

CONCRETE TECHNOLOGY *Today*

Portland Cement Characteristics—1998

by Paul D. Tennis, Materials Research Engineer, Portland Cement Association



Fig. 1. 50-mm (2-in.) mortar cubes are cast (left) and crushed (right) to determine strength characteristics of cement. (69128)(69124)

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Results of a survey of cement manufacturers compiles information on currently available cements

In 1998, the Portland Cement Association requested current mill test certificates from plants manufacturing cement in the United States to compare with a similar survey of cement producers conducted in 1994 by ASTM. The purpose of the surveys was to provide data on modern cement characteristics (see References 1 and 2). The surveys allowed comparisons with past cements, specifically, those manufactured in the 1950s (the last time for which similar data are available). The surveys also serve as an aid to ASTM Committee C-1 on Cement for evaluating standards development needs.

Taking the Survey

Plant managers of all 108 U.S. plants manufacturing cement received the request for current mill test certificates for cement, Types I through V. Masonry, blended, oil well, and other specialty products were not included in the survey. One hundred one plants responded, for a response rate of 94%. These plants produce 234 cements (see Table 1).

Table 1. Classification of Cement Types and Cements Received

Cement type	I	I A	II*	III	III A	V	Total
Number of entries	62	11	76	62	1	22	234

* Includes 56 cements sold as Type I/II. No Type IV data were received.

Where needed for consistency, the following changes were made to data from the mill test reports :

- Strength data were converted from U.S. customary units to metric equivalents
- Fineness values were converted from cm^2/g to m^2/kg

Table 1 lists the major divisions of cement types received. However, some cements meet the requirements of, and are sold under, more than one ASTM C 150 designation. For consistency with the ASTM 1994 survey, the following conventions were applied:

- Cement sold as a Type I and as a Type II, or as a Type I/II, was classified in the database as Type II
- Cement sold as a Type II/V or I/II/V was categorized as Type V
- Cement sold as a Type II/III was categorized as Type III.

Results and Conclusions

Chemical and compound composition values, and fineness, are given in Tables 2 and 3 for the 1998 and 1994 surveys, respectively. Figure 2 compares the relative

strength gain of the 1998 cements and Figure 3 compares the strength gain of Type I cements from 1998 to those from 1994 and the 1950s. A comparison of the 1950s and 1994 data has been presented previously (Reference 2).

Figure 2 demonstrates that the strength gain of Type I and Type II cements is almost identical. As expected, Type III has the earliest strength gain and Type V the lowest. Tables 2 through 5 and Figure 3 indicate that 1998 results are practically the same as those from the 1994 survey.

References

1. Gebhardt, R. F., "Survey of North American Portland Cements: 1994," *Cement, Concrete, and Aggregates*, December 1995, 145-189.
2. "Portland Cement: Past and Present Characteristics," *Concrete Technology Today*, Vol. 17, No. 2, PL962, Portland Cement Association, Skokie, Illinois, July 1996, pages 1-4.

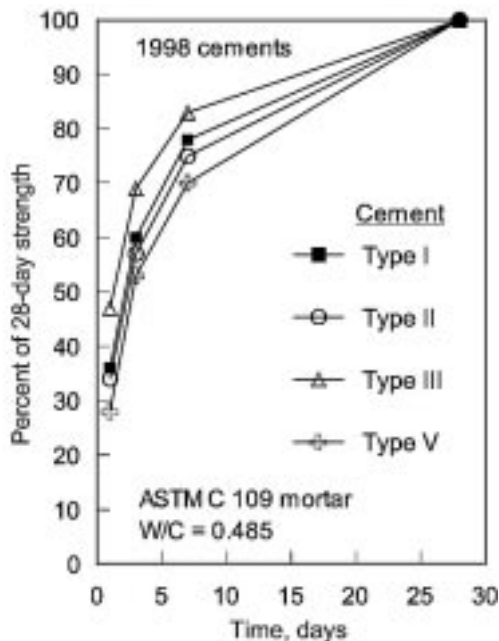


Fig. 2. Strength gain of 1998 cements shows the relative strength compared to 28-day strength.

