SOME STUDIES ON THE FLOWABILITY OF MOULDING SAND

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ABSTRACT

Experiments were carried out to make a comparative study of the merits and draw-backs of three different laboratory tests for flowability measurement, viz., AFS test, +GF+ test and Kennedy method, and also flow value that is supposedly representative of this property and which is calculated on the basis of principles of soil mechanics with a new method of finding flowability of sand during actual mould preparation (jolt squeezing) using test patterns. It was found that all the three test patterns showed similar behaviour in the suitability for measuring flowability and also that among the four methods Kennedy flowability test was the most suitable for measuring flowability in the laboratory with the +GF+ method trailing behid it.

The effect of additives like dextrin, wood flour, silica flour, sea coal and tron oxide on the flowability of a typical grey-iron foundry sand have also been investigated.

1. INTRODUCTION

"Flowability" is a property of sand mix which influences the production of moulds of uniform hardness and density and consequently castings free from defects such as expansion and erosion scabs. Metal penetration which is the worst case of surface finish also depends on the fllowability of the sand.

Considerable confusion and misunderstandings exist regarding the true meaning of flowability. This has led to different methods for its measurement and a universally acceptable method is not available. This

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investigation aims at explaining certain discrepancies and establishing new testing techniques. The effect of additives on flowability which play an important part in foundry sand practice have also been investigated.

2. Previous Work

The flowability of sand is of utmost importance for foundrymen. Although foundrymen recognise its significance, several investigators have measured it in different ways on the basis of one or more of the following: (i) hardness, (ii) deformation, (iii) bulk density gradient, (iv) transverse movement of sand and so on.

The AFS sub-committee[1] for flowability has suggested a "visual comparator" method on the basis of which a sand of good flowability should have better packing characteristics. It is purely a qualitative method. AFS[2] has also recommended a quantitative method for its measurement based on the deformation. In this test change in length of standard 2-in. dia., 2-in. length specimen between the fourth and the fifth ram is recorded; less decrease in length shows higher flowability.

Dietert and Valtier[3], Kyle[4], Buchanan[5], Orlov[6] and Rowell[7] measured flowability by determining hardness values at two points; one adjacent to the rammed face and another at a known distance below in the specimen. According to these investigators lower hardress difference indicates higher flowability. Using Orlov's[6] apparatus Vlasov[8] found that flowability can be improved by additions of propane asphalt suspensions in kerosene or white spirit upto 0.58 per cent; further addition decreases the flowability.

Based on the concept of bulk density gradient are methods by Davies and Rees[9] and Srinagesh *et al*[10]. Davies and Rees considered flow in longitudinal direction only and investigated the effects of squeeze pressure, moisture content, nature of bond and grain shape on flowability whereas Srinagesh, taking into account the flow of sand both in longitudinal and transverse directions, investigated the effects of grain shape, grain size, size ratio and bond on the flowability of moulding sand.

Using the transverse movement of sand as the criterion, flowability was measured by Fair-field and McConachie[11], and Kennedy[11] and the +GF+ method[12] too employs the same principle. Gittus[13] and Dietert *et al*[11] proposed a method to find the flowability of sand in the loose state. The AFS in its publication "Moulding Methods and Materials"[15] has defined a property "mouldability" which bears the same significance as flowability. A novel method of measuring mouldability has been described with a proposed "mouldability tester".

Evstafe'v *et al*[16] have found a means of measuring flowability during vibratory squeeze compaction of moulds and have observed that sand flowability was influenced by the frequency and amplitude of vibrations, the pressure and time.

Based on the concept of uniformly filling of the sand under applied force Kiyan[17] proposed a method for flowability measurement. According to him flowability T of the sand is defined as the ratio of the weight Δm of the sand expelled from the most heavily compacted volume to the initial weight 'm' of the sand in that volume *i.e.*, $T = \Delta m/m$.

3. EXPERIMENTAL WORK

3.1 *Materials* :

(i) Silica sand of AFS grain fineness no.84.1 and clay content of 7.6%.

(ii) Na-base bentonite: pH value = 8 ; liquid limit = 575 ; swelling index 146.5 per cent ; moisture content 7%.

(iii) Additives : Dextrin (−100 mesh), wood flour (−60 mesh), silica flour (−100 mesh, sea coal (177.5AFS fineness no.) and iron oxide (−100 mesh).

3.2 *Test Procedure* :

3.2.1(A) *AFS Method*: Flowability was measured with AFS flowability meter between the fourth and the fifth ram.

3.2.2(B) *+GF+ Method*: The weight of sand required to form a standard AFS specimen was filled into a steel specimen tube similar to +GF+ specimen tube which was fabricated in the department. After applying three rams with the standard rammer, the height of the specimen (h_x) was measured and percentage flowability was calculated using the expression

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

where h_0, h_x and h_{100} are respectively the specimen height corresponding to Figure 1 :

(i) when the sand does not flow into the groove (= 50.8 mm),

(ii) the actual height of compacted sand specimen in the +GF+ type specimen tube and

(iii) when the groove is completely filled (= 36.3 mm).

3.2.3(C) *Kennedy Method*: The sand required to make standard AFS specimen was filled in the Kennedy apparatus and three rams were applied. The sand extruded was collected with care and weighed. The per cent flowability was calculated using the expression,

