose and silica fume) at $\leq$1.0 Hz and any temperature from 30 to 150°C and is highest for mix No. 2 (with latex) at 2.0 Hz and any temperature from 30 to 120°C, and (iii) the storage modulus (Table 3) is highest for mix No. 7 (with methylcellulose and silica fume). The high loss modulus of mix No. 7 is partly due to its high storage modulus. Although mix No. 2 exhibits a high value of tan δ, its relatively low storage modulus causes its loss modulus to be relatively low. For energy dissipation, a high loss modulus is most important, so mix No. 7 is recommended for use at <1.5 Hz, and mix No. 2 is recommended for use at >1.5 Hz. Due to the large amount of latex in mix No. 2, mix No. 2 is more expensive than mix No. 7.

Comparison of mixes No. 1, 2 and 6 shows that the addition of latex (20% by weight of cement) or methylcellulose (0.4% by weight of cement) increases tan δ and loss and storage moduli, though latex is more effective than methylcellulose in increasing tan δ, and methylcellulose is more effective than latex in increasing the storage modulus. As a result methylcellulose and latex are comparable in their effectiveness for increasing the loss modulus. Because of the small amount of methylcellulose and the large amount of latex, the use of methylcellulose is much more economical than the use of latex. Comparison of mixes No. 6 and 7 shows that the addition of silica fume increases tan δ as well as loss and storage moduli.

Comparison of mixes No. 1, 3 and 4 shows that the addition of fibers (carbon or polyethylene) to plain cement paste increases tan δ and loss and storage moduli, though carbon fibers are more effective than polyethylene fibers in increasing any of these three quantities. This difference between carbon and polyethylene fibers is partly due to the smaller diameter of the carbon fibers.

Comparison of mixes No. 2 and 5 shows that the addition of fibers to a mix with latex decreases loss and storage moduli, as well as tan δ. Comparison of mixes No. 6 and 8 shows that the addition of fibers to a mix with methylcellulose increases tan δ, decreases the storage modulus, and increases the loss modulus at most combinations of temperature and frequency. Comparison of mixes No. 7 and 9 shows that the addition of fibers to a mix with methylcellulose and silica fume decreases tan δ and loss modulus at <1.5 Hz, increases tan δ at >1.5 Hz, and decreases storage modulus at all frequencies. Thus, carbon fiber addition is useful for energy dissipation for a mix with methylcellulose, but not for a mix with latex or a

TABLE 3

Storage Modulus (GPa, ± 0.02) of Various Cement Pastes at Various Temperatures and Frequencies. The Highest Value for Each Combination of Temperature and Frequency is Shown in Bold Type

	30°C			60°C			90°C			100°C			150°C		
	0.2 Hz	1.0 Hz	2.0 Hz	0.2 Hz	1.0 Hz	2.0 Hz	0.2 Hz	1.0 Hz	2.0 Hz	0.2 Hz	1.0 Hz	2.0 Hz	0.2 Hz	1.0 Hz	2.0 Hz
1: Plain	1.91	2.05	1.96	1.92	2.01	1.94	1.94	1.99	1.95	1.86	1.96	1.93	1.90	1.92	1.91
2: +L	2.75	2.22	2.38	2.48	2.02	2.06	2.35	2.08	2.07	2.25	2.14	2.08	2.20	2.20	2.08
3: +carbon fibers	3.20	4.40	3.53	3.31	4.22	3.58	3.50	4.20	3.72	3.68	4.10	3.83	3.82	4.02	3.94
4: +poly-ethylene fibers	2.75	3.25	3.05	2.70	3.15	2.91	2.55	3.07	2.68	2.40	2.95	2.45	2.20	2.87	2.25
5: +L+ carbon fibers	1.35	1.51	1.55	1.22	1.41	1.43	1.23	1.39	1.39	1.25	1.34	1.35	1.28	1.31	1.32
6: +M	4.12	4.95	4.83	4.17	4.75	4.75	4.37	4.68	4.68	4.33	4.63	4.62	4.37	4.53	4.52
7: +M+SF	**6.20**	**6.90**	**6.85**	**5.75**	**6.42**	**6.41**	**5.65**	**6.01**	**6.01**	**5.31**	**5.82**	**5.81**	**5.35**	**5.80**	**5.78**
8: +M+ carbon fibers	3.73	4.33	3.67	3.71	4.08	3.61	3.63	3.97	3.59	3.61	3.87	3.62	3.72	3.90	3.59
9: +M+SF + carbon fibers	3.21	3.53	3.48	3.15	3.50	3.41	3.18	3.45	3.35	3.20	3.42	3.40	3.23	3.36	3.41

