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EFFECT OF ELECTRON WATER CURING AND ELECTRON CHARGING CURING ON CONCRETE STRENGTH

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ABSTRACT

By charging normal water under an appropriate electric voltage, electron water can be produced. With its small molecule cluster and high activity, the water has been found to have applications in many fields. This study showed that: 1) by curing concrete specimens in electron water, concrete strength was increased by at least 5% and by more than 15% at early ages in comparison to that of the concrete cured in normal water at the same temperature; and 2) by electron charging curing the strength of concrete could also be improved, especially its 1-day strength, which was increased by as high as 50% relative to that of control specimens. The possible reason for the strength increase of concrete by the both curing methods is that the curing water and the water in concrete both have small molecule clusters and high activity caused by the charging treatment, resulting in the improvement on cement hydration and the decrease in average pore size and the volumes of large pores of concrete. *© 1998 Elsevier Science Ltd*

Introduction

Many kinds of chemical admixtures are now being used for improving the strength of concrete, especially the early strength of concrete. But underground water and reservoir water may be somewhat polluted by the considerable amount of chemical admixtures that exist in large volume concrete. Some developed countries have been paying attention to this problem. It seems to be important and useful to search for other possible ways for that purpose. Two years ago the authors began to study the effect of electron water and electron charging curing method on the properties of cement and concrete.

The so-called electron water is obtained by charging normal water in a tank under an appropriate electric voltage for several hours or 1–3 days. In the water tank there is one kind of special carbon that is used as electrode and active medium (1). Recently, electron water has found application in agriculture, aquiculture, animal husbandry, medical treatment, and

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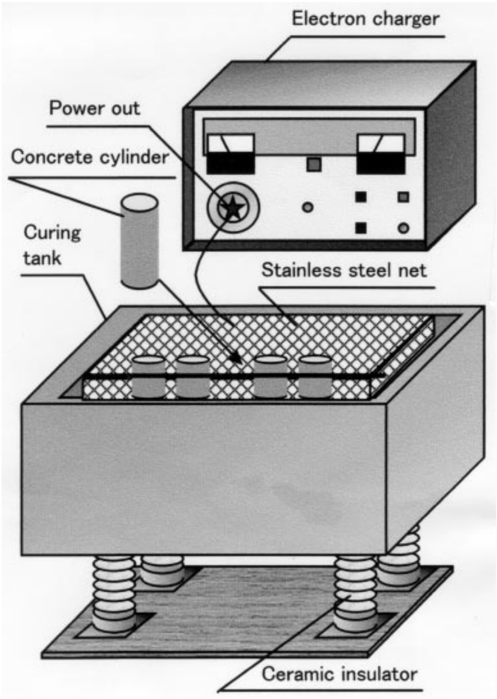

FIG. 1.
Curing tank in which electron water is produced.

the food industry in Japan. Experimental results showed that the water had high activity and was very effective in promoting the growth of animals and plants, improving food quality and taste, and was also helpful to the promotion and recovery of human health (1). Sugita et al. observed that by curing cement mortars in electron water their strength at different ages was increased, and the strength increase ratio was varied with the used charging intensity (2). In this study the strength development of concrete under electron water curing and electron charging curing conditions was compared with that of the concrete cured in normal water or in the air at the same temperature.

Experiments

Variation of Electrical Conductivity of Water After Charging Treatment

The water used in the experiment, called normal water in order to differentiate with the electron water, was normal drinking water at Hachinohe City. At 20 its electrical conductivity was 0.209 mS/cm. After charging for 3 days with an electron charger (Fig. 1), its electrical conductivity was increased to 0.316 mS/cm even though the concentrations of ions in it were not changed. The electrical con-ductivity of water was determined with a digital conductivity meter (Horiba Co., DS-14 type).

TABLE 1
Properties of aggregates.

Aggregate	Specific gravity	Fineness modulus
Crushed stone	2.66	7.00
River sand	2.56	2.85

Raw Materials and Preparation of Concrete Specimens

The used cement and aggregate were ordinary Portland cement (OPC) and crushed stone with nominal maximum size of 25 mm and river sand less than 5 mm in diameter as coarse and fine aggregates, respectively (Table 1). According to Table 2 concrete cylinders of 100×200 mm were prepared, the slump and air volume of fresh concrete were controlled within 8.0 ± 2.5 cm and $5.0 \pm 1.5\%$. In the preparation of concrete specimens normal water and air-entraining (AE) agent were used.

