Surface area standard Ottawa sand = 400 sq. ins. (approx.) per 100 grams.

Assume batch of 500 grams cement and 1,500 grams standard Ottawa sand.

By "surface area" water formula,

Water = (0.24×500)+6,000/210 = 148.6 cc., or 7.42%.

The United States government specification for Portland cement specifies 10.5% mixing water for a 1:3 mortar made with such a cement.

Water = 10.5 × 2,000 = 210 cc.

Those familiar with routine testing of cement are aware that such a mortar with 10.5% water is by no means a flowing, plastic mix, yet the proposed surface area formula furnishes 61.4 grams, or 3.08%, less mixing water. Since natural sands often require several per cent. more mixing water than standard sand for the same consistency, no further comment should be required.

Variation in Areas Disregarded

It is stated that the factor, total area divided by 210, takes into account the varying water requirements due to differences in surface areas of the aggregates. It was shown in the preceding discussion, however, that *w/c* equals a constant, so that water is actually based only upon the cement content of the mix, while the large variations in surface areas, which the author admits require varying quantities, are disregarded. It is an admitted fact that the granular composition or grading of an aggregate is reflected by the amount of water required to produce concretes of the same flowabilities, but this formula is equivalent to one which bases the water requirement on cement content only, as is shown by the following:—

Assume sands A and B having surface areas of 300 and 600 sq. ins. per 100 grams, respectively; a cement requiring 25% mixing water for normal consistency; and proportions of 1 gram of cement for each 10 sq. ins. of surface area.

Sand A.	
Quantity of cement	300/10 = 30 g.
Water	30 × .25 × 300/210 = 8.93 cc.
W/C	8.93/(.67 × 30) = .443
Per cent. water by weight of cement	8.93/30 = 29.7%

Sand B.	
Quantity of cement	600/10 = 60 g.
Water	60 × .25 × 60/210 = 17.86 cc.
W/C	17.86 (.67 × 60) = .443
Per cent. water by weight of cement	17.86/60 = 29.7%

Disregarding the sands for a moment, since the percentage of mixing water based upon the weight of cement, is constant, equal consistencies will be obtained for the cements alone if all the water provided is used.

Why Differences Resulted

If, however, the two sands are then added to their respective quantities of neat pastes, the mix containing Sand A will be much stiffer and less workable than that containing Sand B. It is, of course, also assumed that these two sands are of the same type as would result from screening and recombining any first-class sand. The effect on consistencies is the same as would result from the addition of an aggregate, such as standard sand, to the first paste and a siliceous beach sand to the second. Less calculation would be required if the water formula were stated in terms of the weight of neat cement only.

As stated above, the tests of the Abrams aggregates included in Table 2, Lewis Institute Bulletin No. 1, resulted in concretes varying widely in consistency, although the author stated that equal consistencies were obtained. A study of the proposed "fineness modulus" water formula makes clear why such differences in consistency should result without the employment of the actual tests, which later fully verified the opinion first formed from such a study.

The expression for the quantity of mixing water is as follows:—

$$x = w/c = R[3/2p+(30/1.26^{m}+(a-c)n].$$

It is stated that with *m*, fineness modulus, constant, and *n*, proportion of cement to aggregate, constant, the same consistency will result and the same strength will be obtained, whatever the grading of the aggregate within rather wide limits.

As shown in Table 2, Bulletin No. 1, with *m* constant, there may be wide differences in total surface areas of aggregates. For the aggregates shown, the variation in surface areas is approximately 600%. Concreting practice has established the fact that for the same consistency a fine sand requires more mixing water than a coarse sand; that a sand similar to a beach sand requires more than a coarse, well-graded river sand. Inspection of the granular analyses of sands used for concrete work throughout the country may vary over several hundred per cent. in surface areas. In spite of this well-understood condition, that a "fine" aggregate having a relatively high surface area will require more water than a "coarse" aggregate, it is claimed that the above water formula will result in the same consistency for any group of aggregates having the above-stated conditions constant.

"Undermines Whole Theory"

Although not expressed in so many words, the Abrams water formula is equivalent to the statement that whatever the gradation, aggregates having the same fineness modulus, although varying as much as 600% in surface area, require the same quantity of mixing water for the same consistency.

The addition of any factor to this formula to properly take into account this varying surface area of an aggregate (a condition which Mr. Edwards also admits must be considered, but fails to provide for), will result in different values for *w/c* for different gradations, thereby destroying the constant *w/c* relation which is claimed to be the criterion for equal strengths, and thereby undermining the whole theory of the "design of mixtures."

Summarizing the foregoing briefly, a study of the test data offered by the proponents of the two theories, checked by tests of similar combinations of aggregates, would seem to establish the following:—

Objections to Surface Area Theory

1. The water formula proposed in the surface area theory reduces to a constant water-cement ratio for any fixed relation of cement to surface area of aggregate.

2. The important property of surface area does not enter into the determination of the quantity of mixing water, except in so far as it fixes the quantity of cement at the beginning.

3. The formula is not only incorrect in theory, but is inadequate in practice, and results in mortars and concretes varying widely in consistency, which are, therefore, in no sense comparable on the basis of strength.

4. Tests indicate that compressive strengths increase as the ratio of cement to surface area decreases, although such increase is by no means proportional to the decrease of the ratio.

Objections to Fineness Modulus Theory

1. The foundation of this theory is a water formula which gives no consideration to the varying water requirements of aggregates varying in surface areas.

2. It is shown that, with a given fineness modulus, the total surface areas of aggregates of different gradings may vary as much as 600%.

3. In spite of this wide difference in surface areas, it is claimed that resulting concretes of the same mix will have the same consistency.

4. Tests have shown that the consistencies actually obtained varied more than 25% with the above constant conditions, and such differences were measurable by all known consistency methods as well as apparent to the eye.

5. The strengths obtained in tests of such concretes are not comparable, since the condition of equal consistency ad-