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HIGH-FREQUENCY MAGNETIC-PULSE TREATMENT OF WATER AS A METHOD OF IMPROVING THE TECHNOLOGICAL PROPERTIES OF FINE CONCRETES

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The influence of the time of treatment of the tap and distilled water used for tempering of plasticized fine concretes by a high-frequency magnetic field on the technological characteristics of these concretes was investigated. The optimum regimes of treatment of the mixing water by this field and the dependence of the properties of the concretes obtained with it on the time of its storage after the treatment were determined.

Keywords: *mixing water, electromagnetic field, high-frequency magnetic-pulse treatment, portland cement, concrete, density, compression strength, mobility, hydrogen ion exponent.*

The hardening of concrete mixes and mortars is a multistage process including the dissolution of the cement clinker with formation of oversaturated solutions, the mass transfer and ion exchange in these solutions, the dispergation of the concrete to the point where it represents a mixture of colloidal particles, the formation of coagulating thixotropic hydrated structures and crystallization contacts, and the growth of crystalline aggregations. It is known that one of the most important operations determining the hardening and quality of concrete products is the preparation of a concrete mix. The search for ways of optimization and control of this process is a currently central problem of the construction industry that was solved in a number of investigations of different authors, among which the investigations carried out in [1, 2] are noteworthy. The hardening and properties of portland-cement systems can be controlled by magnetic treatment of the water used for their mixing [3–5]. This treatment can cause [3–5] a change in the orientation of the hydrated ion shells of the dissolved salts and in the adsorption of the surface-active admixtures introduced with the activated water and give rise to the formation of high-density fine-crystalline structures [5–7]. The selection of optimum conditions for treatment of the water used for tempering of concretes by a magnetic field makes it possible to obtain building materials with improved usage characteristics [8].

In recent years, magnetic treatment has been also used widely in other fields of science and technology, in particular for modification of the structure and properties of electrolytic solutions [9], crystalline melts and biological objects [10, 11], polymeric fabrics and fibers [12–14], and alloys of crude and nonferrous metals [15–17]. However, in all the above-indicated works, investigations were carried out with strong magnetic fields ($H \sim 10^3$ A/m) and ultrastrong ones ($H \sim 10^6$ A/m), the obtaining of which is a fairly complex technological problem [18]. At the same time, the action of the easily excited relatively weak magnetic fields with a strength of the order of several hundreds of amperes per meter has not been adequately explored. There are only several works [19–21] showing that the treatment of compounds, including the water used for tempering of cements [5], by these fields can be considered a promising method of their activation.

The aim of the present work is to investigate the influence of the time of low-intensity high-frequency magnetic-pulse treatment (HFMPT) of the water used for tempering of plasticized fine concretes on their technological and mechanical characteristics and the time of conservation of this water in the activated state.

Tap water and distilled water were treated with the use of an experimental setup designed on the basis of a VChI-62-5-IG-101 alternating current generator [11, 20] making possible the excitation of an electromagnetic field at

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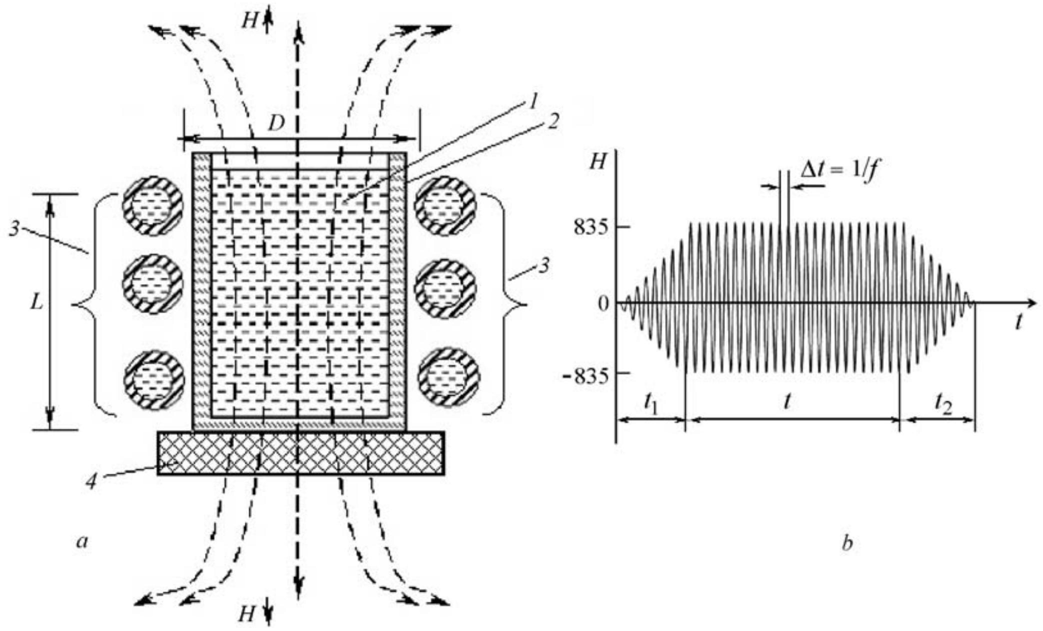


