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"The Specific Gravity of Portland Cement."

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THE specific gravity of Portland cement has long been considered a test of its quality, and is specified as such in the recently-issued British Standard Specification. It is held to denote the degree of calcination to which the cement has been subjected in the course of manufacture, a high specific gravity indicating a thoroughly burned material, and *vice versa*; it is also considered to indicate adulteration with materials of different specific gravity.

It is well known that, owing to absorption of water and carbonic acid (having specific gravities of 1·0 and 0·88 respectively), the specific gravity of cement decreases with age, or after aeration, but the Author was surprised to find that, after ignition at red heat to expel the water and carbonic acid and to reduce the material to practically the same condition as regards these substances as when it left the kiln, the specific gravities of various cements were so nearly identical as to render the test of little or no value as an indication of quality. The results of preliminary experiments with thirty different cements, having specific gravities varying between 3·026 and 3·138 (*i.e.* a difference of 0·112), showed that after ignition the specific gravities differed by only 0·016, which is well within the range of experimental error in ordinary technical determinations.

In order to test the generally accepted theory that specific gravity is an indication of the degree of calcination, twenty-eight samples of black well-burned and yellow under-burned clinker from the same kiln or charge were obtained from various works, and the specific gravity of each sample was ascertained (1) in the condition in which it was received, and (2) after ignition at red heat. The results showed that all the yellow under-burned samples, when they had absorbed any appreciable amount of water and carbonic acid, had a much

[1] The complete Paper, with its accompanying Tables and Appendix, may be seen in the Library of the Institution.

lower specific gravity than the well-burned samples, but that after ignition at red heat the specific gravities of the well-burned and under-burned materials were practically identical, indicating that the difference was merely due to absorption of water and carbonic acid. A notable fact in connection with this series of experiments was that, out of thirteen samples of yellow under-burned material fresh from the kiln, no less than eight would have fulfilled the requirements of most ordinary specifications for well-burned cements, as regards specific gravity. The subject was therefore investigated further, and instead of merely ascertaining the total loss on ignition before determining the specific gravity, the percentage of water and carbonic acid was estimated separately. This was done with forty-one different cements, which were not in any way specially chosen for the purpose, but were ordinary samples passing through the Author's hands in the usual course of his practice. The samples were afterwards classified for more convenient reference, and comprised English, Belgian, and German artificial Portland cement; Belgian natural cement; cement produced by the lately-introduced rotatory kilns; and also cement adulterated with various adulterants. In all these experiments the result was practically the same. Samples which in their commercial condition differed widely in specific gravity, were found to have practically the same specific gravity when "loss free," *i.e.* after ignition at red heat, and consequent expulsion of the water and carbonic acid absorbed since calcination. This similarity suggested that, having ascertained the percentage of water and carbonic acid contained in the ignited sample, and the specific gravity of the "loss free" material, it should be possible to deduce the specific gravity of the unignited sample; or, in other words, given the specific gravity of the material in the condition in which it left the kiln, its specific gravity after it has absorbed given amounts of water and carbonic acid should be determinable by means of a formula. This formula was found to be :—

$$\frac{1}{\text{unignited specific gravity}} = (0{\cdot}0080 \times \text{percentage of } H_2O) + (0{\cdot}0055 \times \text{percentage of } CO_2) + \frac{100 - (\text{percentage of } H_2O + \text{percentage of } CO_2)}{100\,(\text{ignited specific gravity} - 0{\cdot}048)}$$

In several of the Tables accompanying the Paper a column is added giving the specific gravity calculated from this formula, which is found to agree very closely with the actually determined specific gravity, thus proving the Author's contention that the specific gravity

of cement depends entirely upon absorption of water and carbonic acid.

The main body of the experiments having been made with ordinary commercial samples containing comparatively little water and carbonic acid, additional experiments were made with two cements of first-class quality, which had been exposed to the atmosphere for 80 days, during which period they had been periodically examined, and had finally absorbed water and carbonic acid to the extent of about 10 per cent. altogether. The result was the complete corroboration of previous experiments, showing as before that the specific gravity depended entirely upon the water and carbonic acid absorbed, which could be exactly allowed for by calculation. Based on these experiments, calculations have been made of the decrease in specific gravity for each 1 per cent. of water or carbonic acid absorbed; the results are shown in the following Table :—

CALCULATED SPECIFIC GRAVITY OF PORTLAND CEMENT.

(Assuming ordinary cement free from gypsum), if aerated with (1) water only, and (2) carbonic acid only.

	Specific Gravity after ignition	0 Per Cent.	1 Per Cent.	2 Per Cent.	3 Per Cent.	4 Per Cent.	5 Per Cent.	6 Per Cent.	7 Per Cent.	8 Per Cent.	9 Per Cent.
(1) Water only. .	3,248	3·200	3·151	3·103	3·057	3·012	2·969	2·927	2·885	2·894	2·804
(2) Carbonic acid only	,,	3·200	3·167	3·152	3·129	3·106	3·083	3·061	3·039	3·017	2·996

These experiments having been conducted in a somewhat more careful manner than those first described (*i.e.* rather as a matter of scientific research than of ordinary technical determination), it was thought advisable to verify the results obtained in the first instance with well-burned and under-burned clinker, and further samples, twenty-three in number, were therefore obtained, representing practically the entire English cement industry. The results fully corroborated the previous experiments in every respect, and fully demonstrated the fact that the degree of calcination in no way affects the specific gravity when the clinker is fresh from the kiln.

Having regard to the difference in apparent density and weight, between the black well-burned and the yellow under-burned clinker, the porosity of small pieces of each degree of calcination was determined, and showed that the porosity of the yellow under-burned clinker was 66·65 per cent.; of the intermediate clinker 57·2 per cent.; and of the well-burned clinker 22·6 per cent.; in

other words, 9 parts by volume of yellow under-burned clinker become on further calcination 7 parts of intermediate and 4 parts of well-burned clinker.

For purposes of reference the chemical analyses of all the samples of cement used in the experiments are given in an Appendix to the Paper.

Briefly summarized the conclusions which may be drawn from the experiments are :—

(1) That the specific gravity of Portland cement is no indication whatever of proper calcination.

(2) That the specific gravity of Portland cement depends upon its age, and the opportunities which it has been afforded of absorbing water and carbonic acid from the atmosphere.

(3) That the specific gravity of Portland cement, although of no use in determining calcination, may sometimes be of corroborative value in determining slag and other adulteration.

(4) That, given the specific gravity of the ignited sample, and the percentage of water and carbonic acid expelled by ignition, the specific gravity of the unignited material may be calculated with a fair degree of accuracy.