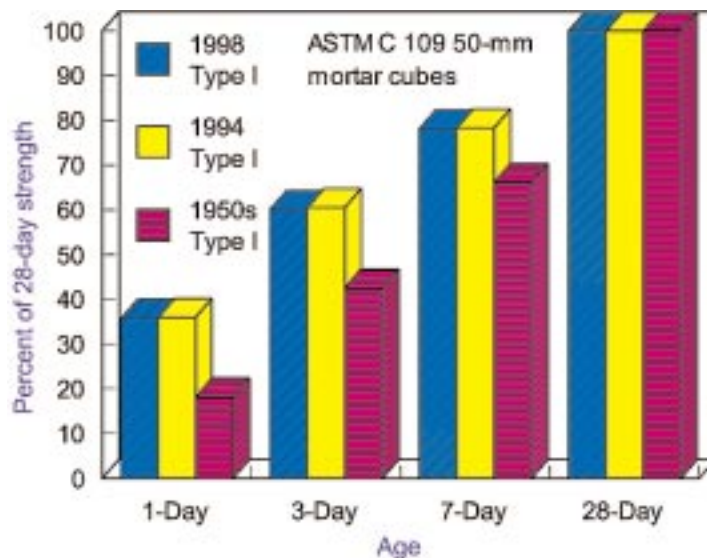


Fig. 3. A comparison of strength gain of Type I cement from 1998, 1994, and the 1950s. Similar relationships exist for Types II, III, and V.

Table 2. Chemical and Compound Composition and Fineness of 1998 Cements*

Type of portland cement	Range of chemical composition, %						Loss on ignition, %	Na ₂ O eq	Range of potential compound composition, %				Blaine fineness, m ² /kg
	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃			C ₃ S	C ₂ S	C ₃ A	C ₄ AF	
I (min-max)	19.1-22.7	4.0-6.5	0.2-4.0	61.2-67.7	0.5-4.6	2.3-4.4	0.6-2.7	0.14-1.26	42-66	9-30	6-14	1-12	310-497
I (mean)	20.7	5.1	2.6	64.0	2.1	3.0	1.3	0.58	56	17	9	8	381
II (min-max)	20.2-22.5	3.9-5.2	2.6-4.5	61.2-66.1	0.8-4.7	1.9-3.6	0.2-1.9	0.11-1.28	46-66	11-30	4-8	8-14	318-514
II (mean)	21.1	4.5	3.4	63.8	2.2	2.7	1.1	0.54	56	19	6	10	378
III (min-max)	18.9-22.7	3.9-6.6	0.3-4.1	60.7-67.5	0.7-4.9	2.6-4.3	0.3-2.6	0.10-1.21	42-65	9-28	1-14	1-12	319-672
III (mean)	20.5	4.9	2.7	63.6	2.3	3.5	1.3	0.56	56	17	9	8	547
V (min-max)	19.7-27.1	2.0-4.7	0.4-5.7	59.7-65.9	0.5-4.3	1.9-3.1	0.3-2.5	0.06-1.02	42-64	13-46	1-5	1-15	287-681
V (mean)	21.9	3.8	3.8	63.8	2.1	2.3	1.0	0.49	56	21	4	11	385

*Air-entraining cements are not included.

Table 3. Chemical and Compound Composition and Fineness of 1994 Cements*

Type of portland cement	Range of chemical composition, %						Loss on ignition, %	Na ₂ O eq	Range of potential compound composition, %				Blaine fineness, m ² /kg
	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃			C ₃ S	C ₂ S	C ₃ A	C ₄ AF	
I (min-max)	18.7-22.0	4.7-6.3	1.6-4.4	60.6-66.3	0.7-4.2	1.8-4.6	0.6-2.9	0.11-1.20	40-63	9-31	6-14	5-13	300-421
I (mean)	20.5	5.4	2.6	63.9	2.1	3.0	1.4	0.61	54	18	10	8	369
II** (min-max)	20.0-23.2	3.4-5.5	2.4-4.8	60.2-65.9	0.6-4.8	2.1-4.0	0.0-3.1	0.05-1.12	37-68	6-32	2-8	7-15	318-480
II** (mean)	21.2	4.6	3.5	63.8	2.1	2.7	1.2	0.51	55	19	6	11	377
III (min-max)	18.6-22.2	2.8-6.3	1.3-4.9	60.6-65.9	0.6-4.6	2.5-4.6	0.1-2.3	0.14-1.20	46-71	4-27	0-13	4-14	390-644
III (mean)	20.6	4.9	2.8	63.8	2.2	3.5	1.3	0.56	55	17	9	8	548
V (min-max)	20.3-23.4	2.4-5.5	3.2-6.1	61.8-66.3	0.6-4.6	1.8-3.6	0.4-1.7	0.24-0.76	43-70	11-31	0-5	10-19	275-430
V (mean)	21.9	3.9	4.2	63.8	2.2	2.3	1.0	0.48	54	22	4	13	373