$$\%F = \frac{W_x}{W_s} \times 100$$

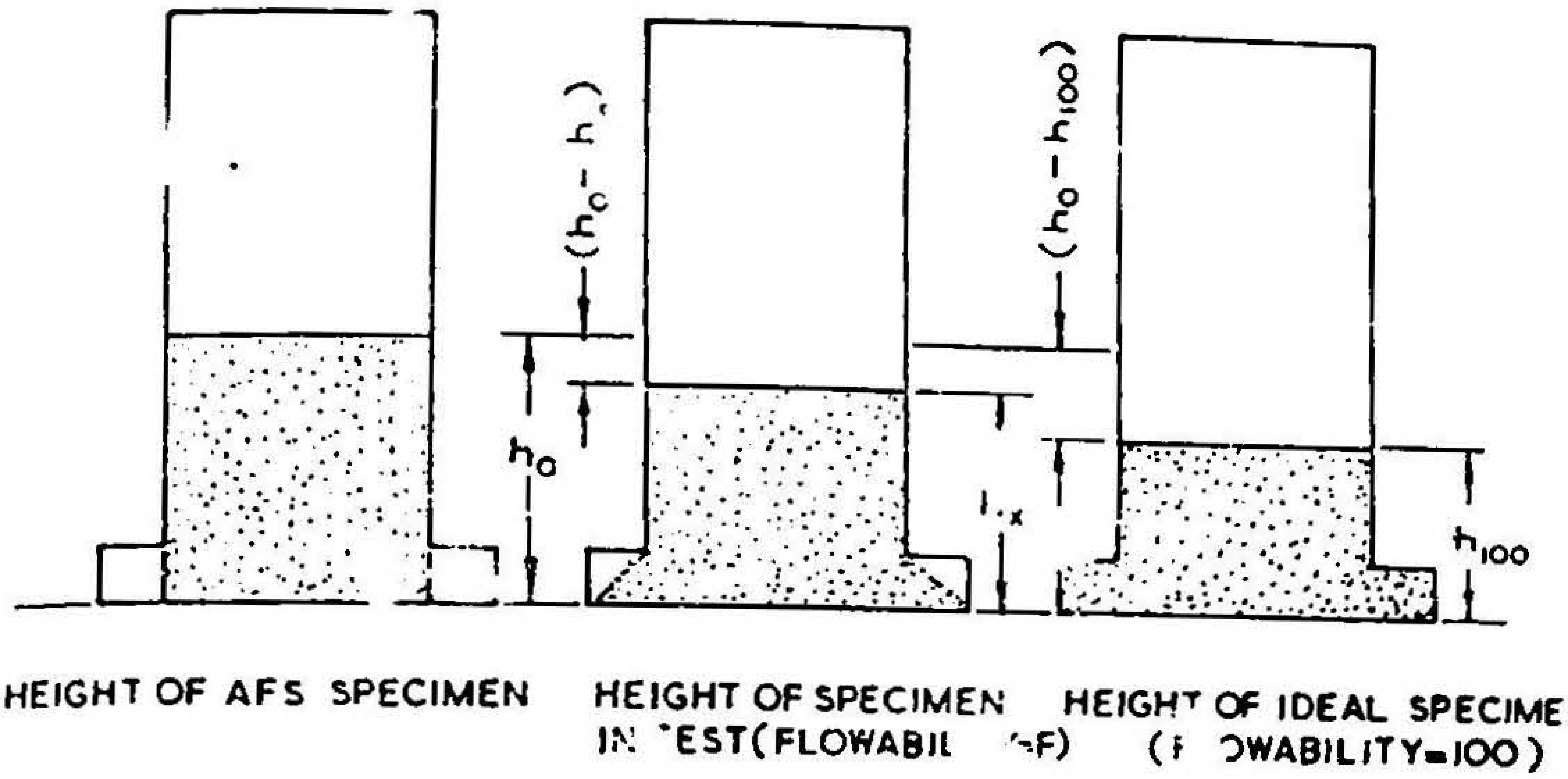

FIG. 1

Flowability measurement by $+G.F+$ method.

where W_x = weight of sand extruded through the annular space and

W_s = weight of sand required for standard AFS specimen.

3.2.4(D) *Analytical Method*: (Based on the flow value according to principles of soil Mechanics): An attempt was made to find the flowability using soil mechanics principle on the assumption that compacted granular masses are no different from rammed granular sand masses.

D. C. Wiliiam[18, 19] has suggested that the expression $\tan^2(45+\phi/2)$, which is known as flow value in soil mechanics, can be used as a means for measuring flowability. In the above expression ϕ is the angle of internal friction. On determining the AFS compressive and AFS shear strengths of the sand, angle of internal friction and hence the value of $\tan^2(45+\phi/2)$ can be calculated using the expression[20] $\tan^2(45+\phi/2)=(f_c/2f_s)^2$ where f_c and f_s are the AFS green compressive and shear strengths respectively. This equation is derived on the assumptions that the AFS shear strength equals the cohesion of the sand and not its actual shear strength unlike William's, according to which AFS shear strength equal actuals shear strength of the specimen.

3.2.5(E) *Flowability measurement during actual mould preparion (jolt-squeezing)*: Special types of patterns, named as " test patterns ", (Fig. 2) were employed. A mould box of 14-in. diameter, 6-in. height was placed around the pattern, which was fixed on the wooden board by means of bolt. Freshly prepared sand was dumped upto the height of the pattern, levelled and jolted at a pressure of 80 psi for 15 secs. Now the box was filled with

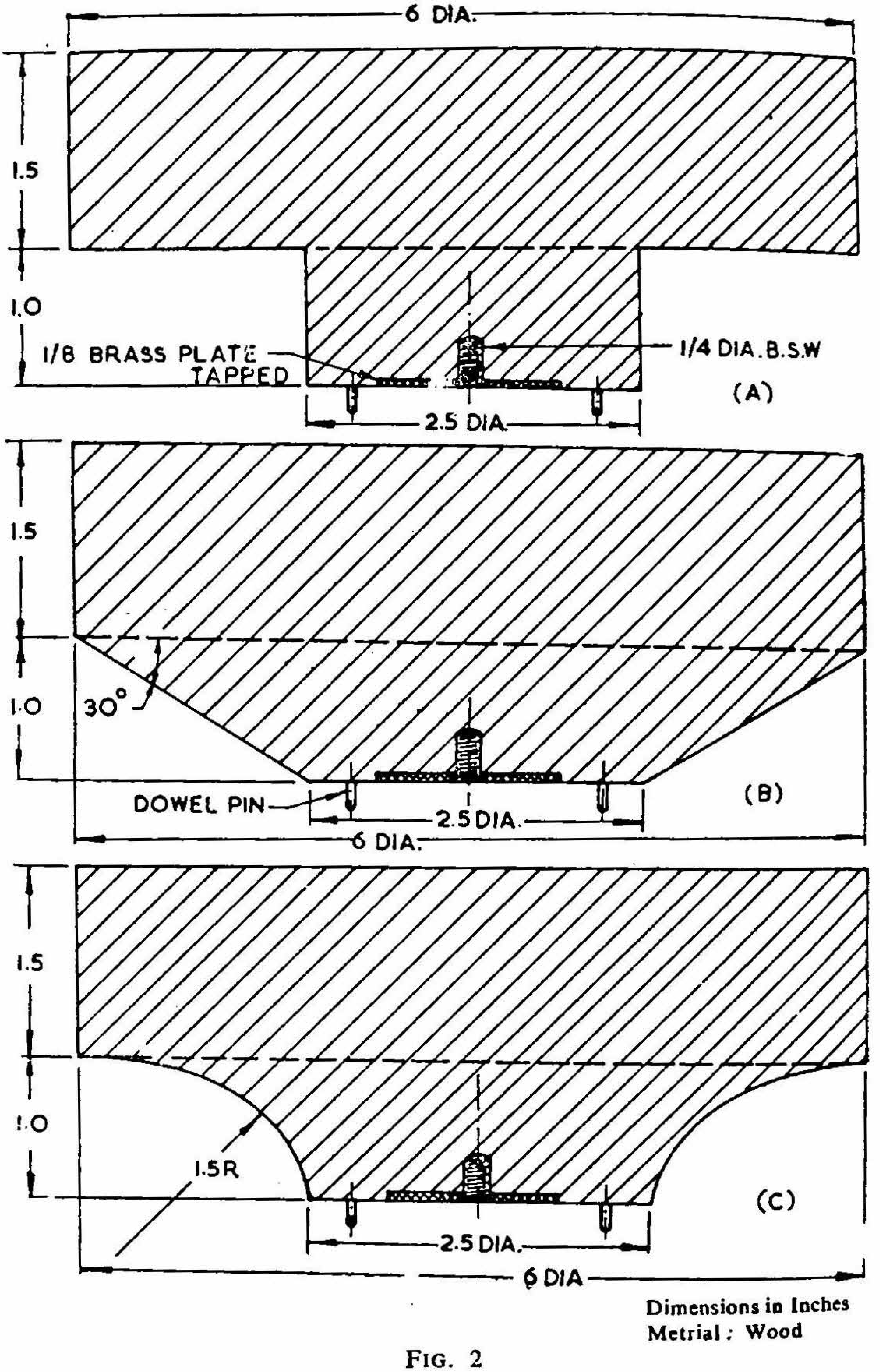

FIG. 2
Test Patterns.