Fig. 1. Schematic diagram (a) and cyclogram (b) of treatment of water by a high-frequency magnetic field: 1) water; 2) glass vessel; 3) cooled work-coil; 4) dielectric support.

an industrial frequency f = 5.28 MHz. The field is localized in a water-cooled spiral three-turn work-coil (Fig. 1a) of inner diameter D = 80 mm and length L = 90 mm connected, as an inductive load, to the output of the generator. Before the setup is switched on, a glass vessel 2 filled with water is set on the dielectric support 4 in the axial zone of the work coil 3.

The mean-square values of the strength of the magnetic H and electric E components of the electromagnetic field excited at the axis of the work coil were determined with the use of a PZ-15 high-field-strength meter with a Ya6P-110 indicator and were equal to 590 A/m ($B \approx 1$ mT with an error of ~6%) and 12,700 V/m (with an error of ~4%) respectively. The amplitude values of $H^* = \sqrt{2}\,\overline{H}$ and $E^* = \sqrt{2}\,\overline{E}$ reached 835 A/m ($B \approx 1.5$ mT) and 17,960 V/m, i.e., the value of H^* exceeded only by 30 times the background induction of the earth magnetic field $B_E \approx 0.5$ mT.

The error in the reproduction of the operating conditions of the generator did not exceed 0.5%, with the result that the total error in the determination of the strength of the electromagnetic field acting on a sample was not larger than 10%. The strength of the field in the edge zone at a distance of ~$D/2$ from the work-coil axis was calculated with the use of the data from [18] for the magnetic component of the electromagnetic field and differed from the field-strength at the axis of the work coil by not more than 15%.

The treatment of the water by an electromagnetic field was carried out in air in accordance with the cyclogram shown in Fig. 1b. The time t_1 of establishment of the stationary operating conditions of the generator, under which the electromagnetic field is excited, and the time t_2 of resetting of it into the initial state added up to no more than 3 sec. The time t of the stationary action of a sinusoidal magnetic field of frequency 5.28 MHz and amplitude 835 A/m on the water was varied from 1 to 16 min. In this case, the water was practically not heated; however, the hydrogen-ion exponent (pH value) of the tap water (State Standard 2874-73) was varied within the range pH = 7.4–8.4 when the time of its treatment changed from 1 to 16 min and reached the maximum value $\text{pH}_m = 8.4 \pm 0.2$ for the treatment time $t \approx 3$–5 min (Fig. 2, line 1).

The distilled water (State Standard 6709-72) was less susceptible to the HFMPT. Its hydrogen ion exponent, unlike the pH value of the tap water, was shifted to the acid side and remained practically unchanged (pH = 6.25 ± 0.15) when the treatment time changed from 1 to 6 min. Only after a 6-min activation of the distilled water was its pH decreased to 5.7 ± 0.14 with a high degree of certainty ($p < 0.01$) (Fig. 2, line 2). A similar insusceptibility of the

