is dependent on the surface area, is the same conclusion arrived at by Mr. Edwards in his study of mortars. The writer's studies of both theoretical and experimental data corroborate this conclusion. The engineers of the Bureau of Standards confirm this partially when they state that their tests indicate that for constant flowability the water required varies with the surface area of the aggregate. Prof. Abrams uses his fineness modulus to proportion mixtures to a given consistency, and to do this uses a formula in which the water required is the sum of a quantity dependent on the amount of cement used and a quantity varying with the fineness modulus. Assuming fineness modulus to be another way of stating surface area, or vice versa, it is evident that the work of each of these investigators point to the same end.

Unnecessary to Make Assumption

It is, however, unnecessary to make the foregoing assumption to show that Prof. Abrams' results bear proof of this relation between mixing water and surface area at a given consistency. Fig. 4, which was worked up from the data in his paper* on "Effect of Fineness of Cement," shows five series of mixtures in which cements of different fineness were used, each proportioned 1: 4 by volume with six different aggregates of a wide range in grading. The mixtures were all gauged to a uniform consistency, the water to do this being determined by means of Prof. Abrams' water formula. It is a striking confirmation of the law outlined in the last paragraph, that in the case of each of the different cements, when the amount of mixing water used is platted against the surface area of the aggregate in the mixtures, five of the six points lie on a straight line. The sixth point represents a mixture in which the material was a very fine sand, 10% of which was dust or silt. Under these conditions it is hardly to be expected that this point would agree with the other and more usual materials, because our means of determining equal mobilities are not such as to function accurately under these conditions.

The results of Fig. 4 cannot be explained by the fact that the surface area and fineness modulus have approximately a linear relation, for in the series represented (see Fig. 3, Series 120), this relation is a slight curve.

Water-Cement Ratio and Strength

Fig. 5, taken from the article by Prof. Abrams which was published in *The Canadian Engineer* for June 6th, 1918, shows the general relation found by Prof. Abrams between compressive strength and water-cement ratio. This curve covers an extremely wide range of mixtures, materials and consistencies. Fig. 6 is platted from the results of Mr. Edwards' mortar tests and show a similar relationship for the range covered by his tests. In these tests the proportions were constant, but the consistency varied. Fig. 7 is platted from data published by the Bureau of Standards from tests in which the consistency was nearly uniform, but in which the proportions varied. Fig. 8 is a similar series, carried out by the writer in the laboratories of the Hydro-Electric Power Commission of Ontario. Similar curves have been obtained in the same laboratory where the proportions were constant and the consistency varied. In all of these curves the mixtures used were plastic. The relationships are practically identical in each of these figures, showing very good agreement on this point.

Prof. Abrams has shown that for given materials and age, approximately equal strength will be obtained even with widely different grading of aggregate and consistency, provided that the mixtures are plastic and that the grading is not too coarse for the quantity of cement used.

Mr. Edwards in his early tests on surface area proved the same things, for he varied both the cement and water according to the surface area and obtained a constant water-cement ratio, and his mortar mixtures were of nearly equal strengths.

It is hard to reconcile the Bureau of Standards' claim that "a wide difference in strength is found with constant water-cement ratio even with the same aggregate and cement," unless it is that these tests were designed to give unusual conditions.

Prof. Abrams, in commenting on the Bureau's tests, has said of the aggregate used: " Over 40% of the aggregates were too coarse for the quantity of cement used; 26% of the mixes were too dry; 21% were both too coarse and too dry; 72% of the aggregates were of freakish grading." The writer agrees with Prof. Abrams' criticism, and considers this to be the explanation of the unusual results obtained.

It is interesting to note that Fig. 7, drawn from data obtained by the Bureau of Standards before the controversy arose, while not bearing upon the disputed question of equal water-cement ratios having equal strengths, shows that a consistent relationship is being obtained in this laboratory for commercial aggregates and plastic consistencies.

Surface Area and Strength

If, for workable mixtures of similar materials, a given strength concides with a fixed water-cement ratio, then it is evident that if the quantity of water required to bring a concrete mixture to a uniform degree of plasticity is a function of the surface area of the aggregate, the quantity of cement required to maintain this fixed water-cement ratio is likewise a function of surface area.

Conversely, if a fixed plasticity is maintained, and the cement content of the mixtures are constant, then the compressive strength varies with the surface area of the aggregate. Both of these points have been brought out nicely in the tests by Mr. Edwards.

Compressive Strength and Cement Content

In the writer's article published in the June 26th, 19 issue of *The Canadian Engineer*, the form of the theoretical relation between compressive strength and the cement content of a mixture was derived. The cement content was given in terms, of "pounds of cement per 100 sq. ft. of surface area," a unit which has been adopted by the Hydro-Electric Power Commission in all of its work. Figs. 9 to 12 show curves of the same form obtained from the experimental data of the investigators referred to, with the exception of Prof. Talbot. In the case of the tests of Figs. 9 and 12, the original results were obtained by other than the surface area method of proportioning. These curves are strikingly similar and are further evidence of the agreement between the data of the different investigators.

It is not within the scope of this article to discuss the relative merits of either the fineness modulus or the surface area methods of proportioning. Enough has been brought out, the writer believes, to show that they are simply different adaptions of essentially the same data.

Shortcoming of "Fineness Modulus"

The fineness modulus method of evaluating an aggregate has one serious shortcoming not present in the surface area method: It is dependent upon the number and sizes of the sieves used in its determination.

The surface area method is not so dependent; the same result can be obtained with any one of the commercial series of sieves in common use, because the surface area of an aggregate is a property of the material and not of both the material and the size and number of the sieves used in the sieve analysis.

A modification of Mr. Edwards' surface area method is being successfully applied by the Hydro-Electric Power Commission in the construction of several of its power developments. It is working satisfactorily and is giving better concrete with less cement than is being obtained on work where it is not in use. It is simple, and has been found easy to introduce into the field. It is not a panacea for all the ills of concrete, and its successful use requires careful inspection, intelligent supervision and a certain amount of laboratory assistance, but these are necessary with any method if good concrete is to be produced. It can be made to do all that is claimed for the "fineness modulus method," and it has certainly been found simpler to "put over" in actual field work.

*Presented June, 1919, before the American Society for Testing Materials; see *The Canadian Engineer*, November 6th, 1919, issue for summary of this paper.