STUDIES ON PHYSICAL PROPERTIES OF HOMOGENEOUS SAND MIXES

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ABSTRACT

Effects of water-clay ratio, particle size and bentonite content on the physical properties of homogeneous sand mixes have been investigated. Results of the investigation indicate that: (i) Water-clay ratio is an important parameter affecting the physical properties of homogeneous sand mixes. (ii) For a given particle size and bentonite content, (a) green compression strength, green shear strength and green hardness attain a maximum around a water-clay ratio of 0·4, *(b) permeability attains a maximum value, bulk density a minimum around a water-clay ratio of* 0·6. *(iii) Riddled density, AFS flowability, + GF + flowability decrease rapidly whereas the compactability increases rapidly with the increase in water-clay ratio upto* 0·6 *and then tend to attain a steady value on increasing the water-clay ratio further. (iv) For a given water-clay ratio and bentonite content the properties vary with the increase in particle size upto a value around* 400 *microns and then become insensitive to particle size. (v) For a given water-clay ratio and particle size the physical properties vary with increase in bentonite content upto a value around 7% and then remain constant with further increase in bentonite content. Attempts made to inter-relate the physical properties indicate that: (i) A linear relationship exists between green compression and green shear strength, and (ii) compactability, GF flowability and Riddle density are linearly inter-related.*

Keywords: Water/Clay Ratio; Bentonite; Swelling Index; Compactability; Flowability.

INTRODUCTION

There have been several investigations [1–3] in recent years to determine the important factors influencing the physical properties of green moulding sand. Moulding sands in general contain more than three fractions of particles and the physical properties of these sands are influenced to a large extent by the grain size, grain distribution, type and amount of bond used and the moisture content. In order to understand the factors affecting the properties and behaviour of moulding sand during mould preparation, it is essential to study the properties of homogeneous, binary, ternary, etc., system of sands.

Earlier investigators [4–6] have reported that the physical properties of clay bonded sand are affected not only by granular material but also by the water/clay ratio and the percentage of clay in the sand mix. Attempts have also been made by them to explain many of the findings of sand-clay-water relationships using water/clay ratio concept. No literature is available on the effect of water/clay ratio and bentonite percentage on the physical properties of homogeneous sand mixes. Experiments were, therefore, carried out to study the effect of water/clay ratio ranging from 0·2 to 1·0 on the physical properties of homogeneous sand mixes containing different particle size silica grains and various percentage of bentonite (3% to 11%). Attempts were also made to interrelate the various physical properties of bentonite bonded homogeneous mixes.

EXPERIMENTAL DETAILS

Materials used.—In Table I are listed the details of the homogeneous sand grains and the clay used in the present investigation.

TABLE I

(a) Details of homogeneous sand grains used

Sand sample No.	B.S. sieve No.	Average size of* grain in micron	Remarks
A	− 16+ 22	851	Single sieve sand samples were sieved from silica sand obtained from Tufron stream bed located about 40 km from Hyderabad (A.P.)
B	− 22+ 30	599·5	
C	− 30+ 44	426·5	
D	− 44+ 60	302	
E	− 60+100	201·5	
F	−100+150	128	
G	−150+200	90	

* The average size of the grain was calculated on the basis of the average sizes of the holes of the two sieves, through one of which the sand passed and retained by another.

(b) Clay used

Bentonite of pH value 8, liquid limit 574, Swelling index 143·0% Base exchange capacity 86 milliequivalents/100 g and moisture 10·2% was used in this investigation.

Mixing.—Homogeneous sand mixes were prepared using a sand muller of 5 kg capacity. The following procedure was adopted for preparing the sand mixes in the sand mixes.

1. Add the required amount of water to silica sand and mix for 3 minutes.
2. Add the required amount of bentonite to mix No. 1 and mix for 5 minutes.

Sand mixes thus prepared were stored in polythene bags to prevent moisture loss, and were subsequently used to determine the following physical properties:

1. Green compression strength,
2. Green shear strength,
3. Green permeability,
4. Green hardness,
5. Bulk density,
6. Riddled density,
7. AFS Flowability,
8. +GF +Flowability and
9. Compactability.

Green compression and shear strengths, green permeability and green hardness were determined using the Ridsdale universal sand strength testing machine, premeability meter, and hardness tester respectively. Bulk density of sand mix was calculated from the knowledge of the weight and volume of AFS standard sand specimen.

Riddled density was calculated from a knowledge of the weight and volume of sand riddled through a 3 mm sieve into a standard AFS specimen tube.

Compactability of sand mix was determined as follows: the sand was riddled through a 3 mm sieve into a AFS specimen tube upto the brim and was given 3 rams. The decrease in height of the sand column was measured. The compactability value was calculated using the expression:

$$C = \frac{\text{Initial height of sand column} - \text{final compacted sand height}}{\text{Initial height of sand column}}.$$

In Fig. 1 is shown the principle of measuring compactability.

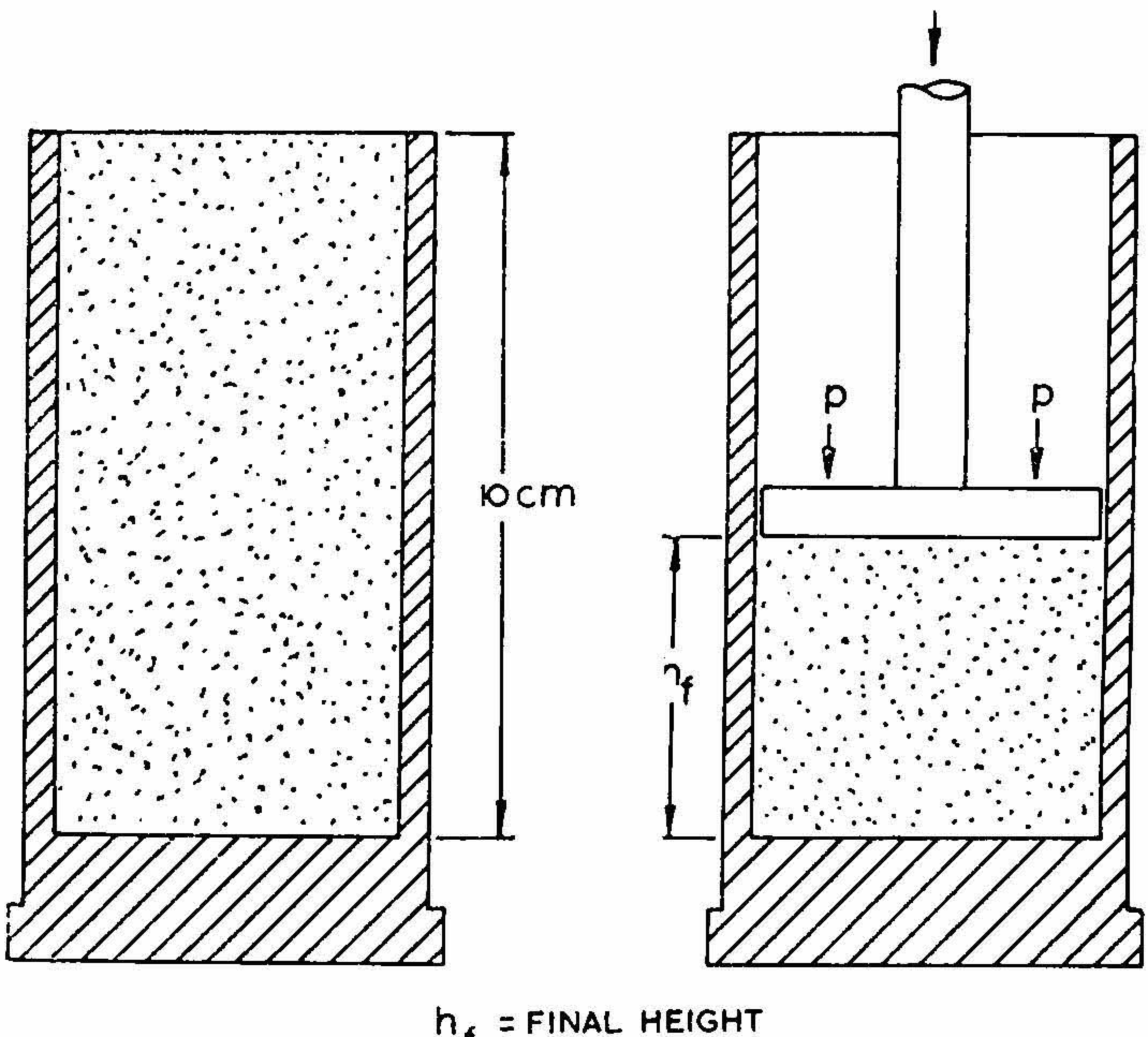

FIG. 1. Principle of measuring compactability.

AFS flowability was determined by measuring the decrease in height of the standard specimen due to the 5th blow of the AFS standard rammer.

To determine the +GF +flowability of sand mix the +GF + flowability tube was filled up with the amount of sand that would make a standard AFS sand specimen and subsequently was given 3 rams. The height of the sand specimen at the end of 3 rams was measured (h_x). The flowability was evaluated using the expression

$$\text{Flowability } \% = \frac{h_0 - h_x}{h_0 - h_{100}} \times 100$$

where

h_0 = height of sand specimen at 0% flowability

h_x = height of sand specimen at x% flowability

h_{100} = height of sand specimen at 100% flowability.

In Fig. 2 is given the principle of measurement of + GF + flowability.

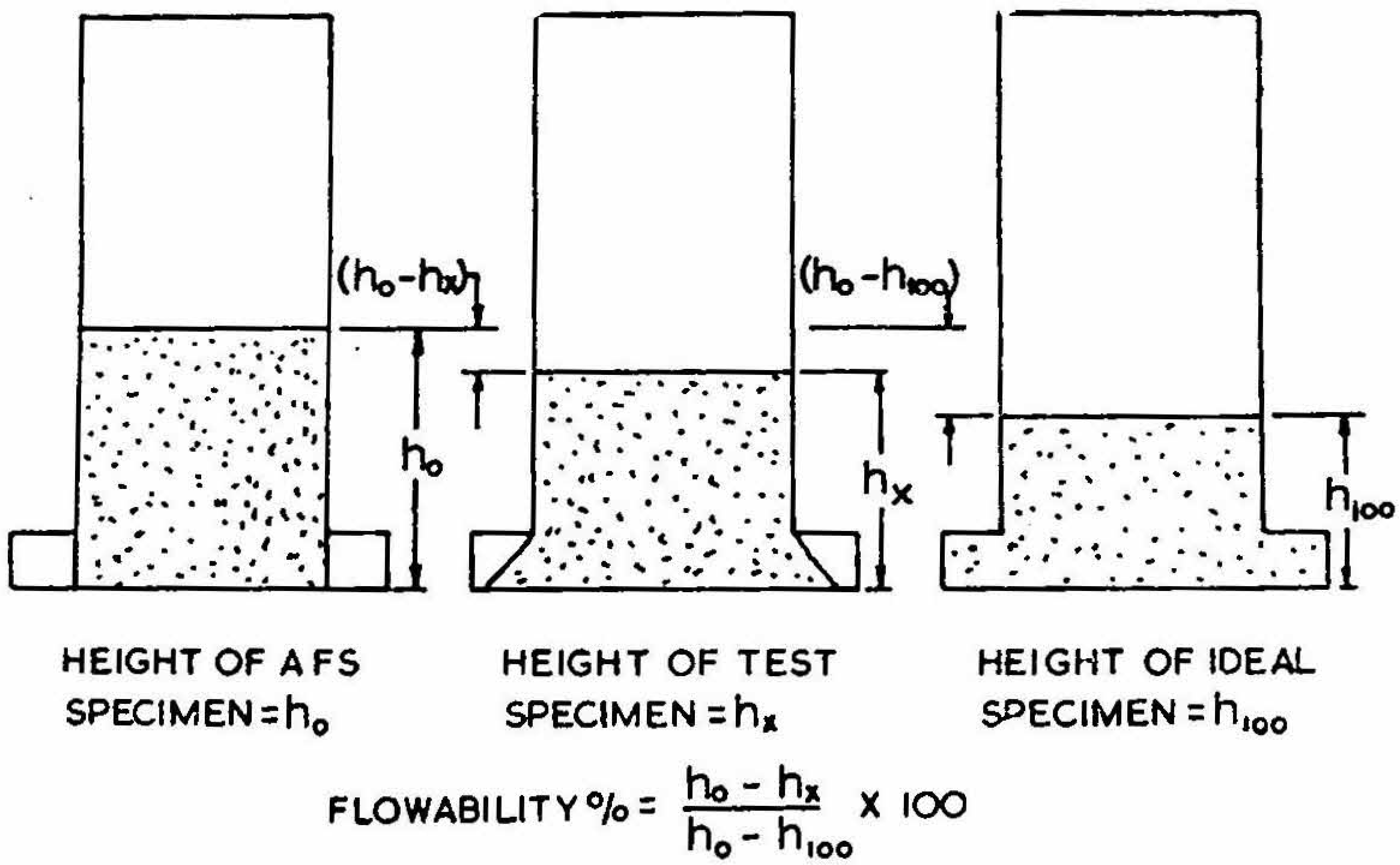

FIG. 2. **Principle of measuring + GF + flowability.**

TEST RESULTS AND DISCUSSION

In Figs. 3 to 16 are shown the test results in a graphical form. These plots were analysed to determine the effect of water/clay ratio particle size and bond content.