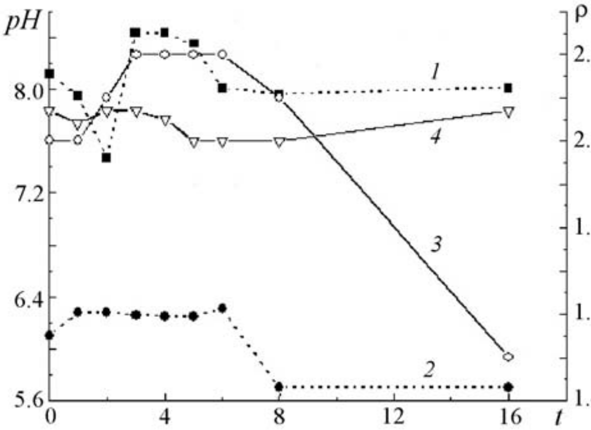


Fig. 2. Influence of the time of HFMPT of tap (1, 3) and distilled water (2, 4) used for tempering of concretes on the hydrogen ion exponent pH (1, 2) and the density ρ (3, 4) of these concretes. t, min; ρ, g/cm^3.

distilled water to the action of a magnetic field was detected in [22] where this effect was explained by the thermal change in the physical properties of the water in the process of its distillation.

Within 30 min after the HFMPT, nontreated water and activated tap and distilled water were used for tempering of cement-sand mixes based on the M500D0-grade cement (Krasnosel'skstroimaterialy Company, Republic of Belarus) and first-class sand (Krapuzhino Open Pit, Logoisk region, Minsk Oblast). Prior to use, the sand was dried to constant mass and sifted out to obtain fractions of size 0.16–3 mm. The mass ratio of the cement and sand was 1/1.5.

To decrease the water-cement ratio in the cement-sand mix, improve the placeability (mobility) of the concrete mix obtained, and increase the density and compression strength of this mix at the early and late stages of its hardening, we introduced a plasticizing admixture agent — a Socalan HP-80 polycarboxylate superplasticizer (Germany) [23] — into the mixing materials. The high efficiency of this admixture agent at a small content in a concrete mix (0.2–0.3% of the cement mass) makes it possible to decrease the water-cement ratio in this mix by 25–30% and substantially increase its plasticity. However, the majority of the traditionally prepared portland-cement compounds, including mixes based on the M500D0 cement, retain a high degree of plasticization for a short time: within 2 h after the addition of water to them, the loss in the placeability of the cement-sand mix obtained comprises about 50–70%.

The properties of cement-sand mixes and the concretes obtained on their basis (mobility, keeping quality, density, compression strength) were investigated with the use of mixes tempered with fresh-activated tap and distilled water and the water kept at room temperature during one and two weeks after the activation.

The mobility l of a tempered cement-sand mix and the change in its keeping quality with time were estimated by Belarus Standard 1545-2005 (Concrete Mixes. Methods of Testing); for this purpose, the diameter of the minicone-sample spread formed on a horizontal surface was measured immediately after the mixture was prepared and successively at intervals of $\Delta t = 30$ min during 2 h. The diameter of this spread was measured repeatedly, at least two times, with an error not larger than 0.1 cm. The error in determination of the mobility of the concrete was not larger than ±2.5%

For determining the density ρ of the concrete and its compression strength σ_{com}, we formed cubic samples of cement-sand mixes and hardened them under normal temperature-humidity conditions (T = 293 ± 2 K, relative humidity 80–90%). Then the samples were tested in accordance with the State Standard 12,730.1-78 (for ρ) and the State Standard 10,180-90 (for σ_{com}). In this case, the values of σ_{com} were determined at the early stages of hardening of the concretes (1–3 days) and within a time interval as large as 28 days. The coefficient of variation in the strength of the concretes was ±3.5%.

The qualitative composition of the initial crystalline phases and the hydration products formed at different stages of hardening of concretes was controlled with the use of a DRON-2 diffractometer with a CuK$_{\alpha}'$ copper emitter.

Our investigations have shown that the dependence of the density of the concrete ρ on the time t of the HFMPT of the mixing tap water (Fig. 2, line 3) as well as the analogous dependence for the pH value are extremum in character with a maximum value at $t \approx 3$–5 min. The samples obtained with the use of water activated for 16 min had the most friable structure and a low density (ρ = 1.5 ± 0.04 g/cm^3).