sand upto the top and after levelling it was again jolted for 15 secs. at the same (80 psi) pressure. After that the box was filled up about $2\frac{1}{2}$ in. above the mould box top, levelled and squeezed at 75 psi.

Finding the weight of sand that had flown inside the recess of the pattern and density at a point on the parting plane away from the pattern per cent flowability was culculated using the following expression:

$$\text{Per cent flowability, } F = \frac{\text{Actual weight of sand flown inside the recess}}{\text{Volume of recess} \times \text{density at a point on the partingg plane away from pattern}} \times 100$$

3.3 *Results and Discussions*:

3.3.1 *Comparison of flowability values obtained using test patterns with that obtained by*: (*a*) *AFS Method*: An examination of (Fig. 3) shows that there is too much scatter in the results when compared with that obtained during mould preparation. The relationship obtained is non-linear. The curve (*B*) is less convex compared to the other two (A & C). The values tend toward linearity with pattern B.

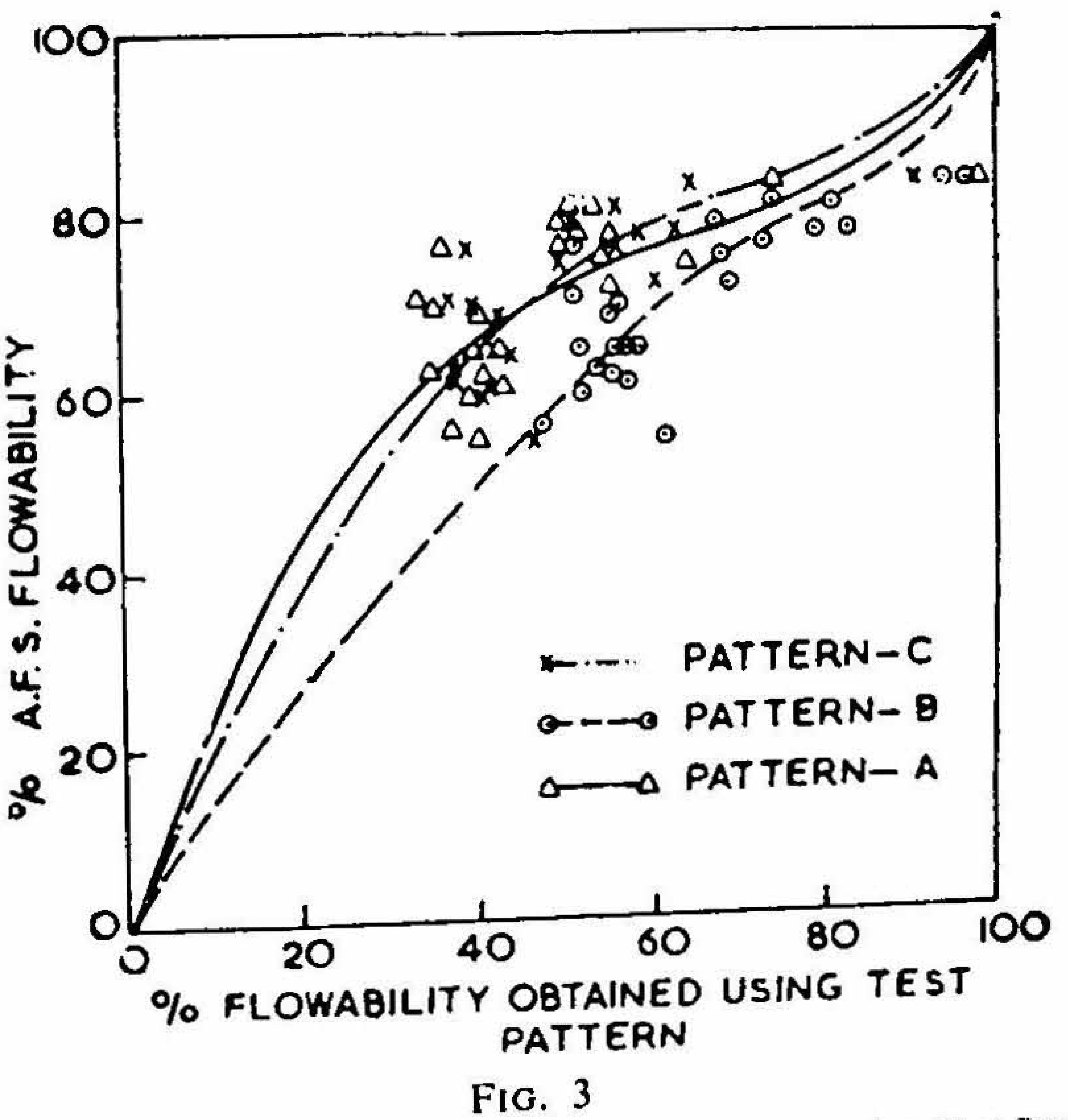

FIG. 3

Percent *AFS* Flowability *Vs* Percent Flowability Obtained using Test Patterns.

The scatter in the results and the deviation from linearity may be attributed to the fact that AFS flowability violates most of the theoretical concepts which a flowability test should have. First of all, compaction is being measured ahead of the rammer in the direction of the ramming force, rather than at right angles to it. Secondly, the test arbitrarily assigns a range of 0 0 – 0.1 in. per 2-in. specimen for measurement of flowability, implying a decrease in length of 0.1 in. on the fifth ram denotes that the sand has zero flowability, which is not entirely valid. Thirdly, this test measures flowability of sand which has already been compacted to a greater degree. Therefore, it is a measure of flow of sand after and not during eompaction.

(*b*) +GF+ *Method*: Bearing the concept in mind that (i) a sand of zero flowability will not flow at all into the pattern recess during mould preparation and also into the bottom groove of +GF+ specimen tube and (ii) a sand of ideal flowabillity (100%) will fill completely the pattern recess and the bottom groove of the +GF+ tube with uniform density, curves were drawn for +GF+ flowability values against flowablily during mould preparation (Fig. 4). It is inferred from those that although the amount of scatter is less compared to those in (Fig. 3), it is not negligible. The relation is non-linear and so the nature of the curve is difficult to find.