Effect of water/clay ratio.—Figures 3 through 6 show the variation of different physical properties of homogeneous sand mixes of particle size

426·5 μ and 201·5 μ with water/clay ratio at various bentonite percentages. From these figures one can observe that for a particular bentonite percentage—

(1) the green compression strength, green shear strength and green hardness increase to a maximum as the water/clay ratio increases

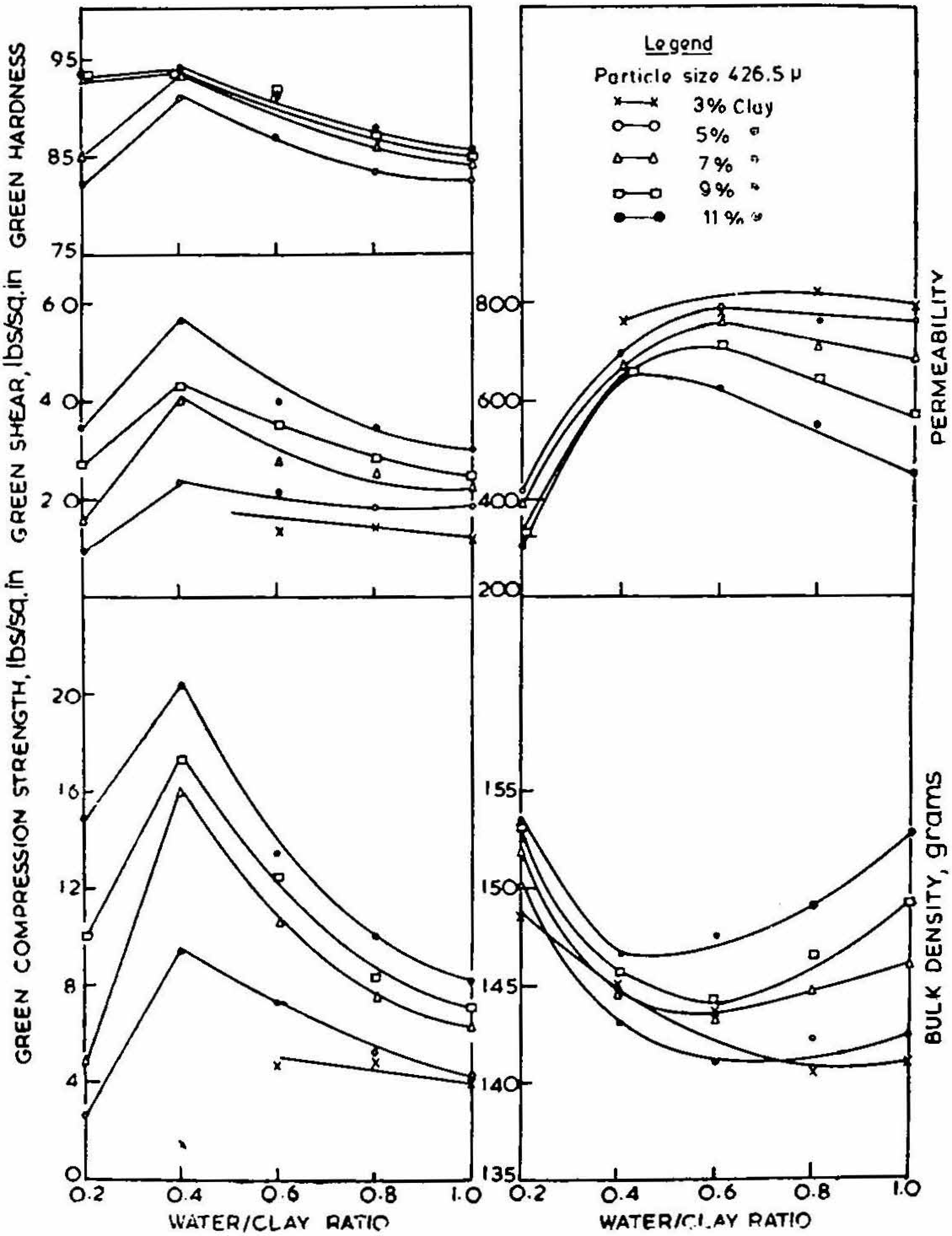

FIG. 3. Effect of water/clay ratio on green compression strength, green shear strength, green hardness, bulk density and permeability of bentonite bonded homogeneous sand grains of particle size 426·5 μ.

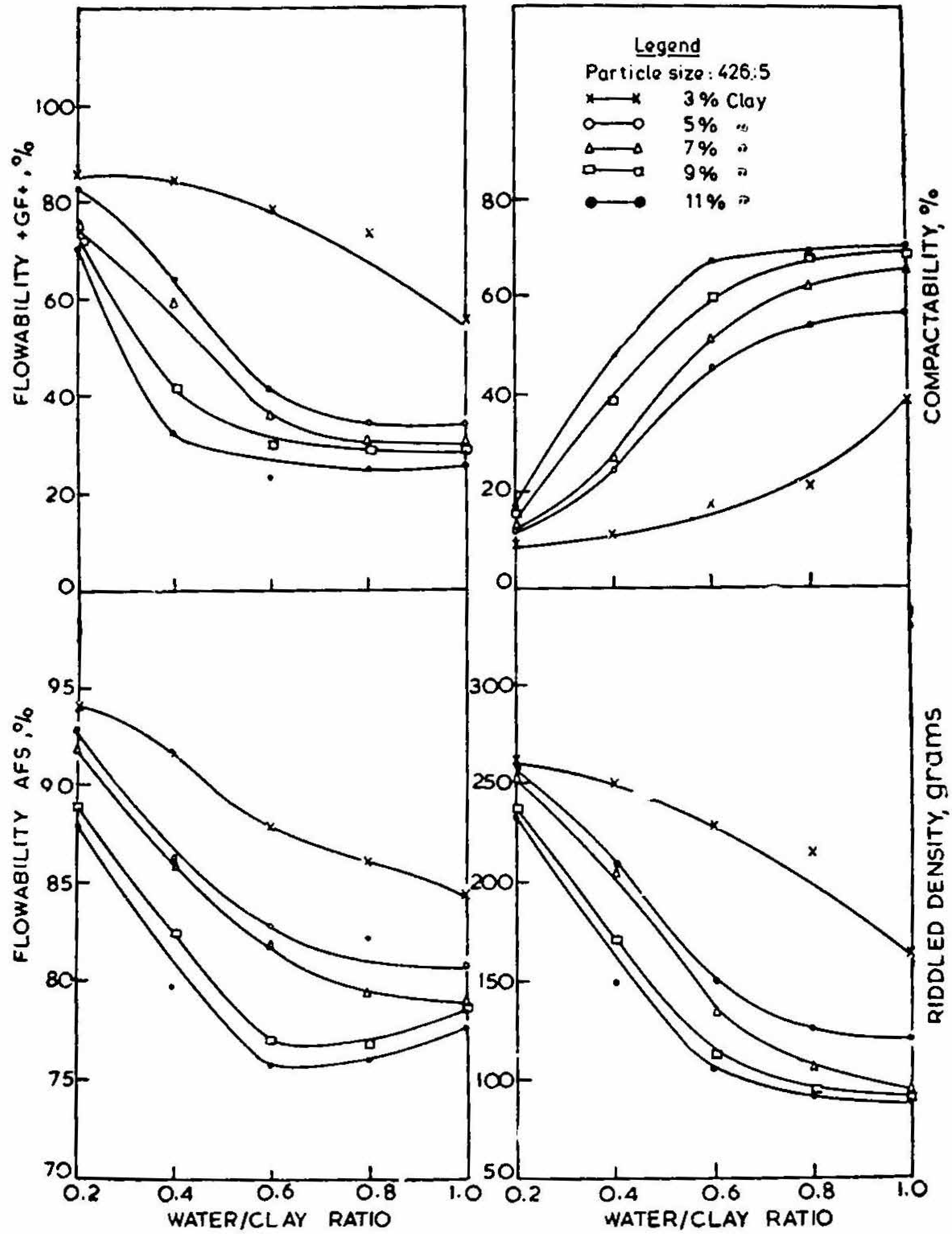

FIG. 4. Effect of water/clay ratio on AFS flowability, + GF + flowability, riddled density and compactability of bentonite bonded homogeneous sand grains of particle size 426·5 μ.

and then decreases with further increase in water/clay ratio; the points of maximum green compression, green shear and green hardness occur around a water/clay ratio of 0·4 at all bentonite percentages studied.

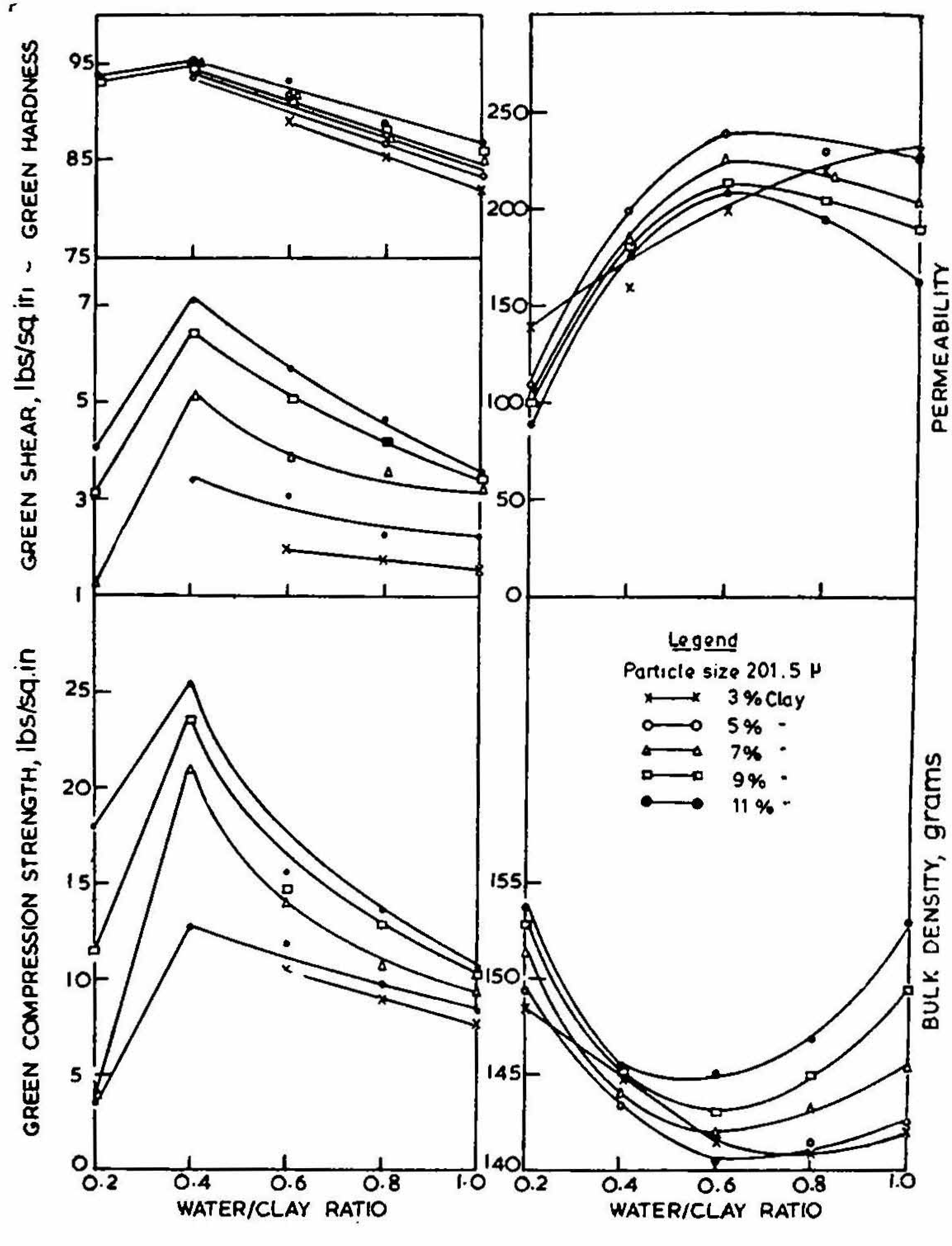

FIG. 5. Effect of water/clay ratio on green compression strength, green shear strength, green hardness, bulk density and permeability of bentonite bonded homogeneous sand grains of particle size 201·5 μ.