*Values represent a summary of combined statistics. Air-entraining cements are not included. Adapted from Reference 1.

**Includes fine grind cements.

Table 4. Strength of 1998 Cements (ASTM C 109), MPa

	1-Day	3-Day	7-Day	28-Day
I (min-max)	10.0-24.5	16.7-32.6	24.1-40.0	35.6-49.6
I (mean)	14.9	25.0	32.5	41.6
II (min-max)	9.3-20.3	17.0-30.1	24.7-38.3	37.6-48.2
II (mean)	14.3	23.9	31.4	42.1
III (min-max)	16.2-31.5	26.7-43.4	33.8-49.9	43.5-59.0
III (mean)	23.7	34.5	41.3	49.9
V (min-max)	8.8-18.1	16.1-26.0	19.4-34.3	29.6-46.6
V (mean)	11.6	21.7	28.9	41.2

Table 5. Strength of 1994 Cements (ASTM C 109), MPa

	1-Day	3-Day	7-Day	28-Day
I (min-max)	9.9-21.6	20.0-30.9	25.6-37.6	31.1-51.4
I (mean)	14.8	24.9	32.2	41.1
II (min-max)	9.4-20.8	15.9-32.1	22.3-39.2	32.4-53.3
II (mean)	13.7	23.8	30.9	41.7
III (min-max)	15.8-32.0	28.3-45.6	34.1-49.3	42.3-56.9
III (mean)	24.1	34.7	41.0	48.4
V (min-max)	7.4-17.1	12.9-29.9	20.4-36.1	33.0-45.7
V (mean)	11.9	21.5	28.5	40.6

PCA R&D Serial No. 2256a



Factors Influencing Color

by Peter C. Taylor and Linda M. Hills

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A qualitative investigation examines the effects of cement, water-cement ratio, curing, and age on color

For architectural finishes, concrete needs to have a uniform appearance. Some variability in materials, handling, and curing, however, is expected, and can result in color differences of the concrete. To minimize nonuniform concrete color, it is necessary to determine what factors have the greatest impact. It is also helpful to be able to quantify color in order to determine:

- color uniformity
- color differences
- the extent (area) and degree of discoloration.

Quantitative color measurements, rather than subjective human determination of color, are especially useful. Some color measurement instruments are able to readily collect measurements in the field, eliminating the need for destructive sampling to acquire laboratory specimens (see Fig. 1).

Test Program

Eight mortar samples were studied over a 90-day period to determine the effect of cement type, water-cement ratio, type of curing, surface finish (off-the-form or tool-finished), and age. Some trends in color were established for each variable. Due to the limited scope of the study, the results indicate only the relative effect of each variable.

Materials

Two cements from different sources were used in the laboratory program: one with 9% tetracalcium aluminoferrite (C_4AF) and one with 13% C_4AF (a Type I and a Type V cement). The two cements contained, respectively, 3.12% and 4.25% iron oxide (Fe_2O_3). It is generally considered that C_4AF and iron have a strong influence on cement color. A prepackaged natural silica sand meeting ASTM C 778 and tap water were used with the cements to make mortar.