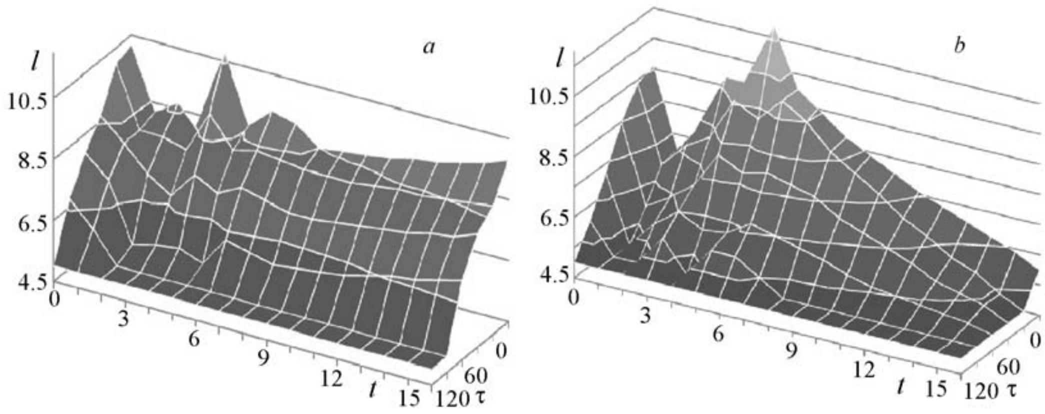


Fig. 3. Time change in the mobility of cement-sand mixes plasticized by a 0.3% Socalan HP-80 superplasticizer and tempered with nonactivated water ($t = 0$) and distilled (a) and tap (b) water subjected to HFMPT for $t = 1–16$ min. τ, min; l, cm.

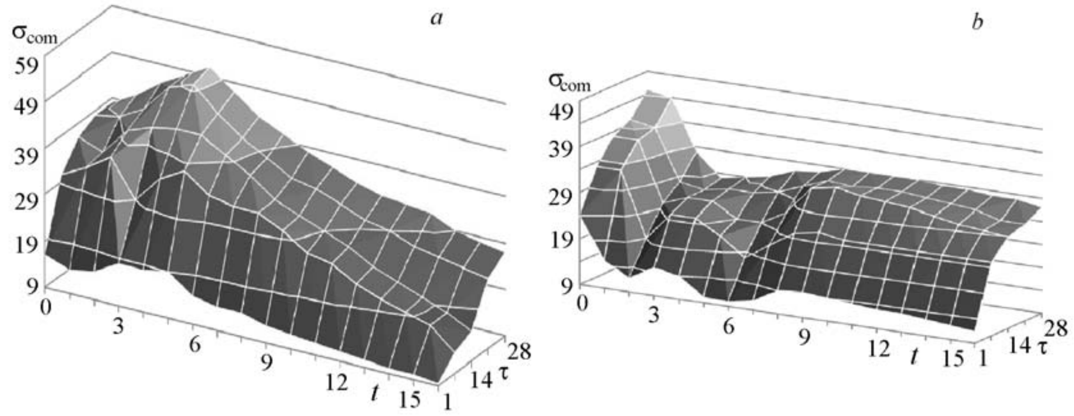
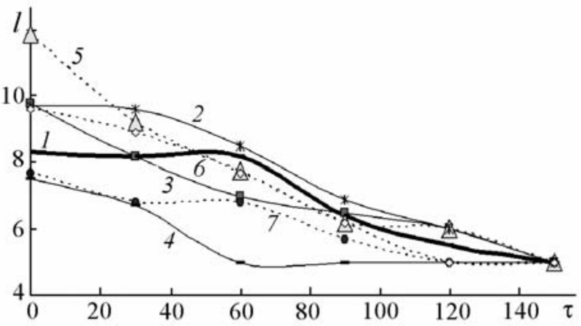


Fig. 4. Kinetics of the strength of a set of fine concretes plasticized by a 0.3% Socalan HP-80 superplasticizer and tempered with nonactivated water ($t = 0$) and tap (a) and distilled (b) water subjected to HFMPT for $t = 1–16$ min. σ_{com}, MPa; τ, day.

In the case where distilled water was used for mixing of concretes, their density was practically independent of the time of its treatment by the magnetic field (Fig. 2, solid line 4). A change in the time of the HFMPT of the distilled water from 1 to 16 min did not cause a substantial change in the mobility l of the tempered concrete mixes (Fig. 3a), even though the distribution $l(t)$ had a poorly defined maximum corresponding to the activation time $t \sim 3$ min.