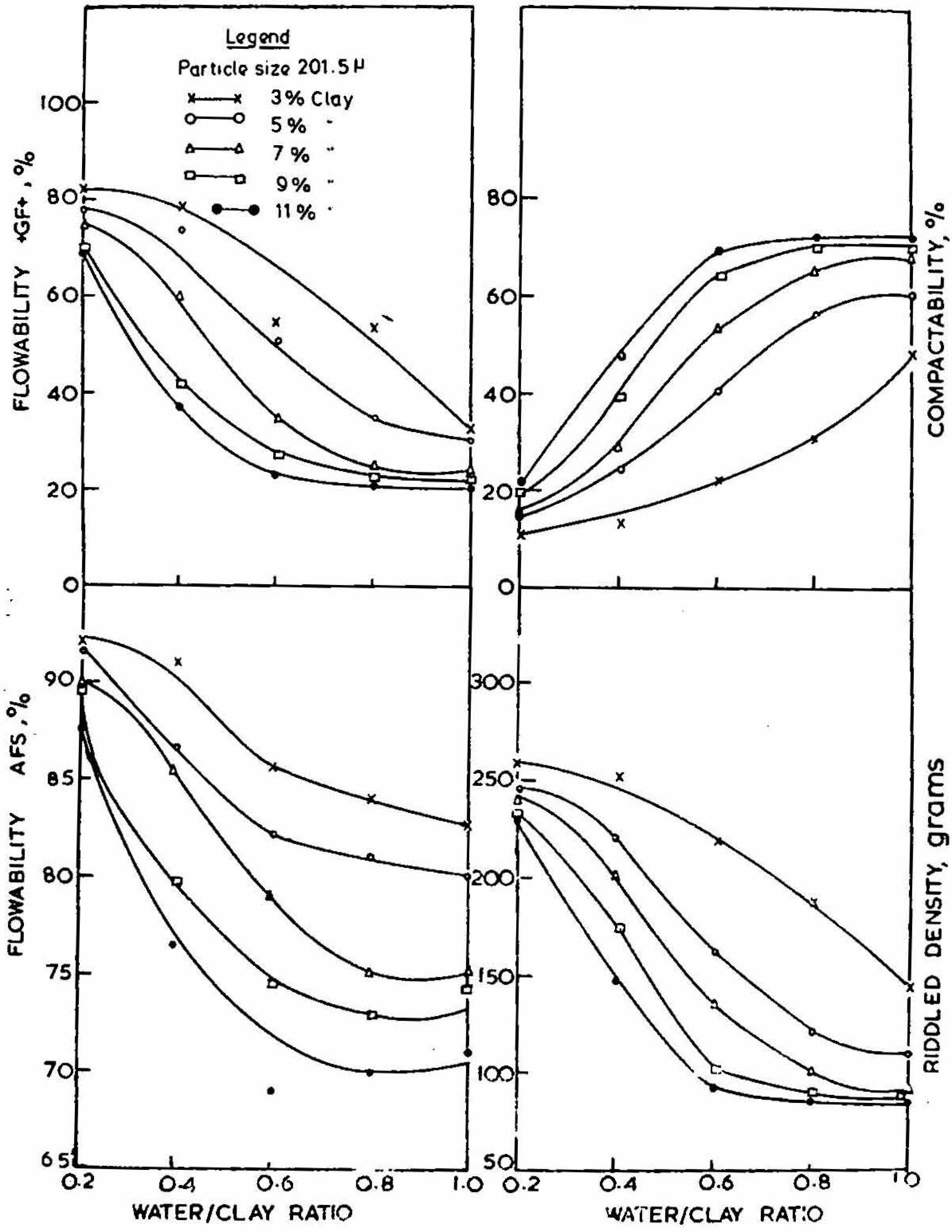

FIG. 6. Effect of water/clay ratio on AFS flowability, + GF + flowability, riddled density and compactability of bentonite bonded homogeneous sand grains of particle size 201·5 μ.

(2) the green permeability increases to a maximum with increase in water/clay ratio from 0·2 to 0·6 and then decreases with further increase in water/clay ratio; the maximum permeability point occurs around a water/clay ratio of 0·6 at all bentonite percentages studied,

(3) the bulk density decreases to a minimum as the water/clay ratio increases from 0·2 to 0·6 and then increases with further increase in water/clay ratio; the minimum bulk density occurs at a water/clay ratio of 0·6 at all bentonite percentages studied;

(4) riddled density, AFS flowability and + GF + flowability decreases with increase in water/clay ratio from 0·2 to 0·6 and then does not vary appreciably with further increase in water/clay ratio; the same trend is observed at other percentages of bentonite also, and

(5) compactability increases as the water/clay ratio increases from 0·2 to 0·6 and then remains almost constant with further increase in water/clay ratio. This is true at other clay contents also.

All these conclusions are found to be valid for all particle sizes employed in this investigation.

Effect of Particle Size

In Figs. 7 through 11 are shown typically the effect of particle size at a particular water-clay ratio on the physical properties of homogeneous sand mixes having different percentages of bentonite. From these type of figures one can conclude that at a given water/clay ratio and for a particular clay content—

(1) the green compression strength, green shear strength, green hardness and compactability decrease with increase in particle size from $90\,\mu$ to a value around $400\,\mu$; however, with further increase in particle size, these properties remain practically unaltered;

(2) green permeability increases with increase in particle size whereas the variation of bulk density with increase in particle size is not consistent;

(3) riddled density, AFS flowability and + GF + flowability increase as the particle size increases upto a value around $400\,\mu$ and then remain almost insensitive to any further increase in particle size,

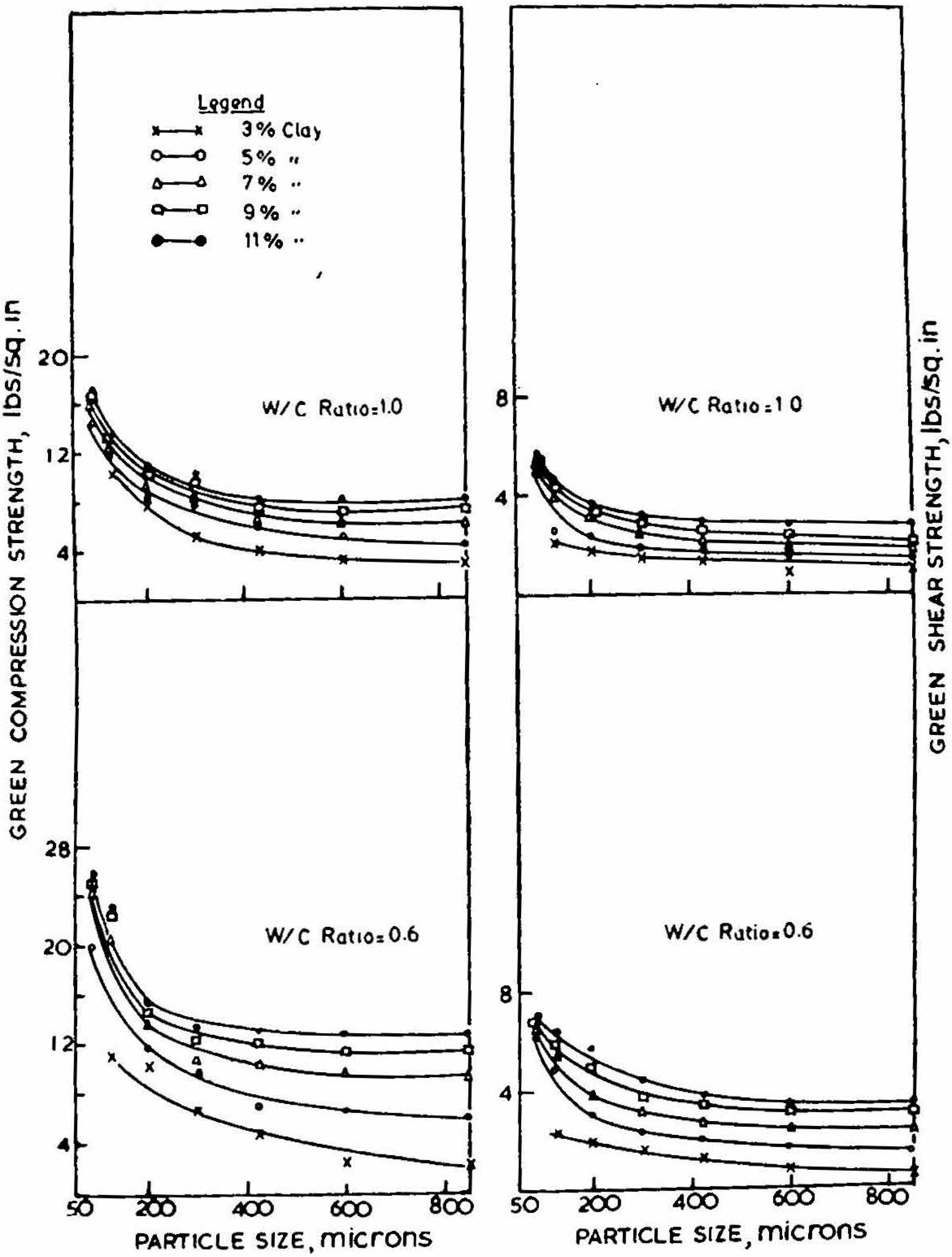

FIG. 7. Effect of particle size on green compression strength and green shear strength of bentonite bonded homogeneous sand grains at water/clay ratios of 0·6 and 1·0.

These conclusions are found to be valid at all water/clay ratios, *viz.*, 0·2 to 1·0.

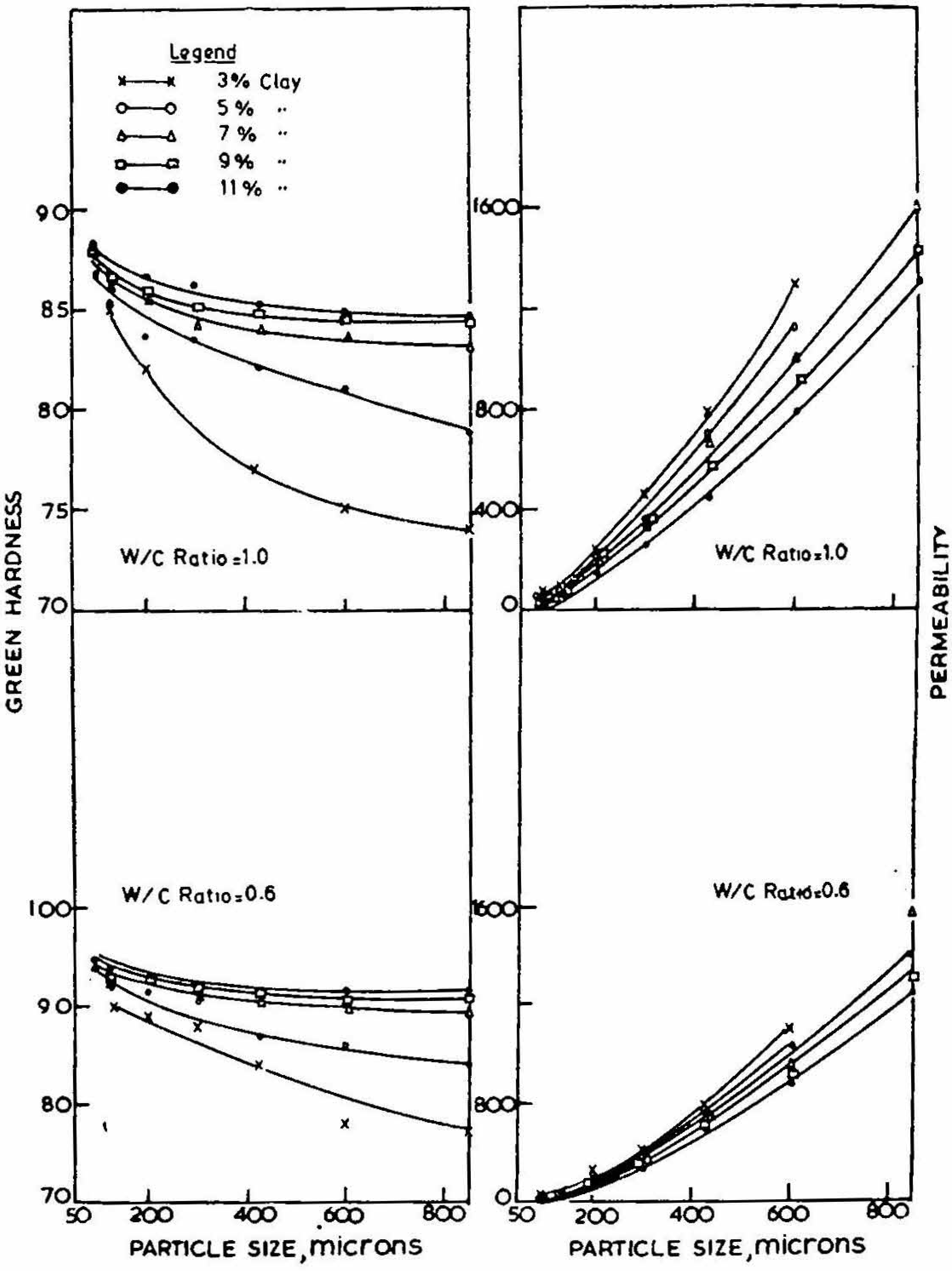

FIG. 8. Effect of particle size on green hardness and green permeability of bentonite bonded homogeneous sand grains at water/clay ratios of 0·6 and 1·0.