Tests

Two mortars were prepared from each cement: one with a water to cement ratio (w/c) of 0.5 and the other of 0.8. No chemical admixtures were used. Mixture proportions are

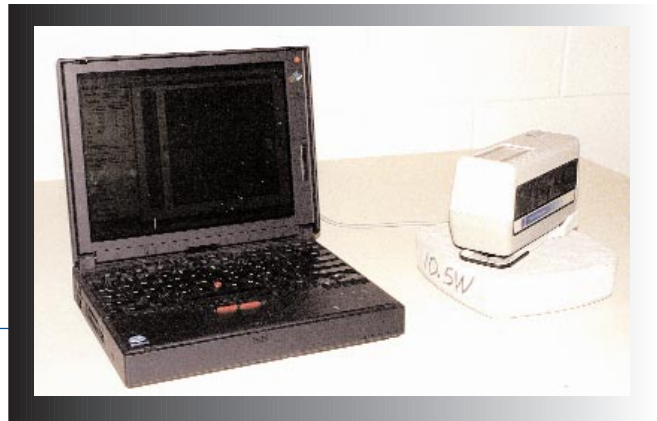


Fig. 1. Instrument for taking color measurements is linked to a laptop computer to download and analyze readings. (69127)

Table 1. Mortar Mixture Proportions, kg/m^3 (lb/yd^3)

Material	Water to cement ratio 0.5	Water to cement ratio 0.8
Cement	507 (855)	439 (740)
Sand	1519 (2560)	1317 (2220)
Water	252 (425)	350 (590)

given in Table 1; the aggregate to cement ratio (by mass) of all four mortars was three.

Two 200 x 200 x 50-mm (8 x 8 x 2-in.) slabs were prepared from each of the four mortar mixtures, for a total of 8 slabs. The slabs were cast into new plastic containers without any applied release agent. The surfaces were struck off with a magnesium float. The slabs were sealed in containers with lids overnight before being demolded. One set of four slabs was then stored in a control chamber with temperature at $23^\circ C \pm 2^\circ C$ ($73^\circ F \pm 4^\circ F$) and relative humidity at $50 \pm 2\%$. The other set of four slabs was stored at the same temperature, but in a fog room having 100% relative humidity. Specimens in the fog room were covered to protect them from dripping water.

Every attempt was made to ensure that the slabs were treated uniformly without introducing extraneous variables.

The slabs were periodically removed from storage and allowed to dry for one day before photographs were taken of the top (finished) and bottom (formed) faces. Photographs for various groupings of the samples were taken at ages of 1, 7, 28, and 90 days using the same photographic equipment and settings. Photographs of the wet-stored slabs at 1 day and 90 days are shown in Figures 2 and 3. The observations are summarized below.

Effects of Curing, Water-Cement Ratio, Cement Type, and Age

Curing. The samples kept in a wet environment were marginally darker than those kept in a dry environment, even after drying.

Water-Cement Ratio. While somewhat difficult to see in the photos, mortars made with a w/c of 0.5 were generally darker than those with a w/c of 0.8 (Figs. 2, 3, and 4). The left-hand portion of Fig. 4 provides quantifiable verification that the lower water-cement ratio mortars are darker. An interesting observation is that the relative difference between the (lightness of) 0.5- and 0.8-w/c samples is approximately the same for both cements shown.

Cement Type. The samples made with Type V cement were marginally darker than those made with Type I at an early age (Fig.2). After 90 days, there was little significant difference

between the Type I and Type V cement samples (Fig. 3). This cannot be extrapolated as a general trend because only two cements were studied. Trace elements can influence color significantly.

Age. The slabs kept in a moist environment became lighter with increasing age up to 28 days after which there was no observable change. Although less noticeable changes occurred in the slabs kept in a dry environment, these slabs also took 28 days to reach essentially constant color.

Color Analysis

Four samples that were wet cured were analyzed for color after a period of drying beyond 90 days. To prepare the samples, the finished (not molded) surface was scrubbed with water and a brush to remove normal minor efflorescence or other deposits that might interfere with the color reading. Although these light efflorescence deposits may not normally be seen, they are detected by the color instrument. In normal usage, this material would be worn away by traffic, rain, or other weathering.

The color measurement used here is based on three distinct values: a red-green reading, a blue-yellow reading, and lightness. The color units are denoted as CIE L*a*b*.