The mobility l of the concrete mixes containing tap water activated for $t \approx 3–5$ min was increased by more than 30% as compared to that of the control samples ($t \approx 0$) (Fig. 3b). In this case, a decrease in the activation time t to 1 min as well as an increase in this time to 8–16 min led to a marked reduction in the plasticization effect, which is a distinctive feature of the distribution $l(t, \tau)$ of concrete mixes. A similar additional plasticization effect caused by the activation of the mixing water was detected earlier in [24, 25] where it was explained by the more uniform adsorption of the mixing liquid by the clinker particles and the new formations. The weak susceptibility of the distilled water to the HFMPT can be due to its resistance to such actions [23] gained by it after the distillation; a reason for this capacity is the removal of the iron-containing impurities from the water.

The kinetics of the strength of concretes obtained with the use of activated tap water is presented in Fig. 4a. At the stage of formation of condensation-crystallization structures in these concretes (1–2 days of hardening), accompanied by the development of internal stresses [25], the concretes had a lower compression strength as compared to that of the control samples. However, after the 3-day hardening causing a large increase in their strength due to the formation of the spatial-crystalline carcass including hardening products, the strength of the concrete mixes obtained



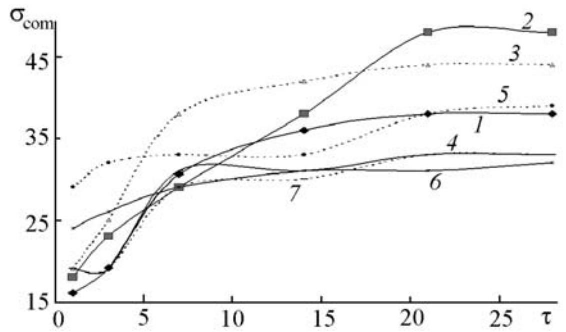


Fig. 5. Time change in the mobility of cement-sand mixes plasticized by a 0.3% Socalan HP-80 superplasticizer and tempered with nonactivated tap water (1) and tap water subjected to HFMPT for 3 min (2–4) and 5 min (5–7): 2, 5) mixing immediately after the water is activated; 3, 6) mixing within one week after the activation; 4, 7) mixing within two weeks after the activation. τ, min; *l*, cm.

Fig. 6. Kinetics of the strength of a set of fine concretes plasticized by a 0.3% Socalan HP-80 superplasticizer and tempered with nonactivated water (1) and water subjected to HFMPT for 3 min (2, 4, 6) and 5 min (3, 5, 7). The concretes were obtained with fresh-activated water (2, 3), activated water kept for one week (4, 5), and activated water kept two weeks (6, 7). σ_{com}, MPa; τ, day.

with water activated for 1 min $\leq t < 7$ min had substantially better strength characteristics as compared to those of the control samples. In this case, a maximum compression strength σ_{com} was characteristic of the concretes tempered with water subjected to the HFMPT during $t \approx 3$–5. The compression strength of such samples of age 28 day was higher by 35–40% than that of the control samples, which is explained by the formation of more perfect high-density macrostructures in these concretes. At the same time, the activation of the distilled water has no positive influence on the strength of the concretes obtained with it (Fig. 4b). The strength properties of such concretes remain at the level of the control samples; however, their strength decreases within the time interval (t = 2–8 min) in which the strength of the concretes tempered with activated tap water increases.

A x-ray phase analysis of a cement slurry tempered with activated tap water, carried out at different stages of its hardening, has shown that the degree of crystallization of the crystalline hardening products decreases somewhat with time and a finer concrete is formed. This circumstance allows one to plan the process of preparation of cement-sand and concrete mixes so that not only the water-cement ratio in them is decreased, but also the cement content is substantially decreased without prejudice to the technological characteristics of the materials obtained.