(*c*) *Kennedy Method*: Graphs drawn between Kennedy flowability values and those obtained using test patterns (Fig. 5) show straight line

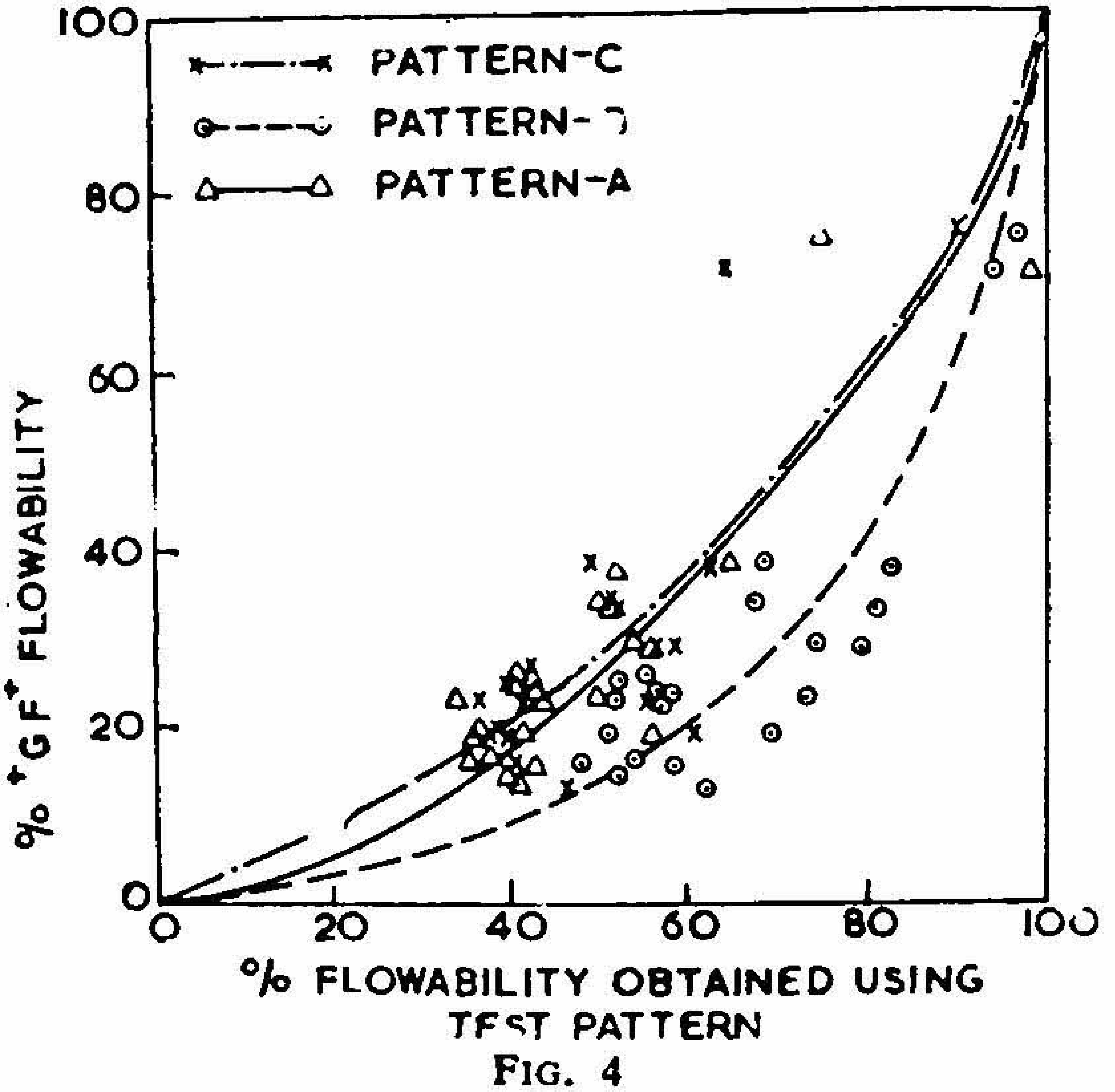

FIG. 4

Percent +*GF*+ Flowability *Vs* Percent Flowability Obtained Using Test Patterns.

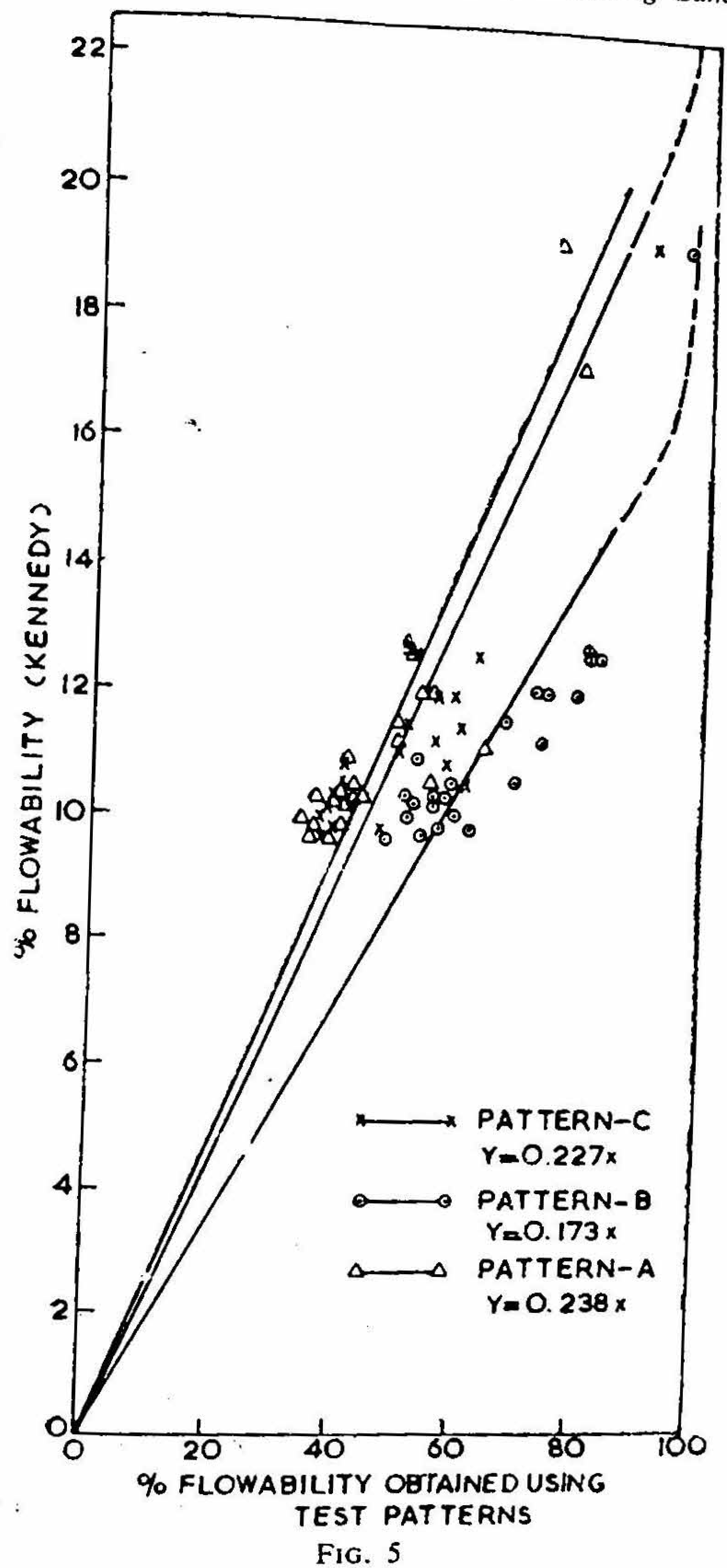

FIG. 5

Percent Kennedy Flowability *Vs* Percent Flowability Using Test Patterns.