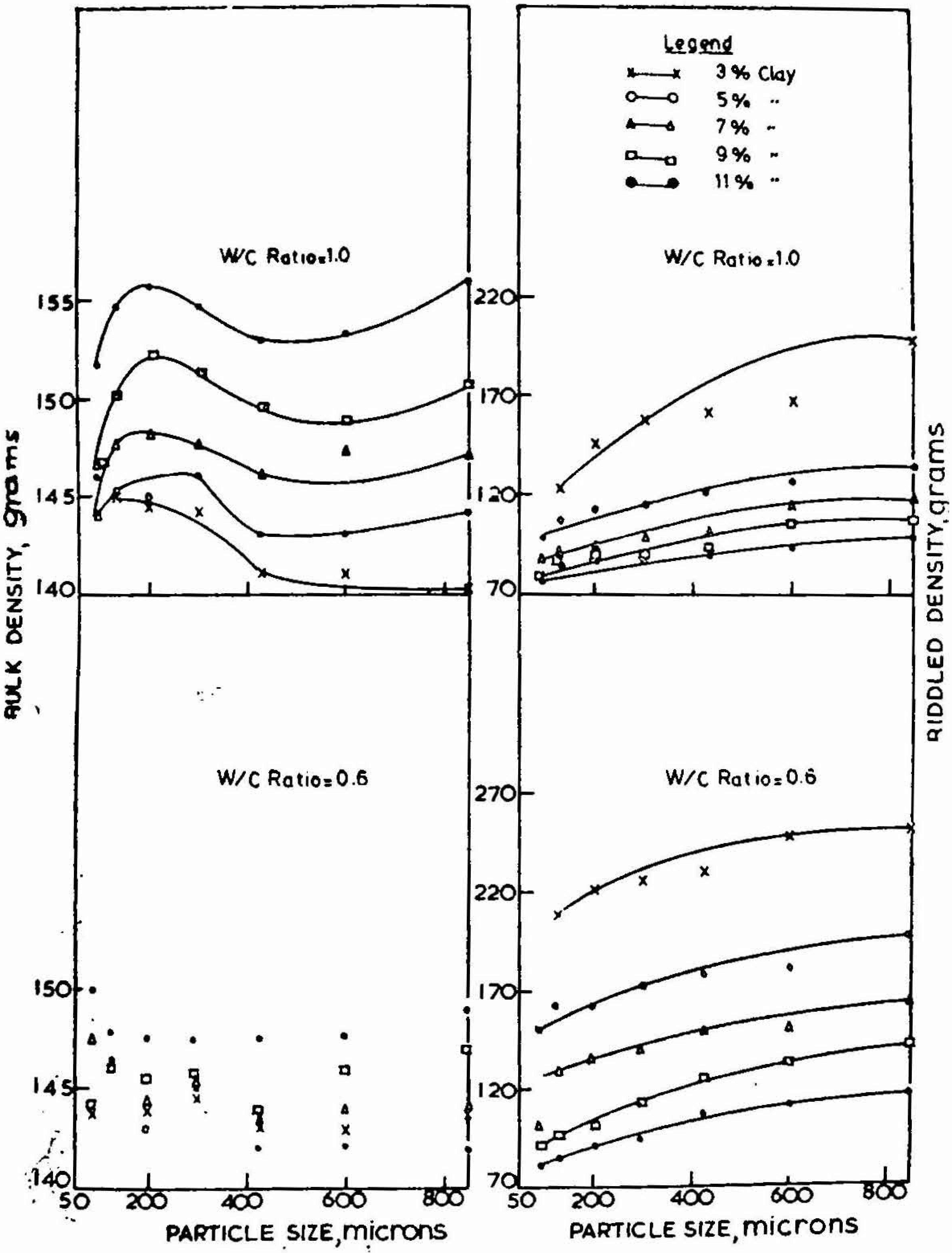

FIG. 9. Effect of particle size on bulk density and riddled density of bentonite bonded homogeneous sand grains at water/clay ratios of 0·6 and 1·0.

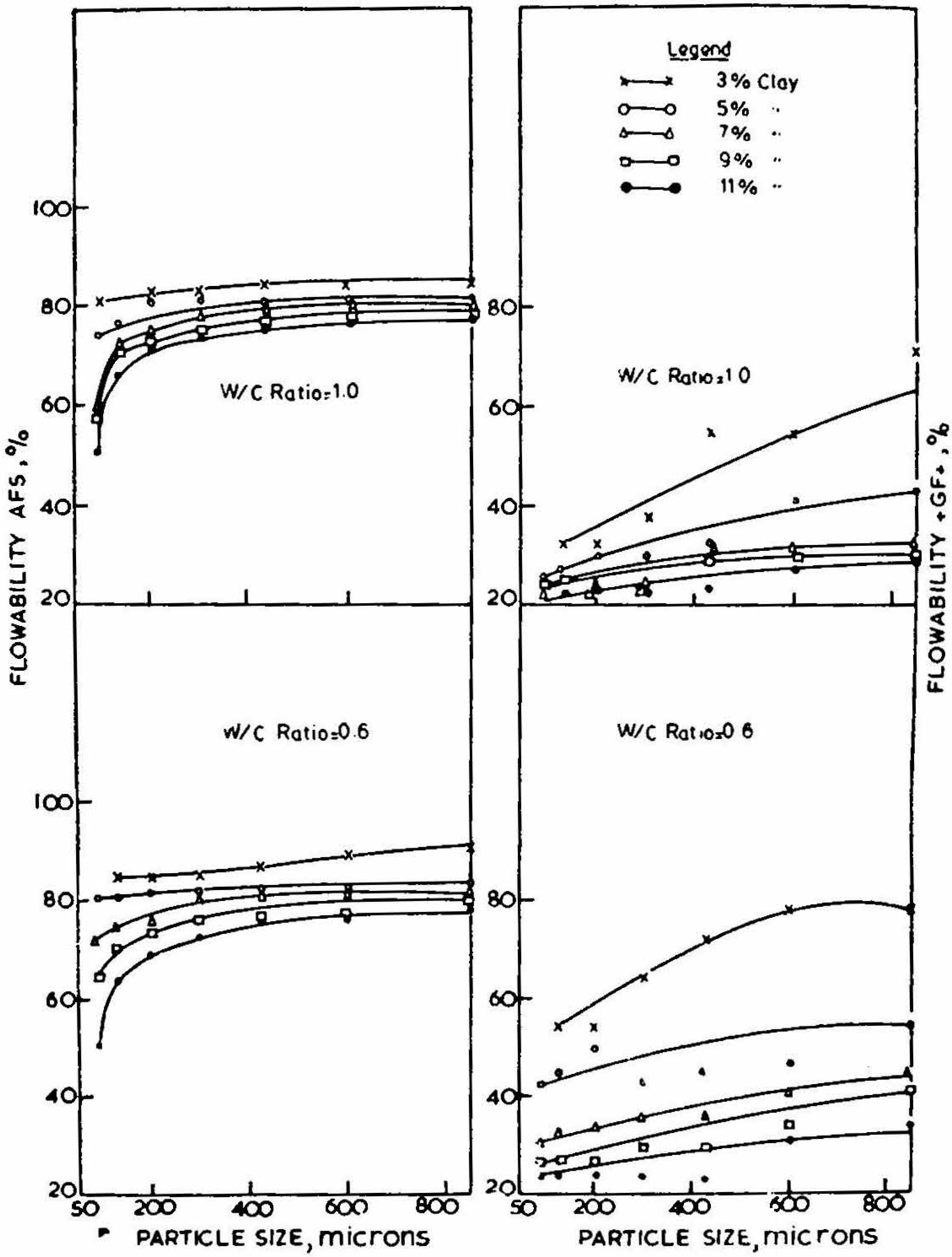

FIG. 10. Effect of particle size on AFS flowability and + GF + flowability of bentonite bonded homogeneous sand grains at water/clay ratios of 0·6 and 1·0.

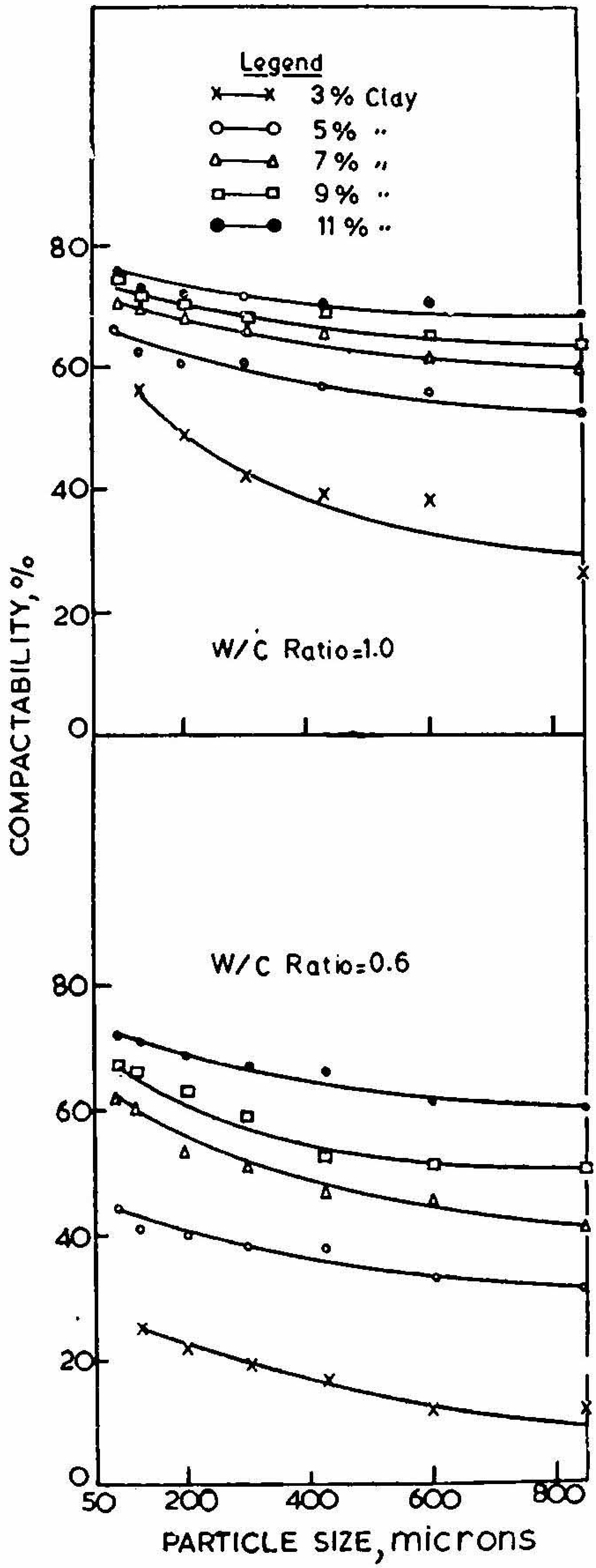

FIG. 11. Effect of particle size on compactability of bentonite bonded homogeneous sand grains at water/clay ratios of 0·6 and 1·0.