It is known [8] that water activated by a constant magnetic field retains its new properties for 15–20 h. In this connection it is interesting to consider the behavior of activated tap water kept under normal conditions. The change in the mobility and conservation of cement-sand mixes and the strength kinetics of a set of fine concretes obtained with this water are presented in Figs. 5 and 6 respectively. Analysis of the detected changes in the mobility of the indicated mixes and in the strength of the concretes allows the conclusion that the "magnetic memory" of water activated under the conditions selected is conserved for 7 day, and even after a lapse of this time the initial mobility of the mixes obtained with this water differs insignificantly from that of compounds obtained with freshly activated water (Fig. 5, curves 2, 3, 5, 6). As is seen from Fig. 6, the compression strength of the concretes mixed with freshly activated water (Fig. 6, curves 2 and 3) is substantially larger (by up to 40%) than that of the control samples. In the case where activated water is used for mixing of concretes within a weak after its treatment (Fig. 6, curves 4 and 5), the early strength of the concretes ($\tau \leq 7$ day) exceeds the strength of the control samples by approximately 25–30%, even though, at later stages (7 day $< \tau <$ 28 day), their strengths are practically equal (Fig. 6, curve 5). When the time of storage of activated water is increased up to two weeks, the initial mobility of the concretes obtained with this water (Fig. 5, curves 4 and 7) and their finite ($\tau \approx 28$ day) compression strength (Fig. 6, curves 6 and 7) decrease by 15–17% as compared to those of the control compounds.

Thus, our investigations have shown that the technological characteristics of plasticized portland-cement systems can be improved by tempering of them with the use of tap water treated by a low-intensity high-frequency magnetic field. It has been established that compounds containing water treated during 3–5 min have the best rheological and strength characteristics. In this case, the activity of the water is conserved for a much longer time that in the case of its treatment by a high-intensity constant magnetic field. The method proposed for activation of the mixing water provides a marked positive effect even in the case where this water is used for preparation of portland-cement mixes after 7 day of its activation.

However, at present a generally accepted clear concept on the mechanism of treatment of water by weak magnetic fields and on the features of action of the water treated by a magnetic field on the structurization of concretes obtained with it is absent. This is explained by the fact that multistage complex physicochemical reactions proceed in the mixing water and in the mixes obtained with it and that the results of investigation of these mixes are difficult to interpret [26].

Currently the fact that water kept at room temperature contains 50% of supermolecular formations (nanoclusters) of the type of $(H_2O)_n$, where n is an integer of the order of several units, has been confirmed [27, 28]. The configurations of the conglomerates that can form the indicated structures were calculated by the molecular-dynamics methods [29–31]. It has been shown that these structures have a fairly stable plane geometry (rings, chains) or a three-dimensional geometry (tetrahedron, hexamer, octamer). Moreover, the formation of giant heterophase structures with sizes of several hundreds of microns and relaxation times greater that 10 sec, called giant heterophase water clusters, was detected in the experiments [32]. It has been established that the deciding factor of the development of these clusters is external action that can give rise to the formation and growth of the indicated structures and, consequently, be responsible for the appearance and disappearance of any property or a group of properties of the water. For example, the authors of [3] argued that the degree of structurization of water determines its diamagnetic susceptibility and, consequently, the ability of this water to wet minerals and other objects. Magnetic treatment of water, by breaking the bonds between its molecules in a cluster structure, improves the ability of the water to wet the cement clinker and, as a consequence, can change the kinetics of the hydration process. An explanation of the destructive changes in the clusters of the water exposed to an electromagnetic field, the energy of whose quantum is much lower than the energy of the hydrogen bond, is given in [33]. Since water used in practice contains different impurities, the authors of the indicated work reason that these impurities can damage cluster structures and give rise to the appearance of internal stresses in them, with the result that the clusters take on the properties of polymers and gain the capacity to accumulate the energy of a low-intensity electromagnetic field. After the energy accumulated by the water reaches any critical value, the cluster structure of the water breaks down with formation of H^+ and OH^- ions and hydrated electrons e^-, which leads to a change in the pH value of the water.

A more comprehensive analysis of the factors responsible for the high degree of activation of water by a high-frequency electromagnetic field as well as the mechanisms of action of this water on the hydration of cement-sand compounds calls for additional systematic theoretical and experimental investigations.

NOTATION

B, magnetic-field induction, mT; f, frequency, MHz; H, magnetic-field strength, A/m; E, electric-field strength, V/m; l, mobility of a concrete mix, cm; pH, hydrogen ion exponent; t, time of HFMPT, min; ρ, density of the concrete, g/cm^3; σ_{com}, compression strength of the concrete, MPa; τ, time of hardening, min, day. Subscripts: com, compression; m, maximum.

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