relationship upto about 85% test pattern flowability values. Beyond this value the nature of the graph changes its form from straight line to a curve, which will probably become asymptotic to 100 per cent ordinate line. The slope of the lines are different and this may be attributed to variation in the shape of patterns.

(*d*) *Analytical Method*: Flowability values found by analytical method do not show a linear relation with the values obtained using test patterns A and C (Fig. 6), but show linear relation with the values of pattern B. However, the scatter in all the cases is quite considerable. The scatter may be due to the fact that in the expression $\tan^2(45+\phi/2)$, ϕ (angle of internal friction) is the only variable. This means flowability depends only on angle of internal friction which is not the case, instead there are also many other factors involved.

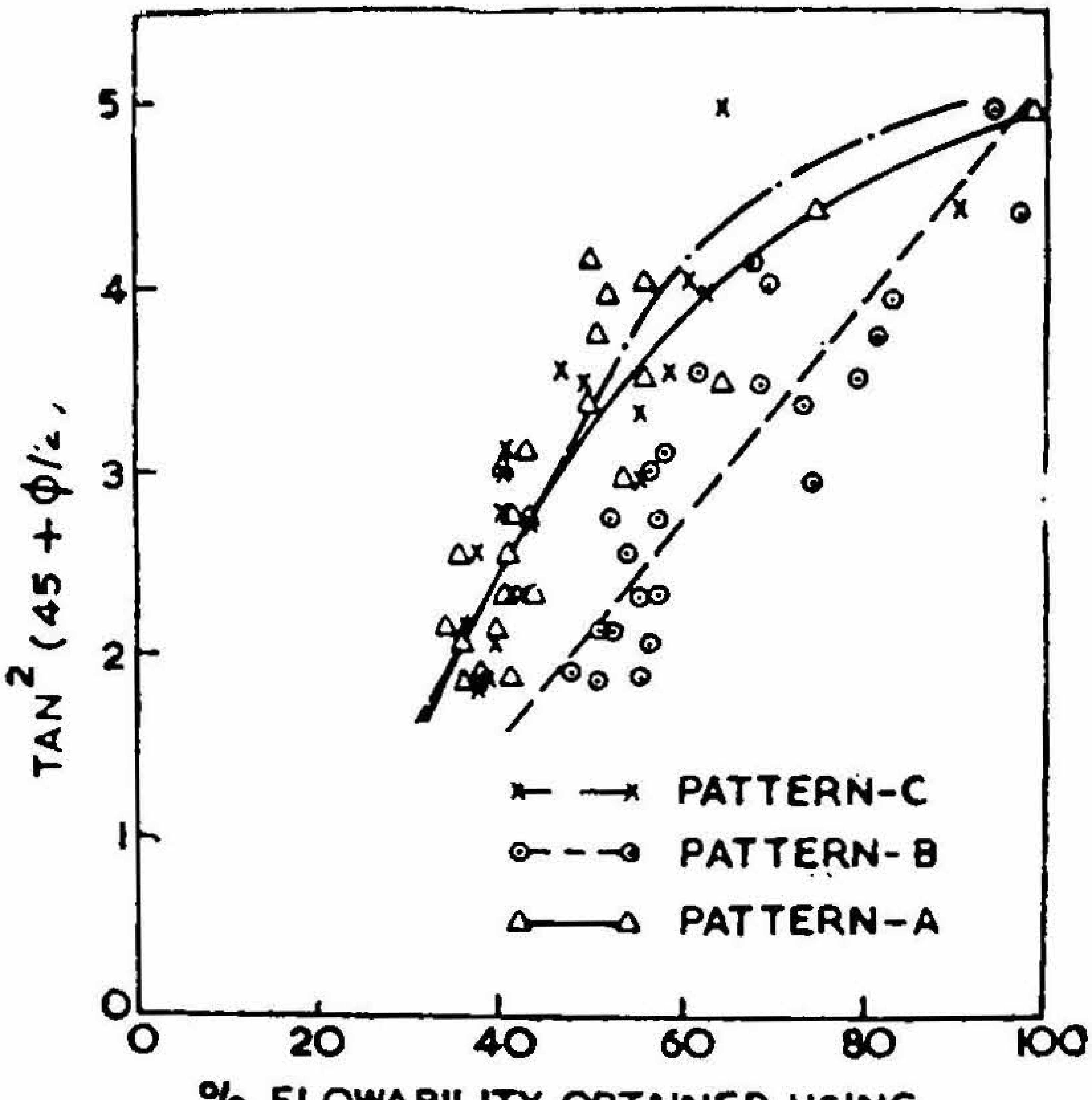

FIG. 6

TAN² (45+φ/2) Vs **Percent Flowability Obtained Using Test Patterns.**

In the calculation of ϕ in this work f_s has been taken as cohesion values which is not actually true, since in the AFS shear test, about half the specimen weight acts on the predermined shear plane as the normal stress. But as a near approximation it is considered valid for our purposes and error due to this assumption can be well expected to be within the errors involved in the experimentation itself.

3.3.2 *Selection of one pattern out of the three used*: The relationship berween the flow values obtained using the test patterns are shown in (Fig. 7).

The graphs showing per cent flowability obtained using pattern A and C against that using pattern B is a straight line upto 85% flowability value obtained by pattern B and above this value it takes the form of a curve. The same type of curve is obtained in Fig. 5(B). The relation between pattern A and C is found to be linear.