Effect of Bond Content

In Figs. 12 to 16 are shown typically the effect of clay content at a particular water/clay ratio on the physical properties of homogeneous sand

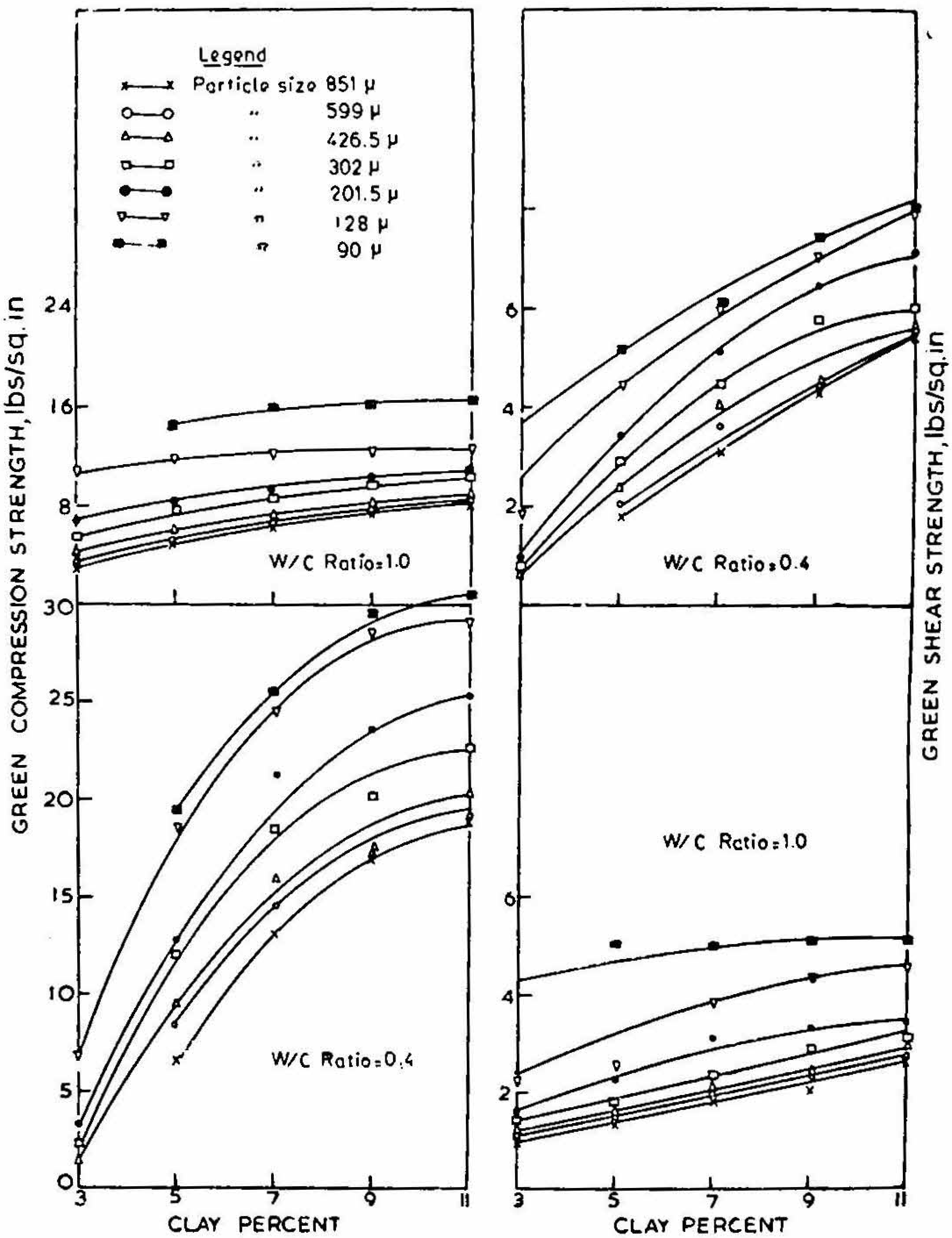

FIG. 12. Effect of clay content on green compression strength and green shear strength of bentonite bonded homogeneous sand grains at water/clay ratios of 0·4 and 1·0.

mixes of different particle sizes. From this type of figures one can infer that for a given particle size—

(1) green compression strength, green shear strength, green hardness and compactability increase with increase in clay content from 3% to 7% and with further increase in clay content the increase in these properties is not appreciable,

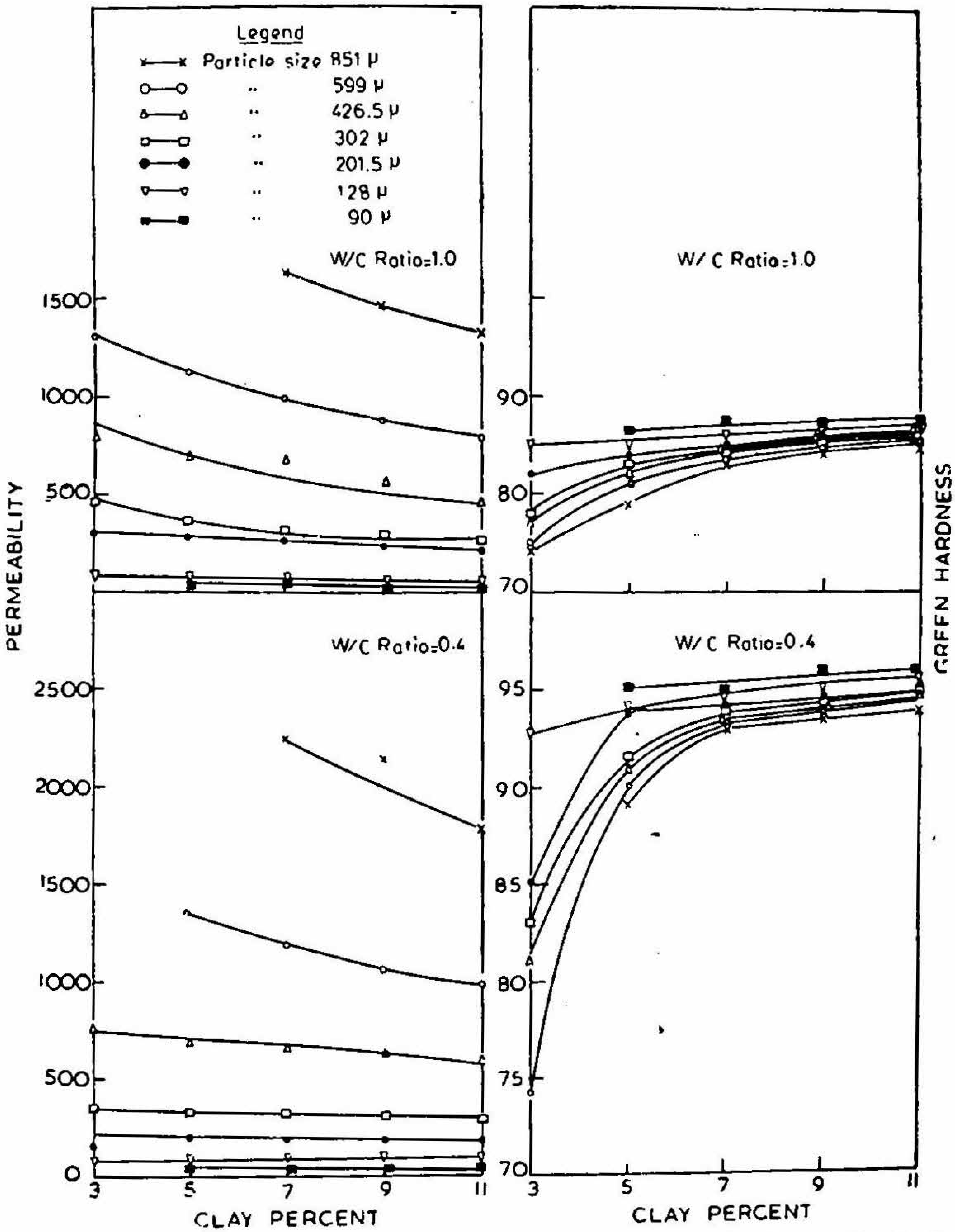

FIG. 13. Effect of clay content on green permeability and green hardness of bentonite bonded homogeneous sand grains at water/clay ratios of 0·4 and 1·0.

(2) green permeability, AFS flowability, +GF +flowability decrease with increase in bentonite content upto 7% and then remain almost constant with further increase in bentonite content, and

(3) bulk density variation with increase in clay content does not follow any definite trend.

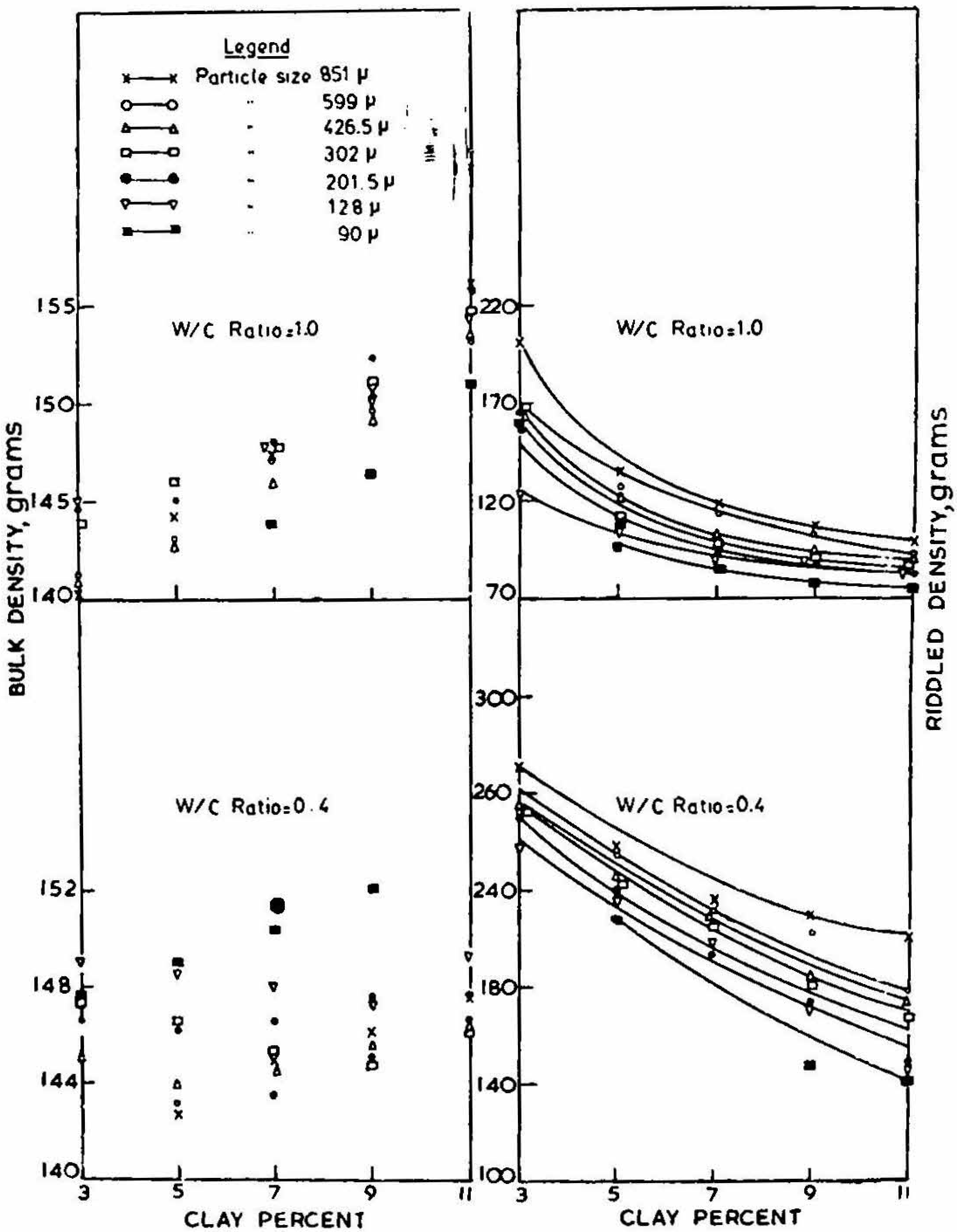

FIG. 14. Effect of clay content on bulk density and riddled density of bentonite bonded homogeneous sand grains at water/clay ratios of 0·4 and 1·0.

The above conclusions are valid for all the particle sizes employed in this investigation. A more or less similar trend is observed at other water/clay ratios also.

