mitted as necessary and fundamental by the proponent of the theory, cannot result.

6. The addition of any factor to the water formula to properly take into account these varying water requirements, destroys the constant water-cement relation which is the criterion for equal strengths.

7. The strength results given in Table 2, Lewis Institute Bulletin No. 1, would seem to discredit the surface theory as advocated by Mr. Edwards. However, these tests are not competent to either deny or affirm that theory, since equal consistencies were not obtained. The strengths of the concretes would be considerably modified by the addition of sufficient water to result in equal consistencies.

Comments on Mr. Young's Paper

The following comments refer more specifically to Mr. Young's discussion of the two theories.

Mr. Young states that "the Bureau's ..... tests indicate that for constant flowability the water required varies with the surface area of the aggregate." Our tests show that aggregates of high surface areas require more water than those having smaller areas, but the increase in water is by no means proportional to the increase in area. This is the very factor which neither of the foregoing formulas takes account of.

As to the results which Mr. Young states Prof. Talbot has obtained, they appear to be quite in accord with our own experience so far as the water requirement is concerned. There are also indications that strengths increase slightly, in some cases at least, with increase in surface of aggregate, when cement is proportioned in the usual volume method, but some rather consistent exceptions make it unwise to draw any definite conclusions until additional work is completed.

However, such a conclusion that strength does increase with surface area, is in this case directly opposed to the surface area theory. These concretes were proportioned in the customary way, one volume of cement to so many volumes of aggregates, so that the ratio of cement to surface area decreases as the surface areas increase, contrary to the theory proposed by Mr. Edwards.

With reference to the results of the investigations of the Hydro-Electric Power Commission of Ontario, the conclusion that "fineness modulus is but another and somewhat approximate method, etc., ...," is not substantiated by a study of aggregates in common use in various sections of the United States. The wide variations which may result is well shown in Table 2, of Lewis Institute Bulletin No. 1.

As to conclusion 2, if the cement is proportioned with relation to surface area, the Edwards water formula will result in wide differences in consistency, as shown above, while if the cement is proportioned in the customary manner, an increase in strength with increase in area of aggregate is directly opposed to the surface area theory.

Conclusion 3 is true beyond doubt, since with the same cement, the same aggregate, and the same age for test, water is the only ingredient to be varied, and the variation in strength with change in water content under such conditions is too well recognized to require proof.

"Will Result in Soupy Consistencies"

Strict adherence to the surface area theory, if sufficient water is supplied to make workable the mixtures having a low surface area, will result in very soupy consistencies for the richer mixtures having the greater surface areas, so that much of the gain in strength which should result, will be thrown away.

It is very apparent that "there is no mathematical relation between surface area and fineness modulus," since it has been shown that with a given fineness modulus the surface area may vary more than 600%, while aggregates with any given surface area may have moduli differing considerably. Fig. 1 in Mr. Young's article shows this fact, and were he to plot on this diagram aggregates in use in other localities, he would find the points scattered over a wide zone, rather than along a single line. With the wide differences in surface areas which may be had with a given fineness modulus, it is difficult to understand how the expression of this term may be considered as another way of expressing the surface area.

Fig. 5 in Mr. Young's article furnishes a clear demonstration of the fallacy of averaging tests of concretes, especially when such concretes are not comparable, owing to wide differences in consistency. It is clear from a study of this diagram, which has been widely used as a proof of the accuracy of the "fineness modulus" theory of proportioning, that no consideration has been given to the consistencies of the concretes represented by the plotted points.

This diagram has little value beyond showing graphically that the function of increase in mixing water, whatever may be the mix or combination of the aggregates, is to lower compressive strengths. With the same mix, cement and grading of the aggregate, a line may properly be used to indicate the reduction in compressive strength with increase in water content, and the general trend of such a curve will be somewhat like the one shown in the figure.

But, even assuming that strict consideration has been given to the necessity for equal consistencies for all concretes included, the variations in compressive strength between mixtures having the same *w/c* relation, is seen to be as high as 50%. The inclusion of more tests will tend to increase this difference. The strength trend as influenced by the amount of mixing water can best be represented by a broad band or zone rather than by a line.

"Conclusions From Few Tests"

In Mr. Young's Fig. 7 he shows six plotted points which he states were taken from Technical Paper 58 of the Bureau of Standards, and which he believes indicates the concordance of the results of that report with the conclusions of the two theories. A full study of the tests reported in that paper will in no way confirm his conclusions, but, on the other hand, that report furnishes data which controvert the claims of both theories, and show the fallacy of drawing conclusions from a few tests, as has been done in the case of Fig. 7.

In Fig. 1, accompanying, are shown the relation of the water-cement ratios to compressive strengths of the large group of sands included in Table 5, Technical Paper 58. The results are comparable, since the same consistencies were used for all mixtures.

In Fig. 2, accompanying, are shown the concrete strength results given in Tables 8, 9, 10, 11 and 12, plotted in the same manner. The aggregates used in these tests were mainly limestone and gravel, with a few samples of granite and trap rock. The extremely wide variations in strength for any given value of *w/c* are probably due to the different types of aggregates, but the values for either gravel or limestone alone can only be represented by a broad zone rather than by a line.

The results given in the above-mentioned tables of Technical Paper 58 furnish further evidence to discredit the surface method of proportioning, as the relations can be seen at a glance without the computation which was required for a study of the *w/c* relation. Two sands, differing little in surface areas, were generally used, with a large number of coarse aggregates, and since the area of a coarse aggregate is usually less than 10% than that of a sand, the total areas of the mixtures do not greatly differ. Therefore, for any given proportion we should expect to obtain equal strengths, but such a relation is not found.

Actual Tests Required

Rather than furnish proof of the accuracy of these two theories, the results included in Technical Paper 58 still appear to justify the conclusions in that paper that "no standard of compressive strength can be assumed or guaranteed for concrete of any particular proportions made with any aggregate unless all the factors entering into its fabrication are controlled"; and "the relative compressive strength of concrete to be obtained from any given materials can be determined only by actual tests of those materials combined in a concrete."