Curing of Specimens

After demoulding, concrete specimens were respectively cured in normal water and in electron water at 20 ± 2°C. In the latter case the curing tank was connected with an electron charger, as shown in Figure 1. By regulating the output voltage of the charger, one can control the charging intensity. The maximum output voltage of the charger was 10 kV; in this experiment 7.0 kV was adopted, at which the power consumption was only about 300 W-h per day. The water in the curing tank had been charged for 3 days before specimens were placed in it.

Some specimens, being sealed in steel moulds, were cured for 1 day, 2 days, 3 days, 7 days, and 28 days in the air at 20 ± 22? with R. H. of about 40% or on a stainless steel table that was connected with an electron charger as shown in Figure 2. The output voltage of the charger was also 7.0 kV.

Concrete strength is shown in Table 3. After the strength test, the pore volume and pore size distribution of some specimens were studied with a mercury porosity meter.

Non-Evaporable Water in the Tested Cement Pastes

Cement pastes were prepared at a water-to-cement ratio of 0.30 by mixing OPC with normal water or electron water, then they were tightly sealed in glass bottles and cured in the air at 20 ± 2°C for 1 day. After removal from the glass bottle, the paste was cured in normal water

TABLE 2
Mixture proportion of concrete (kg/m^3).

w/c	s/a	OPC*	Normal water	River sand	Crushed stone	AE agent
0.49	0.43	318	156	763	1051	0.86

*Blaine specific surface area = 321 m^2/kg, gravity = 3.16.

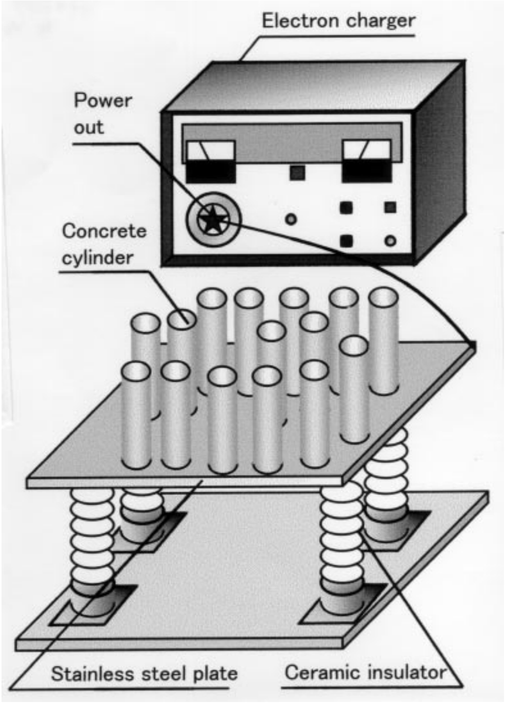

FIG. 2.
Electron charging table.

and in electron water at 20± 1°C for 7 days and 28 days, respectively. The method for determining non-evaporable water in the pastes is shown in Equation 1 (3) and the result is listed in Table 4

$$W_c = [(W_d - W_i)/W_d] \times 100\% - W_o \tag{1}$$

where W_c is the amount of non-evaporable water of paste (%), W_d is the weight of the ground paste after being dried at 105°C for 1 h, W_i is the weight of the paste after calcined at 1000°C to constant weight, and W_o is the ignition loss by weight percentage of the respective cement.

TABLE 3
Strength of the concrete cured under different curing conditions.

Sample	Curing method	Compressive strength (MPa)				
		1 day	2 days	3 days	7 days	28 days
Concrete	In normal water	4.4(100)*	10.7(100)	15.7(100)	26.7(100)	37.4(100)
	In electron water	4.4(100)	12.5(117)	18.6(118)	28.0(105)	40.7(109)
	On charging table	6.6(150)	12.5(117)	18.3(117)	27.4(103)	36.6(98)
	In air	4.4(100)	11.8(110)	17.6(112)	25.8(97)	35.8(96)

*Figures in parentheses are strength ratios by percentage.