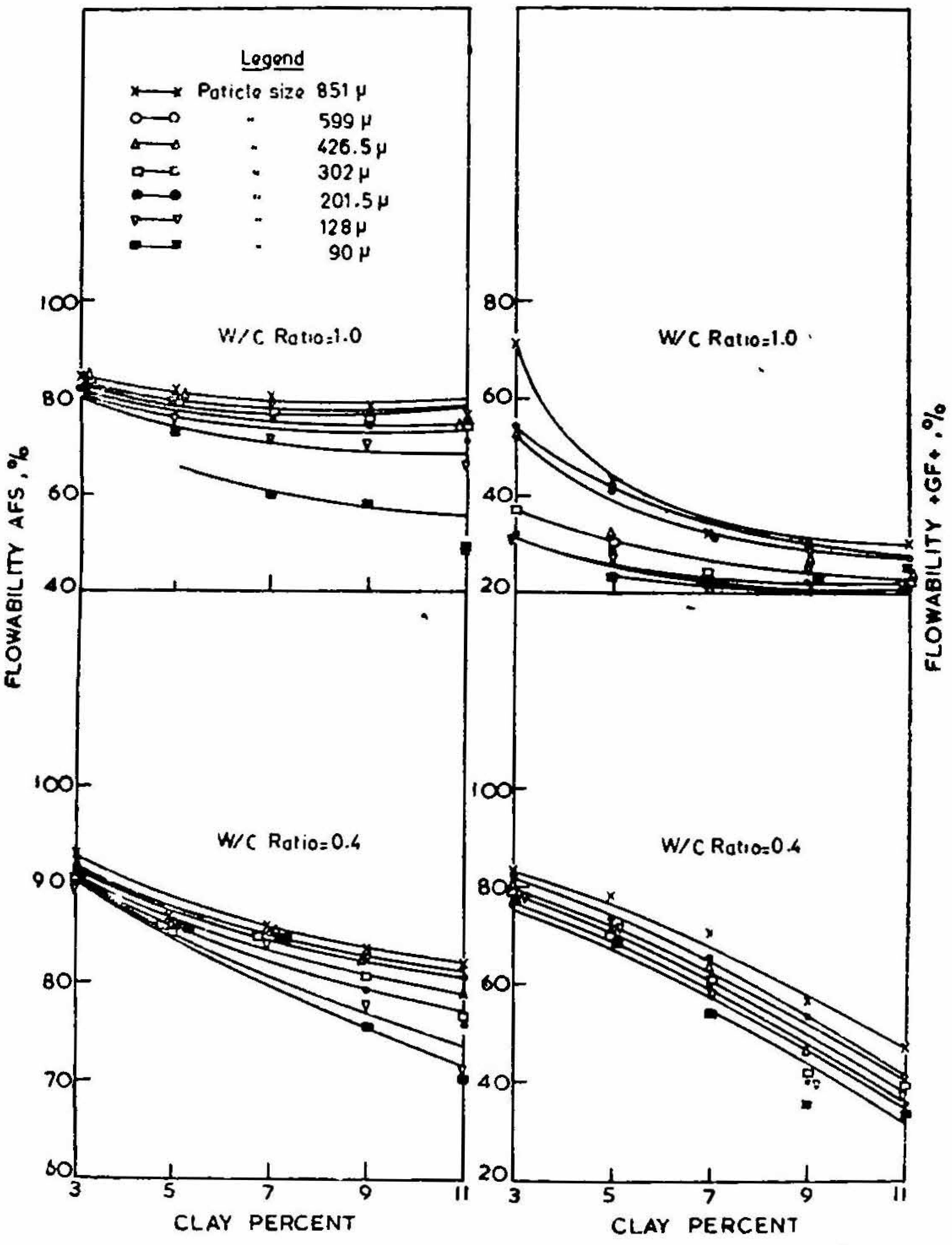

FIG. 15. Effect of clay content of AFS flowability and + GF + flowability of bentonite bonded homogeneous sand grains at water/clay ratios of 0·4 and 1·0.

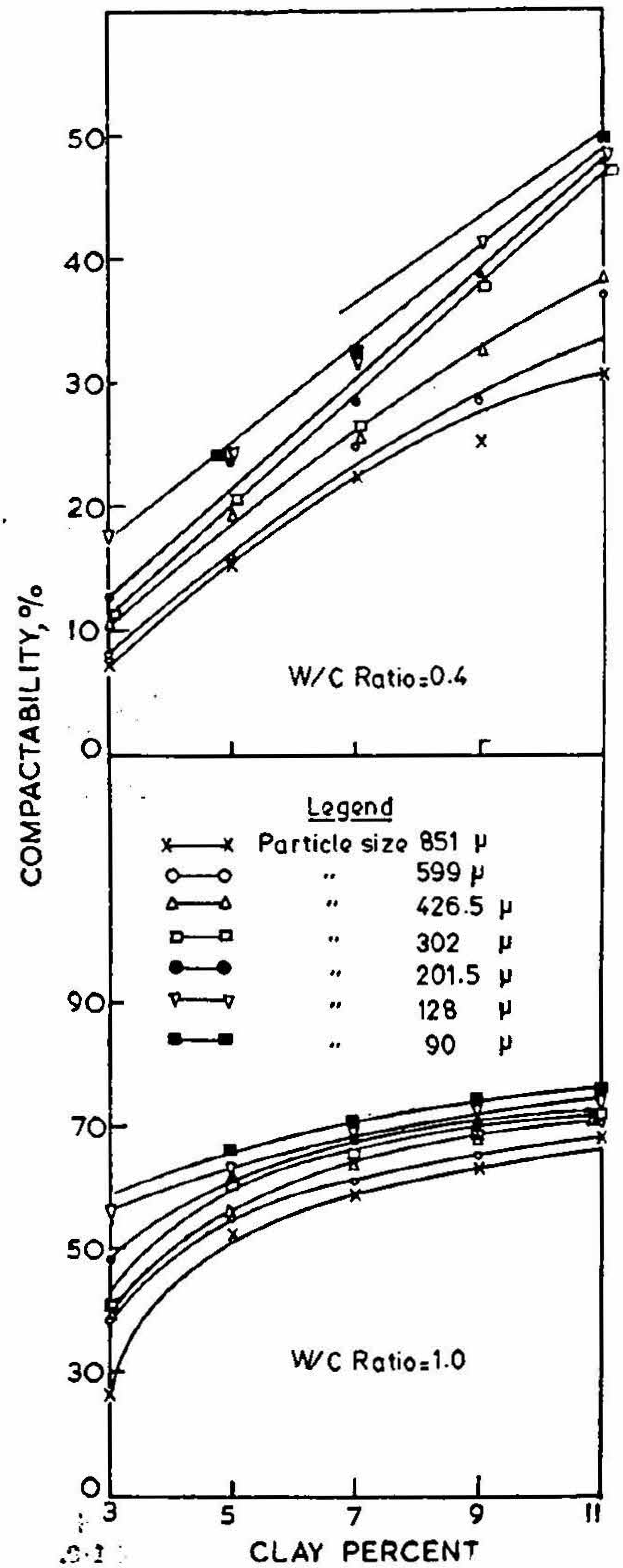

FIG. 16. Effect of clay content on compactability of bentonite bonded homogeneous sand grains at water/clay ratios of 0·4 and 1·0.

Interrelation between Physical Properties of Sand

In foundry practice, the determination of physical properties is essential for sand control and it is difficult to determine all the physical properties in the control laboratory. The physical properties, in general, are inter-related. A study of the literature indicates that few attempts have been made to relate the various physical properties. Hence the physical properties

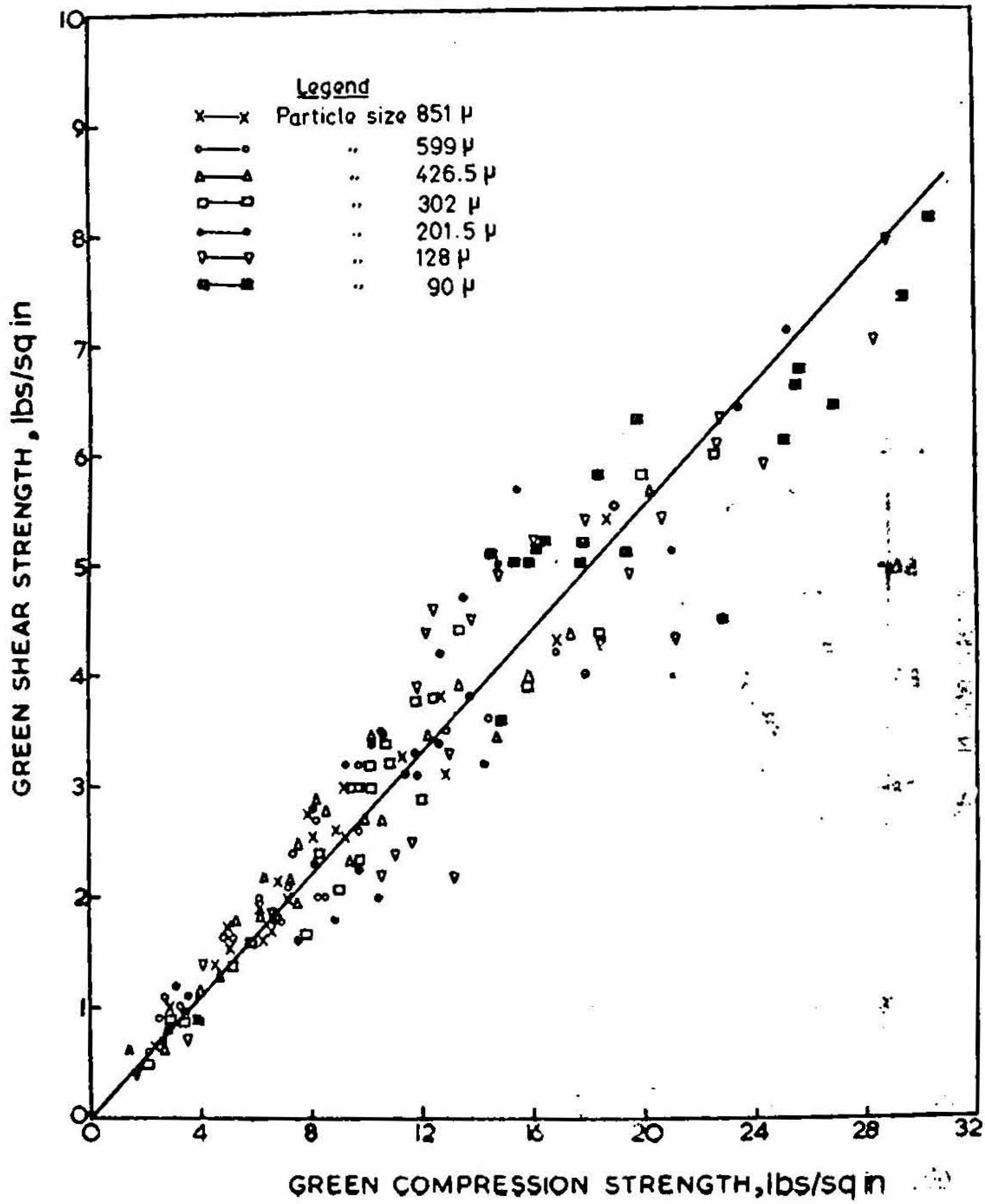

FIG. 17. Interrelationship between green compression strength and green-shear strength of bentonite bonded homogeneous sand grains.

of sand mixes obtained by using homogeneous sand grains were interrelated. In Fig. 17 through 23 are shown the interrelationships of various physical properties for all particle sizes, all clay percentages and all water-clay ratios employed in this investigation.