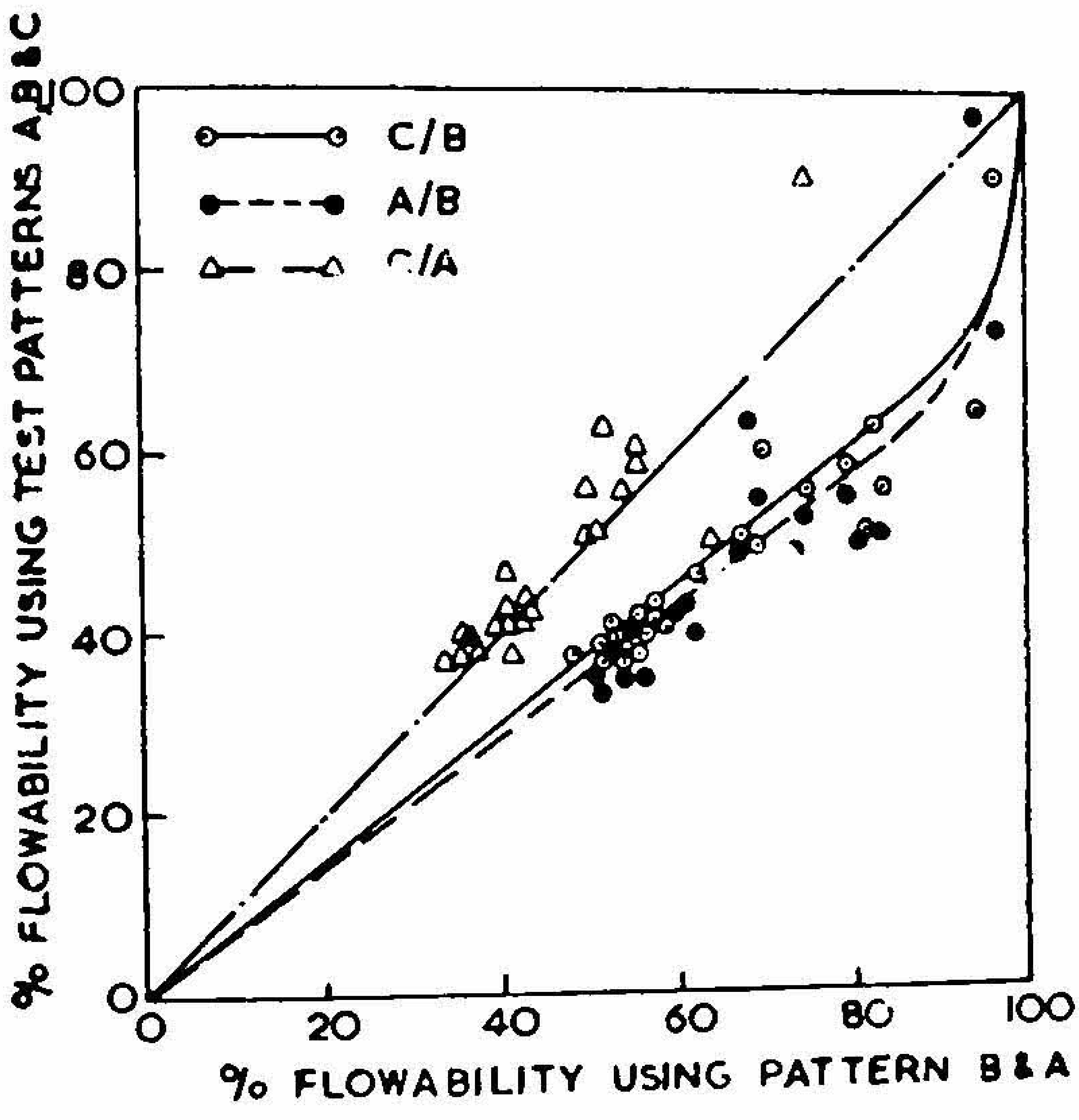

FIG. 7

Relationship between the Flowability Values Obtained by the Test Patterns.

3.4 *Effect of Bentonite-water ratio on Flowability*:

From the results shown in Figs. (8–11) the following can be inferred:

(i) There is close confirmity between the flowability values obtained by Kennedy and +GF+ methods and that obtained during mould preparation

(ii) Within the limit of experimental errors, patterns show similar behaviour for all the ratios considered.

(iii) For bentonite-water ratios of 0.8 and 1.0 there are not much changes in the flowability values obtained by all the methods considered.

(iv) For bentonite-water ratios of 1.33 and 2.0 decrease in flowability is noticed from 6% bentonite content to 8% of it and afterwards it remains almost constant.

(v) The effect of bond content on the flowability is not so significant at lower bentonite-water ratio as on the higher (> 1) bentonite water ratios.