TABLE 4
Non-evaporable water in cement pastes with a water-to-cement ratio of 0.30 at 20 ± 1°C.

	Cured in NW*				Cured in EW**			
	OPC + NW		OPC + EW		OPC + NW		OPC + EW	
Sample	7 days	28 days	7 days	28 days	7 days	28 days	7 days	28 days
Non-evapor. Water (%)	11.5	13.1	11.7	12.9	12.9	15.7	12.9	15.6

*NW, normal water.
**EW, electron water.

Results and Discussions

Variation of the Characteristics of Water by Charging Treatment

Water in nature, even the pure water prepared in laboratories, does not exist in the form of single H_2O molecules because water molecules generally combine with each other to form large $(H_2O)_n$ clusters (Fig. 3). It has been observed that many kinds of health-giving spring water in the world contain small molecule clusters, and the biochemical activity of water is closely related to the size of $(H_2O)_n$ cluster (1,4). As far as the water with the same or close ionic composition is concerned, the smaller the cluster size of water, the higher the biochemical activity the water will have (1).

The decrease of the peak width of O-NMR spectrum of water (Fig. 4) proves that the molecule cluster of water has been reduced by the charging treatment as shown in Figure 1. Therefore it could be said that the activity of the water after charging treatment is higher than that of normal water. In this study the observed increment of the electrical conductivity of water after charging treatment gives another evidence for the influence of charging treatment on the properties of water. The increment of electrical conductivity of water by the charging

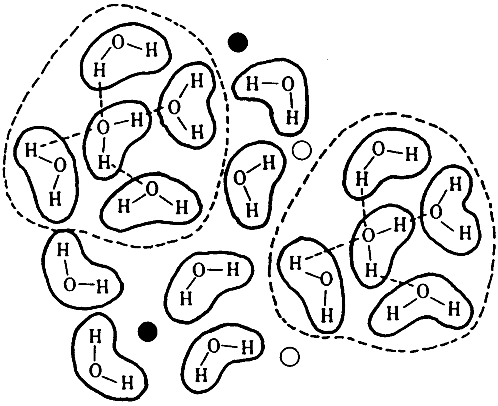

FIG. 3.
Structure of the molecule clusters of water.

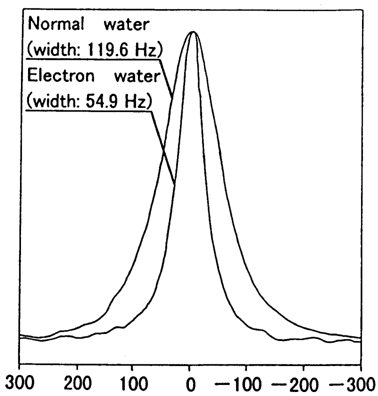

FIG. 4.
O-NMR spectrums of electron water and normal water.

treatment might be due to the decrease of motion resistance of ions in water caused by the reduction of the size of water molecule cluster.

Strength Development of Concrete Under Different Curing Conditions

From Table 3 it can be found that: 1) by electron water curing concrete strength was improved by at least 5% and by more than 15% at 2 days and 3 days compared with that cured in normal water; and 2) by curing concrete specimens on the charging table the strength of concrete at every age, compared with that of the concrete cured in air, was all enhanced; in particular, its 1-day strength was increased by as high as 50%.

After 3 days the strength increase ratio of the concrete cured on the charging table became less than that cured in electron water, which was possibly due to the decrease of hydration water in it caused by water evaporation under dry curing condition.

Cement Hydration Under the Condition of Electron Water Curing

Table 4 shows that the non-evaporable water in cement paste was increased by electron water curing; this means cement hydration has been improved. What is the reason for this? Yet it might be difficult to make a full answer for it. But, because electron water has a small molecule cluster and high electrical conductivity, can it be said that the main reason or one of the main reasons is that the penetration of electron water through the hydrates in hardened paste and the transfer of reactant ions in the liquid of hydrating cement are improved by the charging treatment? This needs to be further investigated.

Pore Size Distribution of the Tested Specimens

From Table 5 it can be seen that the average pore radius of the concrete cured in electron water was decreased compared with that of the specimens cured in air or in normal water.

TABLE 5
Average pore radius and porosity of concrete specimens cured at 20 ± 2°C.