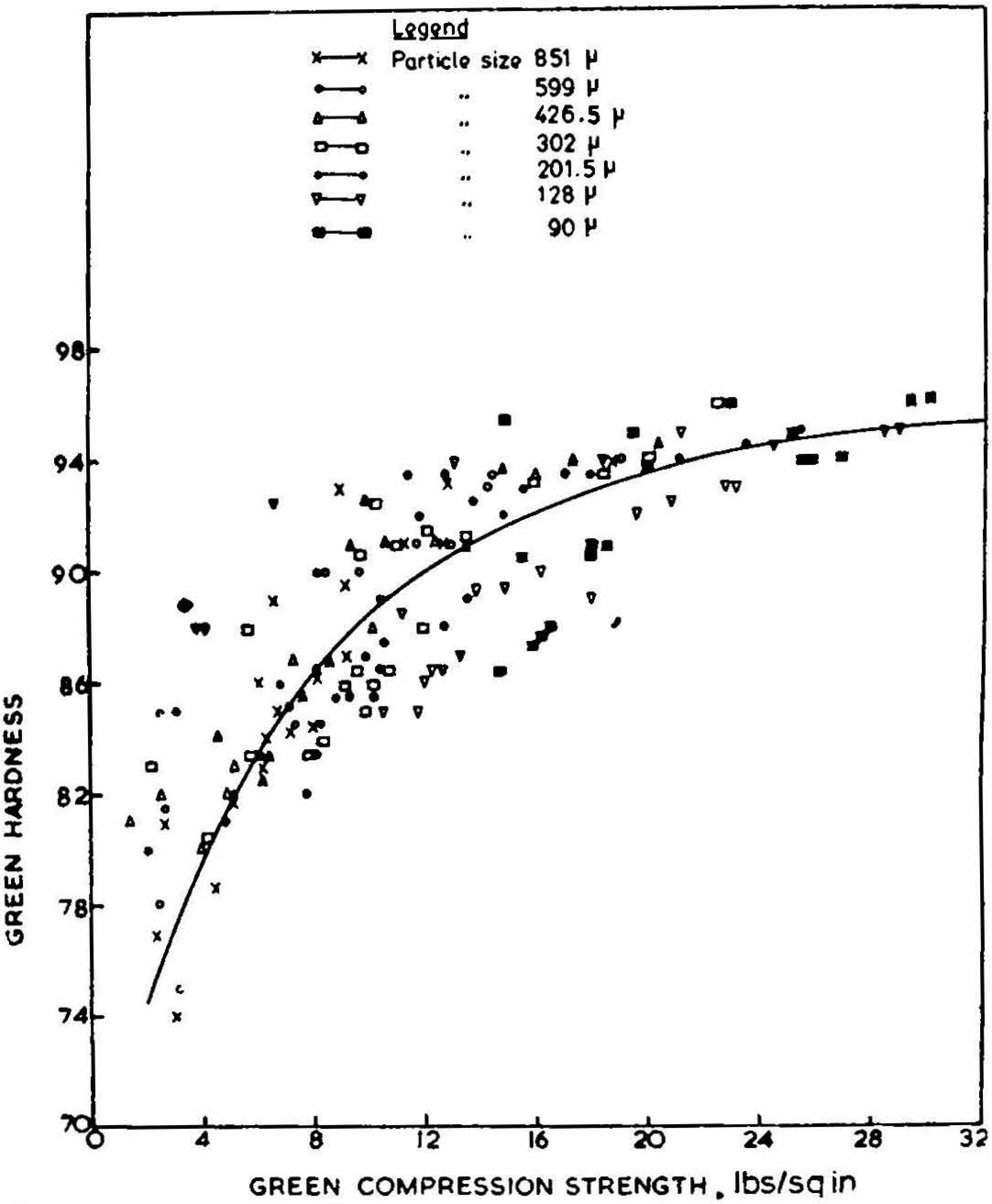

FIG. 18. Interrelationship between green compression strength and green hardness of bentonite bonded homogeneous sand grains.

(1) *Green Compression and Green Shear Strength*

In Fig. 17 is shown the interrelation between green compression strength and green shear strength. It can be observed from this figure that

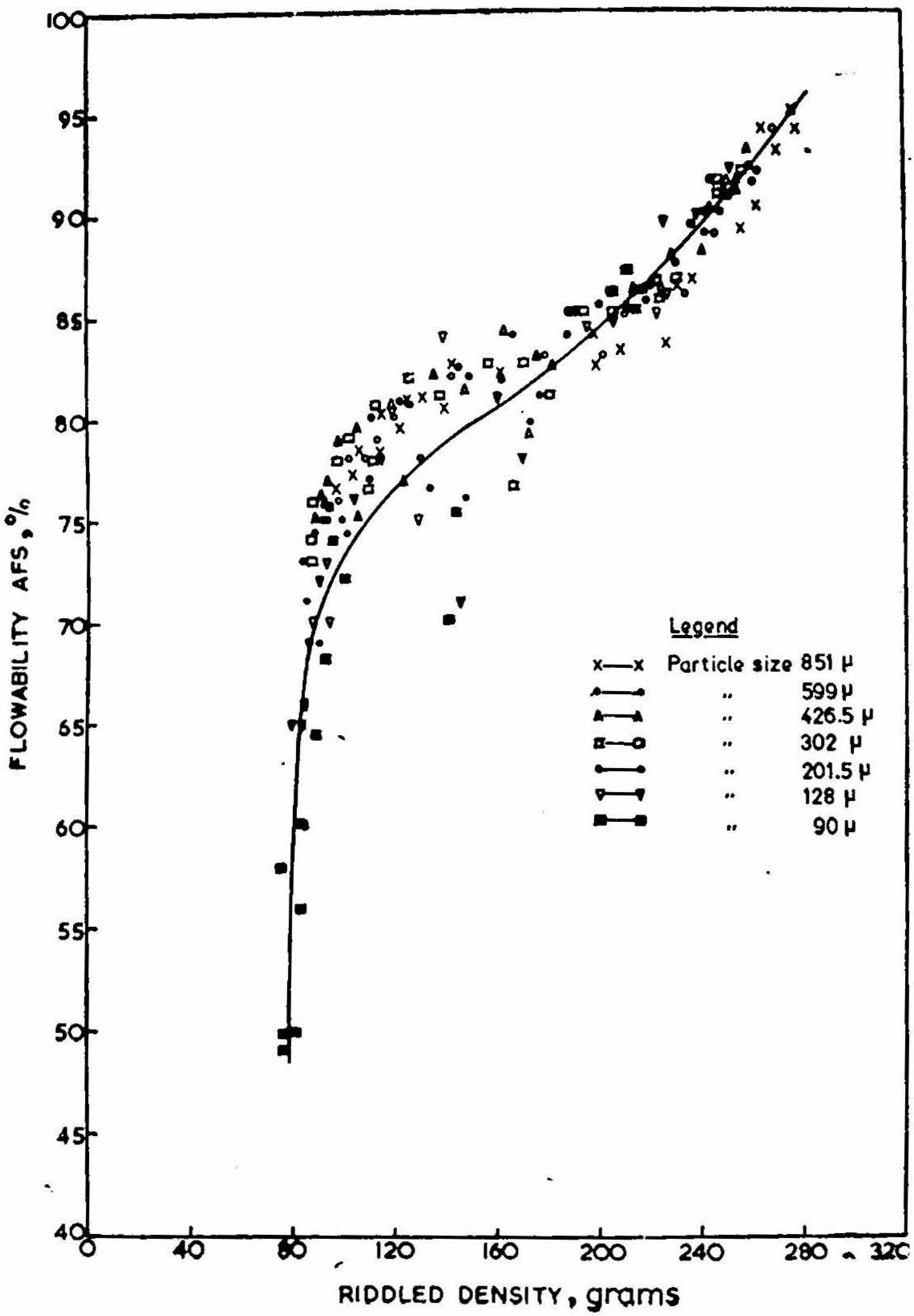

FIG. 19. Interrelationship between riddled density and AFS flowability of bentonite bonded homogeneous sand grains.

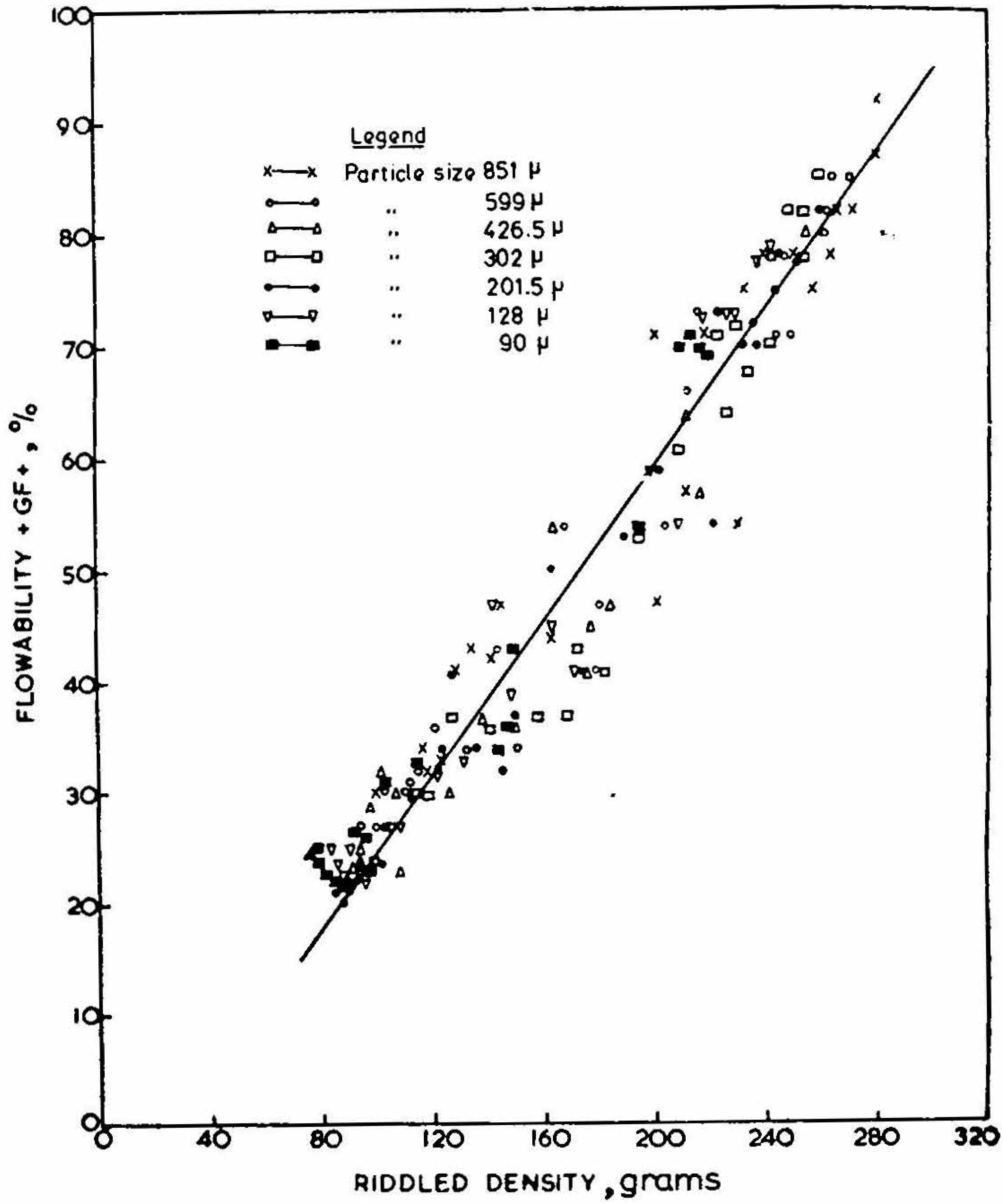

FIG. 20. Interrelationship between riddled density and + GF + flowability of bentonite bonded homogeneous sand grains.

an approximately linear relationship exists between the two properties. The slope of the curve indicates that the ratio of green compression strength to green shear strength is around 4.

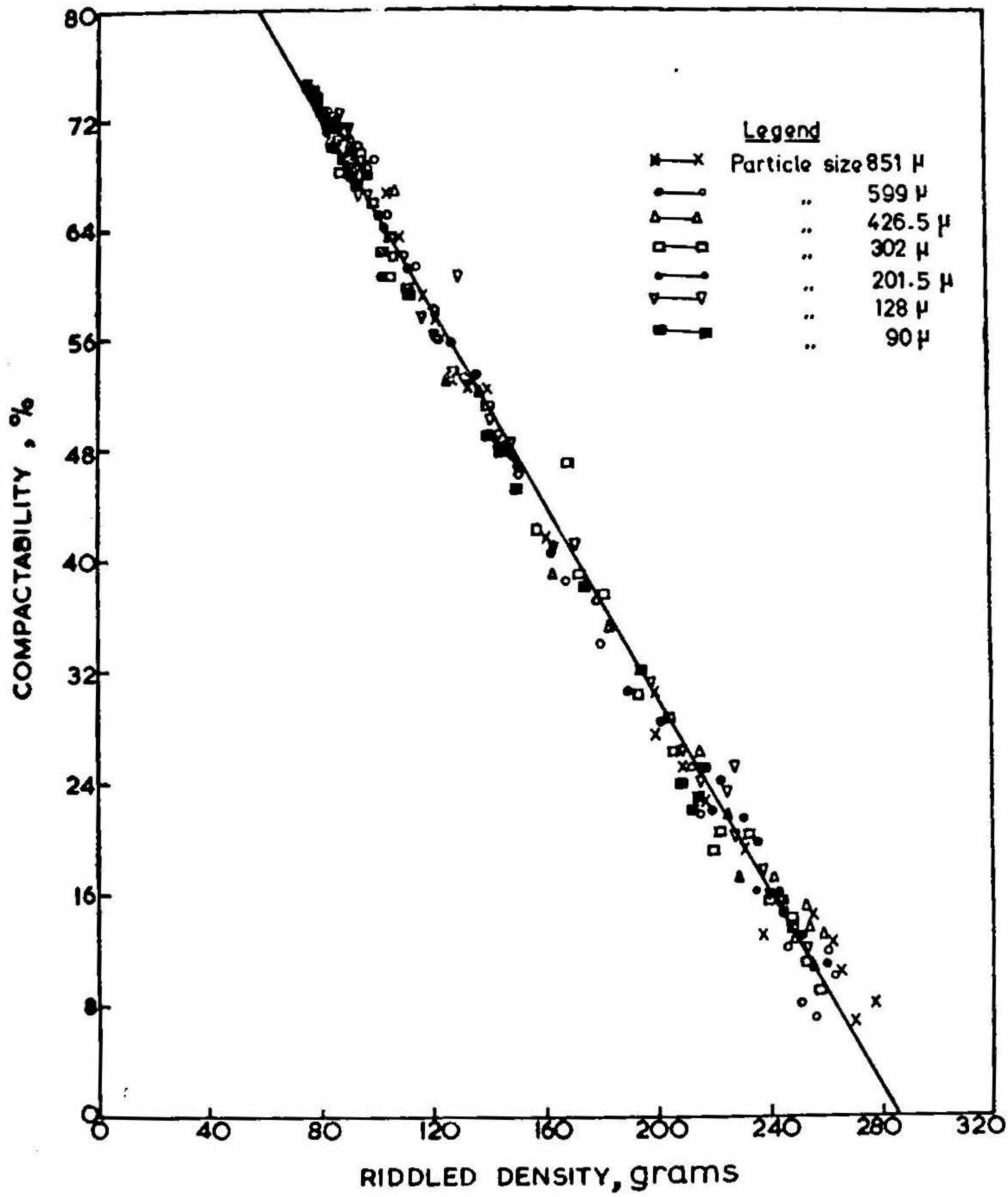

FIG. 21. Interrelationship between compactability and riddled density of bentonite bonded homogeneous sand grains.