Five readings per sample were averaged to arrive at composite readings (one white dot per sample) (see Fig. 4). Measurements were also taken of the sand used in the mortars (green dot). The CIE L*a*b* plot shows the results relative to each other, using the four-sample composite average (Fig. 4). If all colors were the same the dots would fall on top of one another on the plot in Fig. 4.

The results demonstrate differences in both lightness and in color. On the left side of Fig. 4, the Type V cement mortar is darker than the Type I for the same water-cement ratios. The lower water-cement ratio mortars are darker by approximately the same amount for both types of cement. These results confirm visual observations.

The measured differences in color, however, were not apparent to the naked eye. On the right side of Fig. 4, the lower water-cement ratio mortars are slightly more yellow



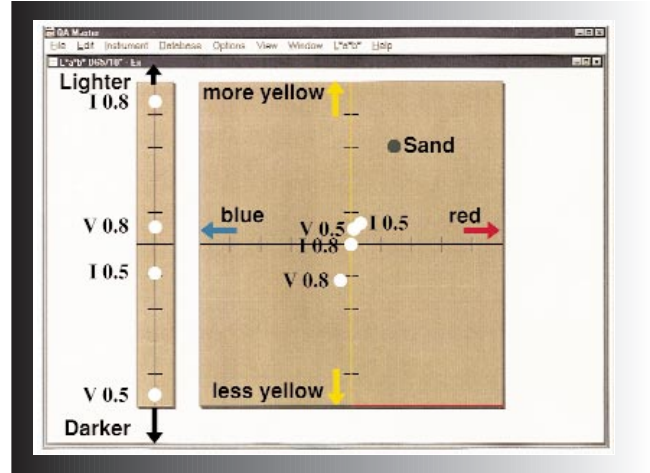
Fig. 2. All samples (L): 1 day old, wet storage, finished surface. Top left: w/c = 0.5, Type I cement. Bottom left: w/c = 0.8, Type I cement. Top right: w/c = 0.5, Type V cement. Bottom right: w/c = 0.8, Type V cement. (68348)

Fig. 3. All samples (R): 90 days old, wet storage, finished surface. Top left: w/c = 0.5, Type I cement. Bottom left: w/c = 0.8, Type I cement. Top right: w/c = 0.5, Type V cement. Bottom right: w/c = 0.8, Type V cement. (68349)



and red compared to their respective higher water-cement ratio mortars. Results of the sand used in the mortars also demonstrated more yellow and red coloration. Therefore, the difference in mortar color appears to be due to the detection of more sand in the lower water-cement ratio mortars; this may be due to the smaller amount of cement paste versus aggregate particles.

*Fig. 4. Samples analyzed using CIE L*a*b*. The composite readings are shown as white dots (one for each water to cement ratio and cement type) and the sand reading is denoted by a green dot. The sand color is more yellow and red than the mortars. (69126)*



General Observations

From the visual examination, trends described above were masked in many of the samples by the effects of handling and normal efflorescence. The color of the formed faces of the samples tended to be much more variable than the finished faces, particularly for the wet stored samples. Efflorescence was observed on the wet stored samples and had a large effect on the perceived colors prior to washing. The finished faces of the samples showed markings caused by contact with other samples or materials during demolding or storage (Figs. 2 and 3).

From the instrument measurements, two key pieces of information were noted. First, in the case of each cement type, the 0.8 water-cement ratio mortar was lighter in color (see Fig. 4). Second, the relative difference in lightness between the 0.5 and 0.8 water-cement ratio samples was similar for the Type I cement and for the Type V cement.

Conclusions

In general, increasingly light colors were observed with increasing water-cement ratio, increasing age, and drying. However, these parameters were generally of less significance than the effects of handling and protection, despite the care taken in the laboratory. The effects of efflorescence on perceived color may increase or decrease with time depending on exposure of the concrete surface. Extreme care during mold (or form) preparation and removal is necessary if consistent colors are to be achieved within a single batch of concrete. This conclusion also applies to batches placed on different days when greater variations are anticipated.

The measurements from the color instrument confirmed that good control of the water-cement ratio is important for maintaining uniform color.