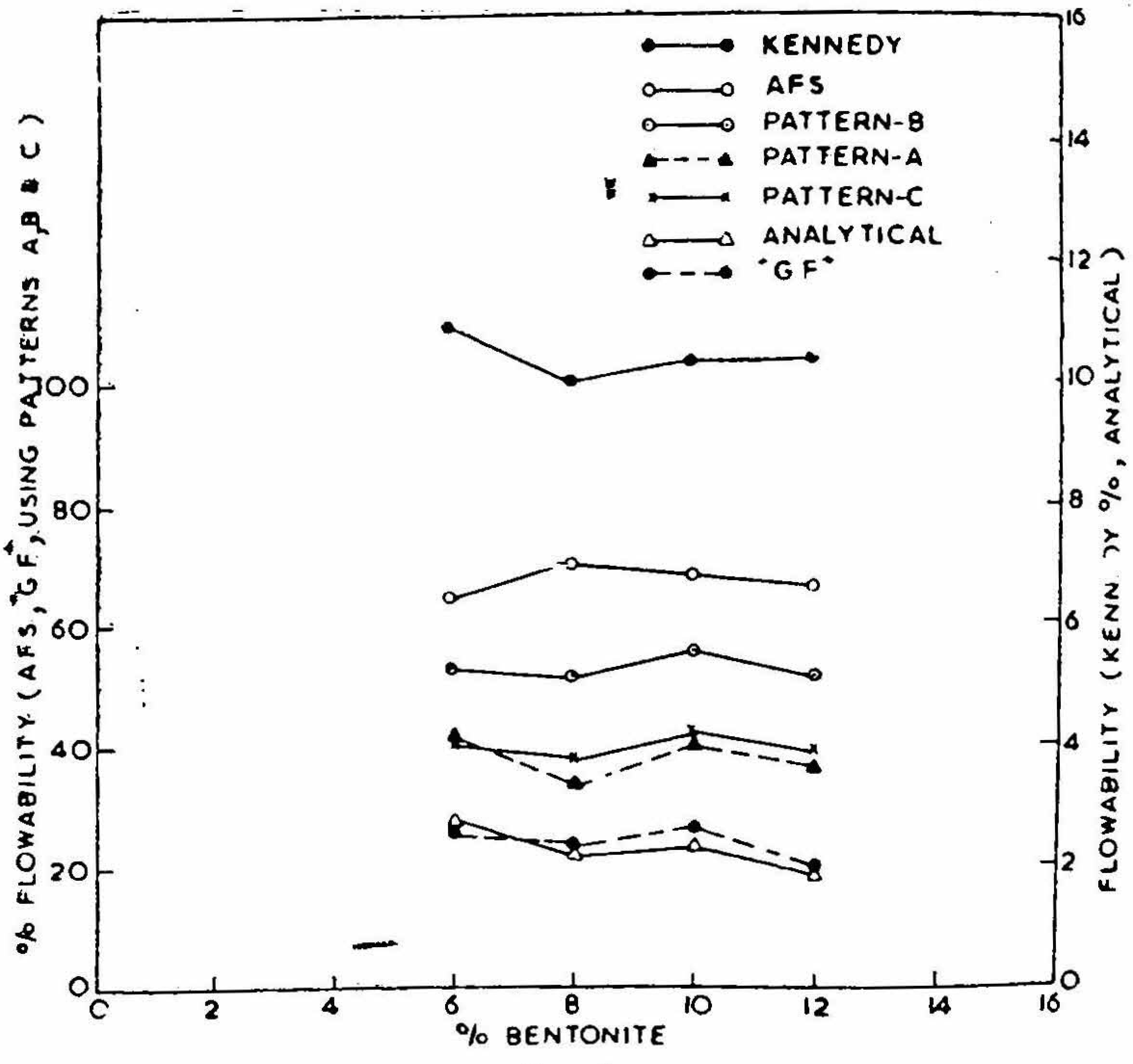

FIG 8

Effect of Bond content on Flowability for Bentonite Water Ratio of 0.8.

3.5 *Effect of Additives:*

From the previous discussion Kennedy test was found to be most representative method and so it was used to study the effects of additives on the flowability of the sand mix, designed for medium type grey iron foundry The sand contained 6% bentonite and 4.5% water.

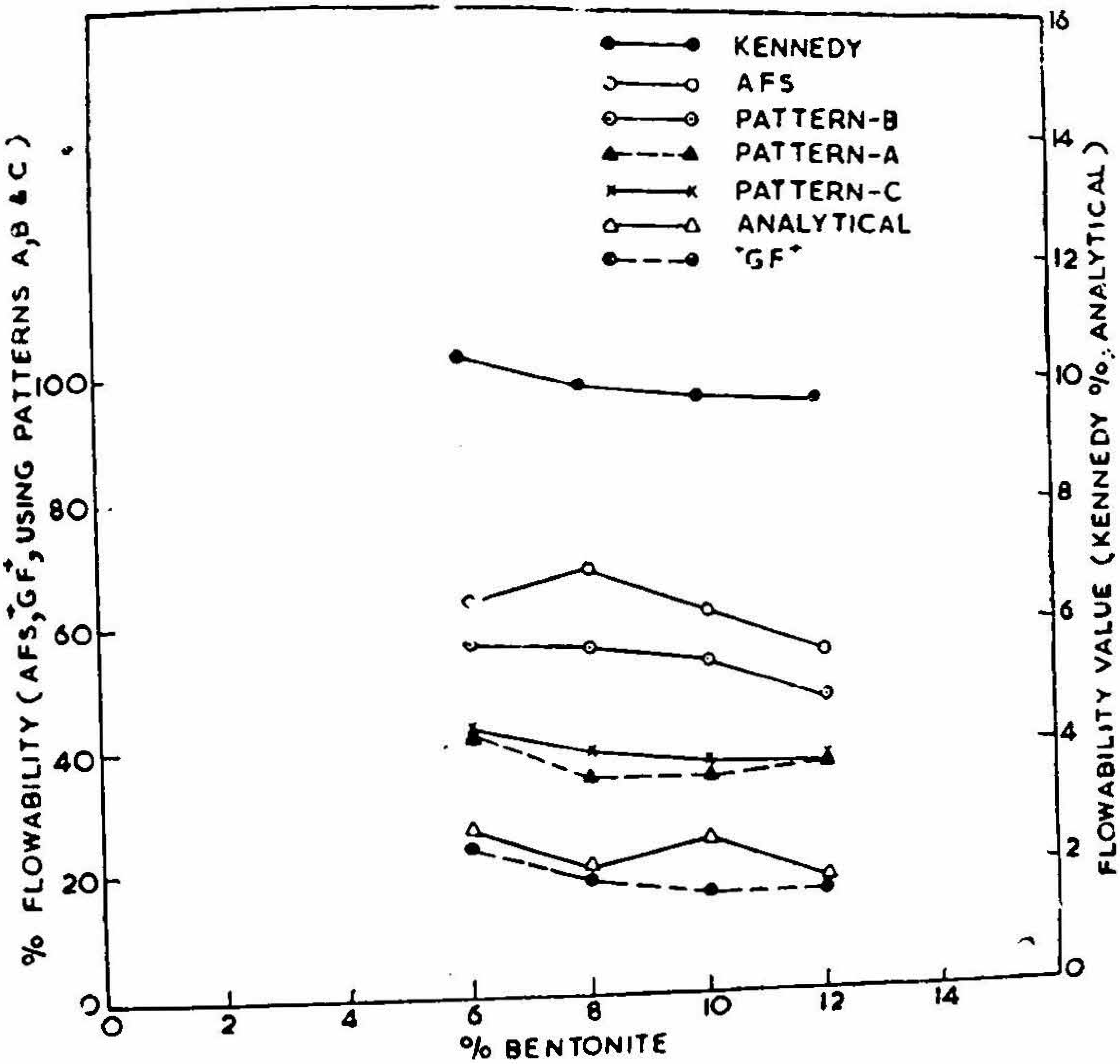

FIG. 9

Effect of Bond content on Flowability for Bentonite Water Ratio of 1.0.