(2) *Green Compression and Green Hardness*

In Fig. 18 is shown the variation of green hardness with green compression strength. A study of this figure indicates that the green hardness value increase sharply with increase in green compression strength upto a value of 95 and any further increase in green strength does not alter the green hardness much,

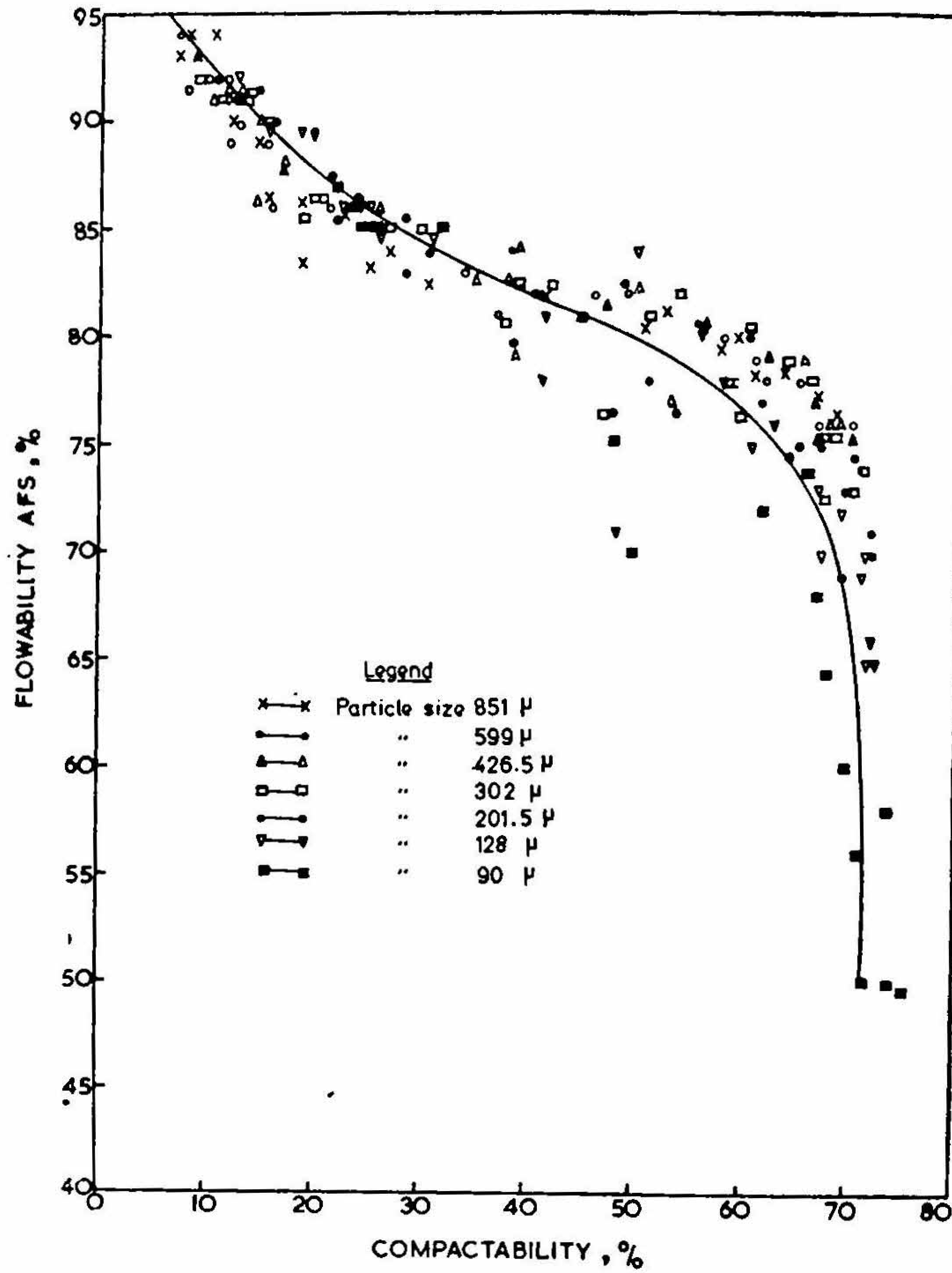

FIG. 22. Interrelationship between compactability and AFS flowability of bentonite bonded homogeneous sand grains.

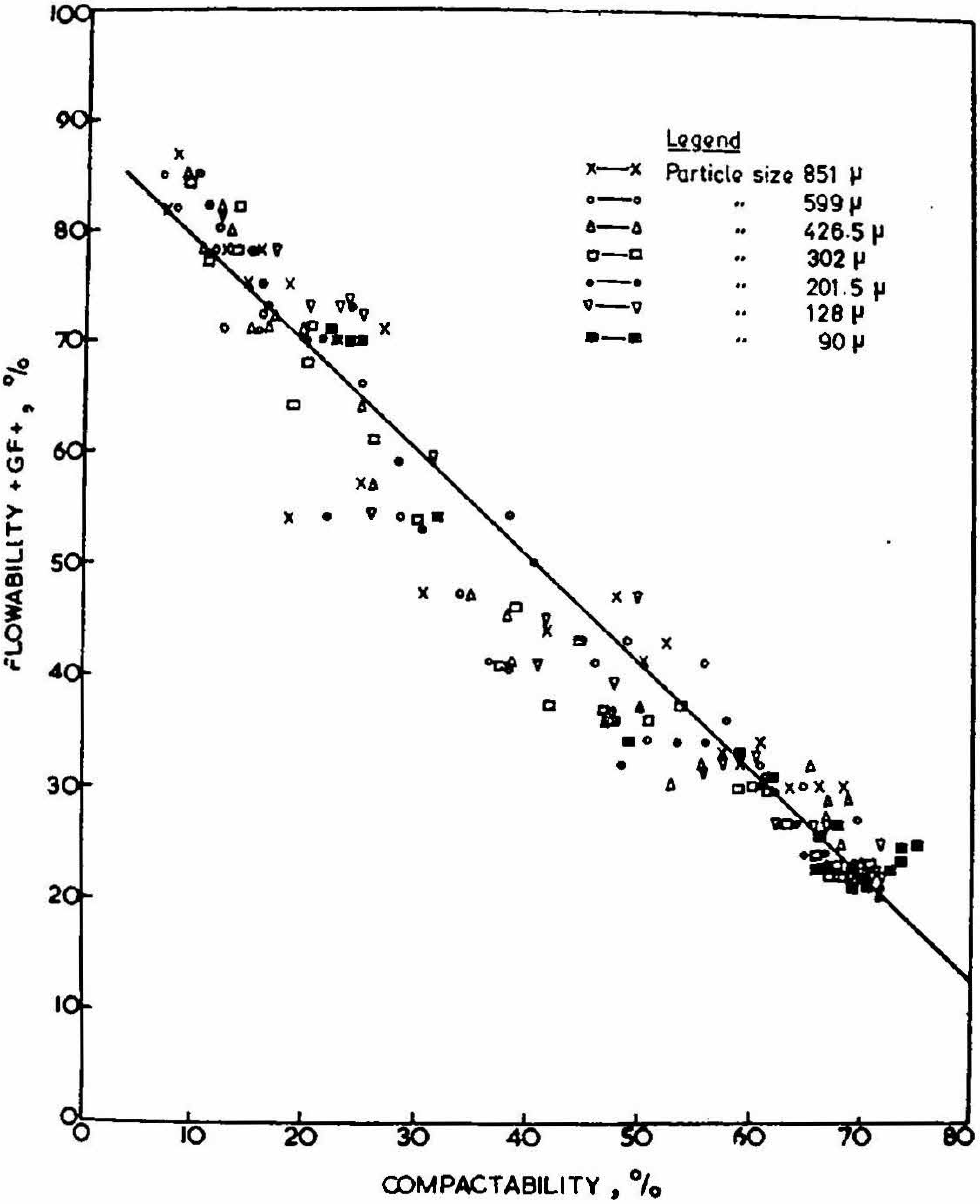

FIG. 23. Interrelationship between compactability and +GF+ flowability of bentonite bonded homogeneous sand grains.

(3) *Riddled Density and Flowability*

In Figs. 19 and 20 are shown the interrelationships riddled density *versus* AFS flowability and riddled density *versus* +GF +flowability respectively. From these figures one can conclude that:

(*a*) AFS flowability does not correlate well with riddled density, and

(*b*) +GF +flowability increases linearly with riddled density.

(4) *Compactability and Riddled Density*

In Fig. 21 is shown the variation of compactability with riddled density. A study of the figure indicates that an increase in riddled density decreases compactability in a linear manner.

(5) *Compactability and Flowability*

As flowability and compactability measure the decrease in height of sand column during compaction, an attempt was made to relate flowability and compactability. In Figs. 22 and 23 are shown the variation of AFS flowability and +GF+ flowability with compactability value respectively. A study of the figures indicates that

(*a*) AFS flowability does not correlate well with compactability value. Compactability increases upto a value of 75 with decrease in AFS flowability,

(*b*) a linear relationship exists between +GF+ flowability and compactability, and an increase in compactability decreases flowability.

From Figs. 20, 21 and 23, it is interesting to note that compactability, +GF+ flowability and riddled density are linearly interrelated and they measure one and the same property.

CONCLUSIONS

The results of the investigation to study the effect of water-clay ratio, particle size and clay content on the physical properties of homogeneous sand mixes indicate the following:—

For a given particle size and clay content,

(*a*) with increase in water-clay ratio, the green compression strength, green shear strength, green hardness and green permeability increase to a maximum and subsequently decrease whereas bulk density decreases to a minimum and then increases; the maximum points of green compression strength, green shear strength and green hardness occur around a water-clay ratio of 0·4 while the maximum green permeability and the minimum bulk density occur around a water-clay ratio of 0·6, and

(*b*) riddled density, AFS flowability, +GF+ flowability and compactability vary with increase in water-clay ratio upto a value around 0·6 and then remain insensitive to further increase in water-clay ratio, For a given water-clay ratio and bentonite content,

(*c*) the properties vary with increase in particle size upto a value around 400 μ and then become insensitive to particle size.

For a given water-clay ratio and particle size,

(*d*) the physical properties vary with increase in clay content upto a value around 7% and then remains constant with further increase in clay content.

The interrelationships of various physical properties indicate that

(*e*) a linear relationship exists between green compression strength and green shear strength, and

(*f*) compactability, + GF + flowability and riddled density are linearly interrelated and they measure one and the same property.

ACKNOWLEDGEMENT

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REFERENCES

[1] Yearly, B. C. .. *Foundry*, 1967, 94, 82.

[2] Seaton, T. W. .. *Trans. AFS*, 1960, 68, 45.

[3] Srinagesh, K. .. *Ph.D. Thesis, Indian Institute of Science, Bangalore*, 1967.

[4] Wenninger, C. E. and Volkmar, A. P. *Trans. AFS*, 1970, 78, 17.

[5] Hofmann, F. *et al.* .. *Trans. AFS*, 1969, 77, 134.

[6] Wenninger, C. E. and Lang, W. J. *Trans. AFS*, 1969, 77, 39.