As a secondary finding, and having much less relative influence, the testing also indicated that sand color becomes more prominent at lower water-cement ratios.

Color measurement instruments provide reproducible and quantifiable data compared to the subjective human determination of color. Instruments can also detect differ-

ences that cannot be detected visually on small sample areas. This confirms the need for larger mock-ups for critical architectural concrete applications. Also, quantitative color measurements are useful in documenting color, color difference, and color uniformity.

Obtaining Uniformly Colored Concrete Surfaces

- Use the same materials throughout the entire job, especially the same cement source and type
- Maintain consistent mix proportions, especially water-cement ratio
- Do a test placement (mock-up)
- Always use clean mixing equipment and clean tools
- Use the same finishing or forming techniques throughout the job
- Do not handle the concrete more than necessary
- Use the same curing methods and curing materials throughout the job
- Strip formwork at consistent ages

PCA R&D Serial No. 2198a

Related PCA Literature

Color and Texture in Architectural Concrete, SP021

Removing Stains and Cleaning Concrete Surfaces, IS214

"Pinto Concrete: Is There a Cure?," *Concrete Technology Today*, PL961



New VOC Regulations

Volatile organic compounds (VOCs) combine in the atmosphere with other chemicals to form ground-level ozone. The federal Clean Air Act Amendments of 1990 gives the EPA authority to control VOC emissions for products. Beginning September 11, 1999, there will be a reduction in the national allowable limits of VOC levels for consumer products. Manufacturers will no longer be able to produce products exceeding these VOC emissions for use in the U.S.

For the concrete industry, the following materials will be affected:

- form-release agents
- curing compounds
- dampproofing materials
- wall and floor coatings and primers

- membranes
- sealers
- water repellents.

The new national ruling does not always affect local regulations. The more stringent of the national or local law applies: if state or municipal levels are lower (notably California and Arizona), the local limits remain in effect.

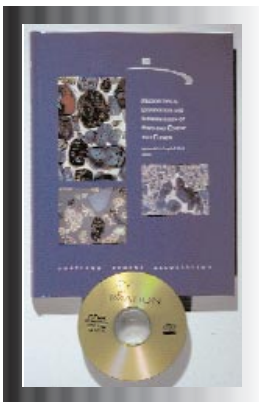
For the concrete industry, many familiar products will have new formulations to comply with the new law. Certain high-VOC products will no longer be made. Specification writers should pay attention to their choice of products to be sure they don't inadvertently choose materials that will be difficult or impossible to find after September 1999. Specifiers should consult product manufacturers or distributors on the availability of certain construction products and make sure that these comply with local regulations. Ultimately, the regulations place responsibility for meeting local limits with the contractor or applicator.



New Edition of *Microscopical Examination and Interpretation of Portland Cement and Clinker*, SP030

by Donald H. Campbell

State-of-the-art in cement and clinker microscopy



Microscopy can be used to study raw materials, clinker, cement, and concrete. By understanding the microstructures of cement and clinker, it is possible to improve quality and reduce production energy. The

second edition of PCA's Special Publication SP030 is a comprehensive reference that has been updated to include the latest advancements in the field. This book and microscopy have become an essential part of production control at cement plants.

The expanded publication is now a 224-page printed hardcover book with a companion CD-ROM. The electronic file (PDF format) is fully searchable providing quick access to key topics. Improving quality control, maximizing production, and optimizing clinker processing are just a few of the many uses readers will find for this book.

The new chapter on raw materials examines the effects of raw feed particle size, mineralogy, and homogeneity on resulting clinker characteristics. Drawing correlations between raw feed characteristics and clinker microscopy is increasingly important from the standpoint of energy consumption.

Many new photomicrographs showing the color, angularity and microscopic structure have been added. The electronic images (PDF and JPG) can be easily located and manipulated to facilitate analysis and interpretation. A Michel Levy™ color chart is removable for ease of use in analyzing clinker.

This comprehensive technical manual includes more than 350 observations and interpretations of cement, clinker and raw feed. It provides invaluable data as a standard reference or training manual for cement chemists and research and materials scientists. Cement microscopists and concrete petrographers will find this book to be a critical resource.



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