Sample	Cured in NW			Cured in EW			Cured in air		
	3 days	7 days	28 days	3 days	7 days	28 days	3 days	7 days	28 days
Average pore radius (nm)	44.2	35.4	27.1	37.2	28.2	20.5	–	30.3	29.6
Porosity (%)	18.5	18.5	15.2	19.0	18.2	13.1	–	16.7	11.6

Table 6 shows that (1) within the investigated range the total pore volume of concrete was not evidently changed at 3 days and 7 days by electron water curing, but at 28 days it was decreased by about 11% relative to that of the concrete cured in normal water; and (2) the relative volumes of the pores larger than 50 nm in radius in the concrete cured in electron water were considerably decreased instead of the increment of the volumes of the pores with radius less than 50 nm. The variation of cumulative pore volume with pore size of concrete is shown in Figure 5.

Strengthening Mechanism of Concrete by Electron Water Curing and Electron Charging Curing

Due to the difficulty in studying the relations among the structure variation of water molecule clusters, cement hydration, and the microstructure of hardened cement, at present the authors can only attribute the strength increase of concrete by the two curing methods to the following reasons: 1) hydration rate of cement is increased; and 2) average pore size of concrete and the volumes of large pores in concrete are decreased. The improvement of cement hydration by the two curing methods may be possibly related to the decrease of the size of water molecule cluster and the activation of curing water and the water in concrete by the charging treatment.

TABLE 6
Variation of relative pore volume of concrete with pore radius ranges under different curing conditions.

Curing method	Age (days)	Pore radius range (nm) - Relative pore volume (%)							Total vol. mm^3/g
		<15	15-25	25-50	50-100	100-500	500-10^4	10^3-10^4	
In NW	3	22.68	9.90	21.34	15.28	15.66	11.70	3.44	92.73
In EW	3	24.90	11.93	22.88	15.86	14.23	7.41	2.78	97.11
In NW	7	25.81	12.88	29.55	15.44	6.55	6.42	3.34	90.56
In EW	7	29.80	15.11	32.65	8.49	5.27	6.11	2.57	90.88
In NW	28	32.61	14.27	29.52	6.35	6.73	7.32	3.20	72.56
In EW	28	39.02	21.17	18.83	5.91	7.08	5.48	2.52	64.51

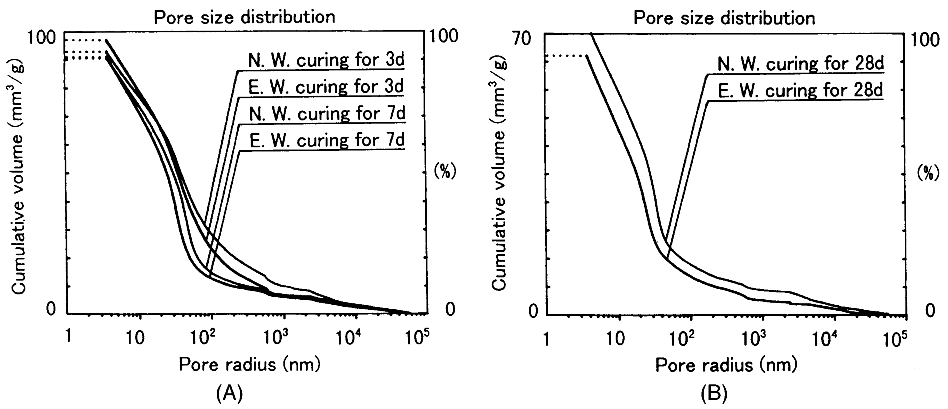

FIG. 5.
Pore size distribution of concrete under different curing conditions.

Conclusions

1. Under charging treatment the molecule cluster size of water was reduced; at the same time the electrical conductivity of water was increased.
2. By the methods of electron water curing and electron charging curing, concrete strength, especially the strength at early ages, could be considerably improved. Being simple and energy-saving, the two curing methods are applicable in concrete industry.
3. The possible reasons for the strength increase of concrete by the two curing methods are that the curing water and the water in concrete are activated and their molecule cluster size is decreased by the charging treatment, resulting in the improvement on cement hydration and the decrease in average pore size and the volumes of large pores of concrete.

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