Note: L = latex; M = methylcellulose; SF = silica fume

TABLE 4

Loss Tangent (tan δ) of Various Cement Pastes at Various Temperatures and Frequencies.
The Highest Value for Each Combination of Temperature and Frequency is Shown in Bold Type

	30°C			60°C			90°C			100°C			150°C		
	0.2 Hz	1.0 Hz	2.0 Hz	0.2 Hz	1.0 Hz	2.0 Hz	0.2 Hz	1.0 Hz	2.0 Hz	0.2 Hz	1.0 Hz	2.0 Hz	0.2 Hz	1.0 Hz	2.0 Hz
1: Plain	0.035	<0.0001	<0.0001	0.044	<0.0001	<0.0001	0.051	<0.0001	<0.0001	0.053	<0.0001	<0.0001	0.054	<0.0001	<0.0001
2: +L	**0.122**	**0.075**	**0.045**	**0.118**	**0.066**	**0.028**	0.107	**0.068**	**0.018**	0.105	**0.062**	**0.016**	0.110	**0.060**	**0.018**
3: +carbon fibers	0.110	0.038	<0.0001	0.113	0.039	<0.0001	**0.122**	0.037	<0.0001	**0.126**	0.038	<0.0001	**0.130**	0.039	<0.0001
4: +poly-ethylene fibers	0.056	0.015	<0.0001	0.057	0.022	<0.0001	0.059	0.024	<0.0001	0.059	0.026	<0.0001	0.056	0.025	<0.0001
5: +L+ carbon fibers	0.074	0.037	0.015	0.077	0.034	0.008	0.079	0.035	0.010	0.081	0.036	0.012	0.083	0.038	0.013
6: +M	0.073	0.005	<0.0001	0.081	0.008	<0.0001	0.071	0.008	<0.0001	0.070	0.011	<0.0001	0.068	0.015	<0.0001
7: +M+SF	0.105	0.035	<0.0001	0.105	0.043	<0.0001	**0.120**	0.051	<0.0001	0.120	**0.063**	<0.0001	0.120	**0.061**	<0.0001
8: +M+ carbon fibers	0.075	0.012	0.004	0.082	0.018	0.005	0.085	0.023	0.006	0.087	0.018	0.005	0.085	0.024	0.013
9: +M+SF + carbon fibers	0.055	0.013	0.003	0.055	0.018	0.003	0.061	0.015	0.001	0.061	0.015	0.003	0.065	0.017	0.004

Note: L = latex; M = methylcellulose; SF = silica fume

mix with methylcellulose and silica fume. In other words, fiber addition is useful for energy dissipation for mixes which are inherently not very good for energy dissipation, but is not useful for mixes which are inherently good for energy dissipation. Fiber addition is also unattractive economically.

Conclusion

The loss and storage moduli, as well as tan δ, of various cement pastes were measured at different frequencies and temperatures. The addition of latex or methylcellulose to plain cement paste increases all three quantities, though latex is more effective in increasing tan δ and methylcellulose is more effective in increasing the storage modulus, so that latex and methylcellulose are comparable in their effectiveness in increasing the loss modulus. The addition of silica fume also increases all three quantities. The addition of short fibers (carbon or polyethylene) to a plain cement paste increases all three quantities, though carbon fibers are more effective than polyethylene fibers. The addition of carbon fibers to a mix with methylcellulose increases tan δ and loss modulus, but decreases storage modulus; the addition of carbon fibers to a mix with methylcellulose and silica fume decreases all three quantities at <1.5 Hz and the addition of carbon fibers to a mix with latex decreases all three quantities at all frequencies studied (up to 2 Hz). For energy dissipation applications, a mix with latex is recommended for use at >1.5 Hz, while a mix with methylcellulose and silica fume is recommended for use at <1.5 Hz. The use of fibers is not recommended.

Reference

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