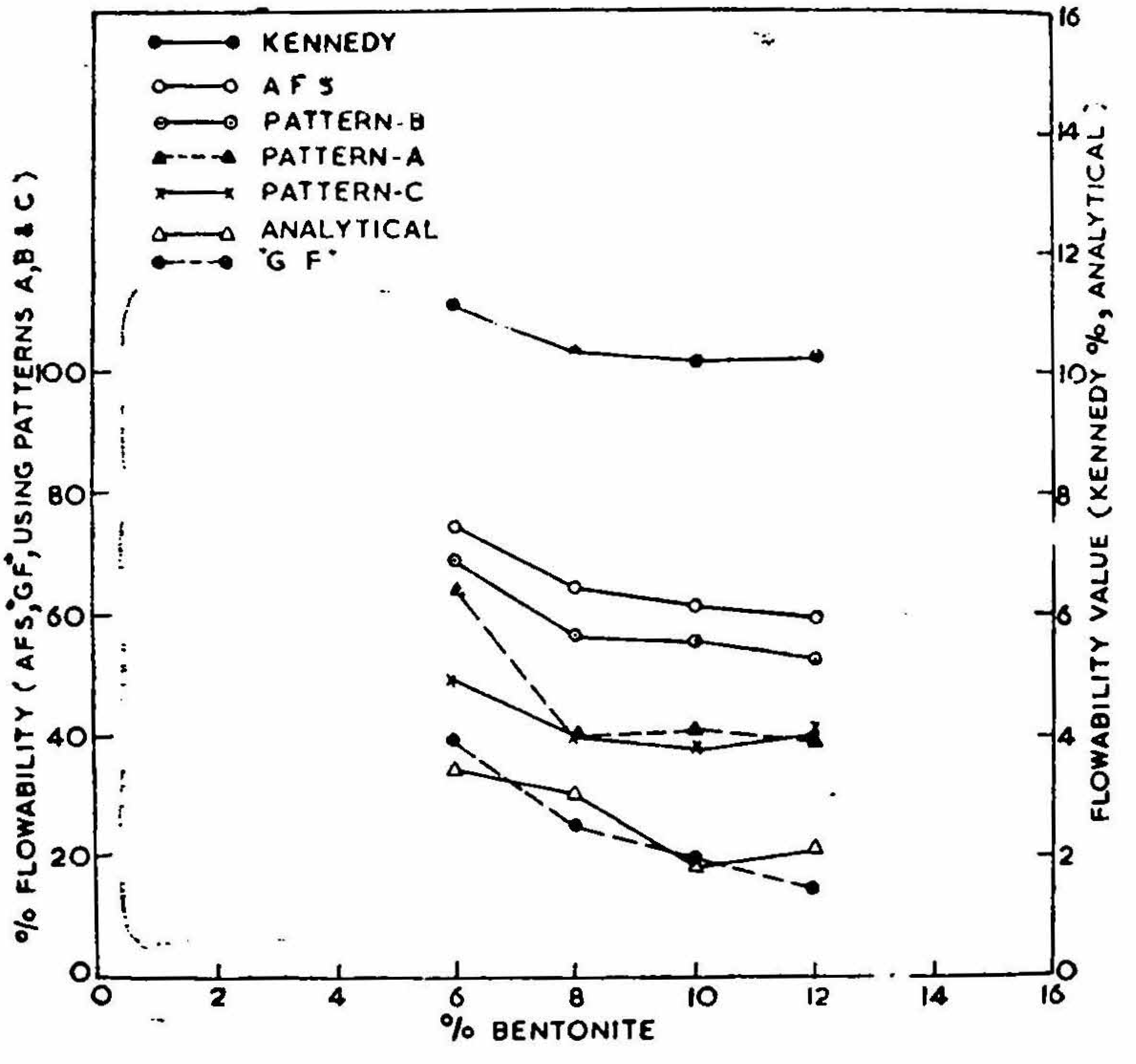

FIG. 10

Effect of Bond content on Flowability for Bentonite-Water Ratio of 1.33.

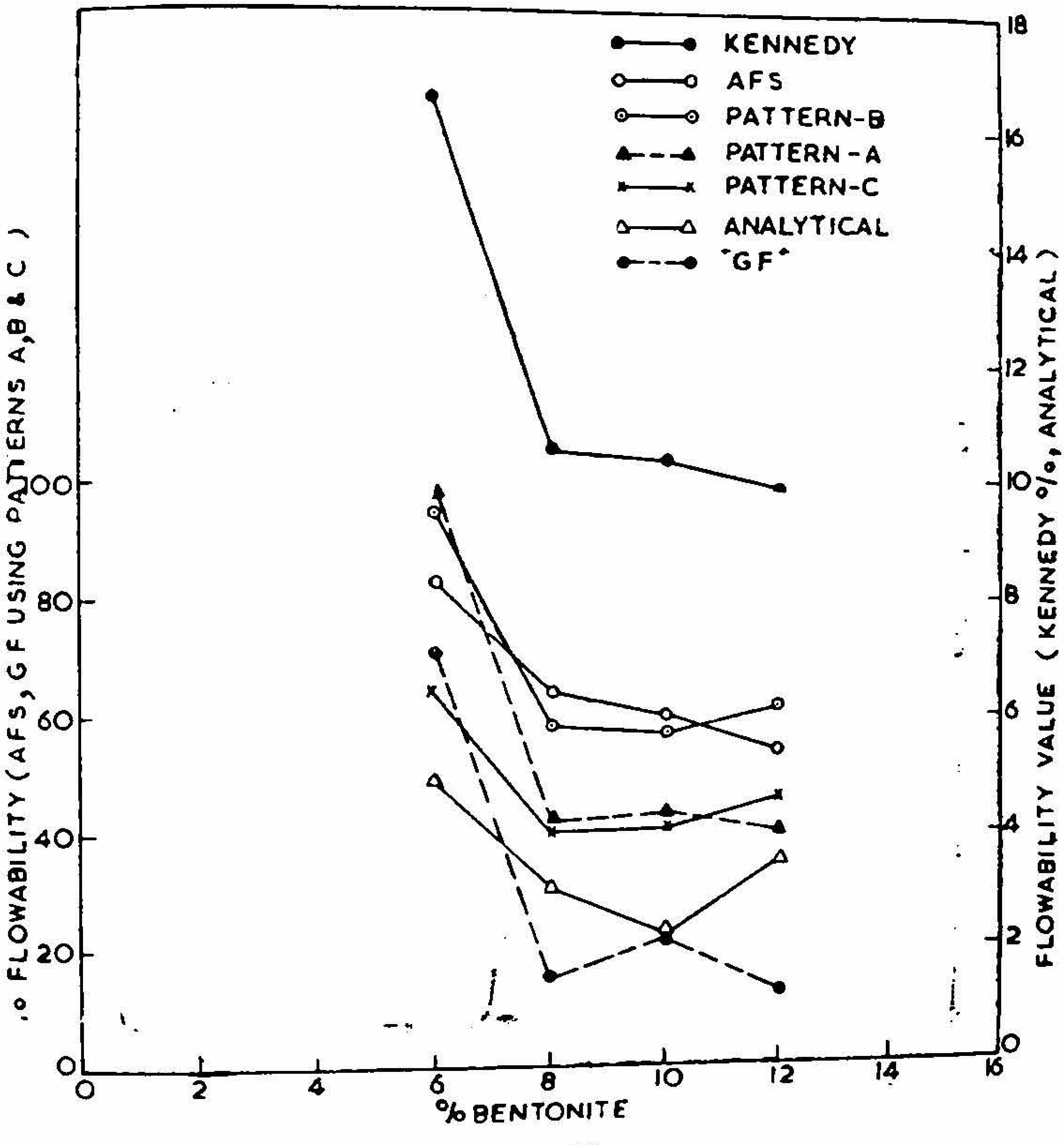

FIG. 11

Effect of Bond content on Flowabilty for Bentonite-Water Ratio of 2.0

Fig. 12(A) shows that flowability increases upto 1% of dextrin addition and further addition of it decreases the flowability. The reason for such effect may be as follows: As dextrin is added it absorbs a part of water added and so bentonite water ratio increases. Also decrease in strength upto 1% dextrin addition was noted. So due to increase in bentonite water ratio and decrease in compressive strength increase in flowability is noticed. Beyond one per cent addition dextrin also starts acting as bond, hence increase in strength is observed which makes the sand less flowable.

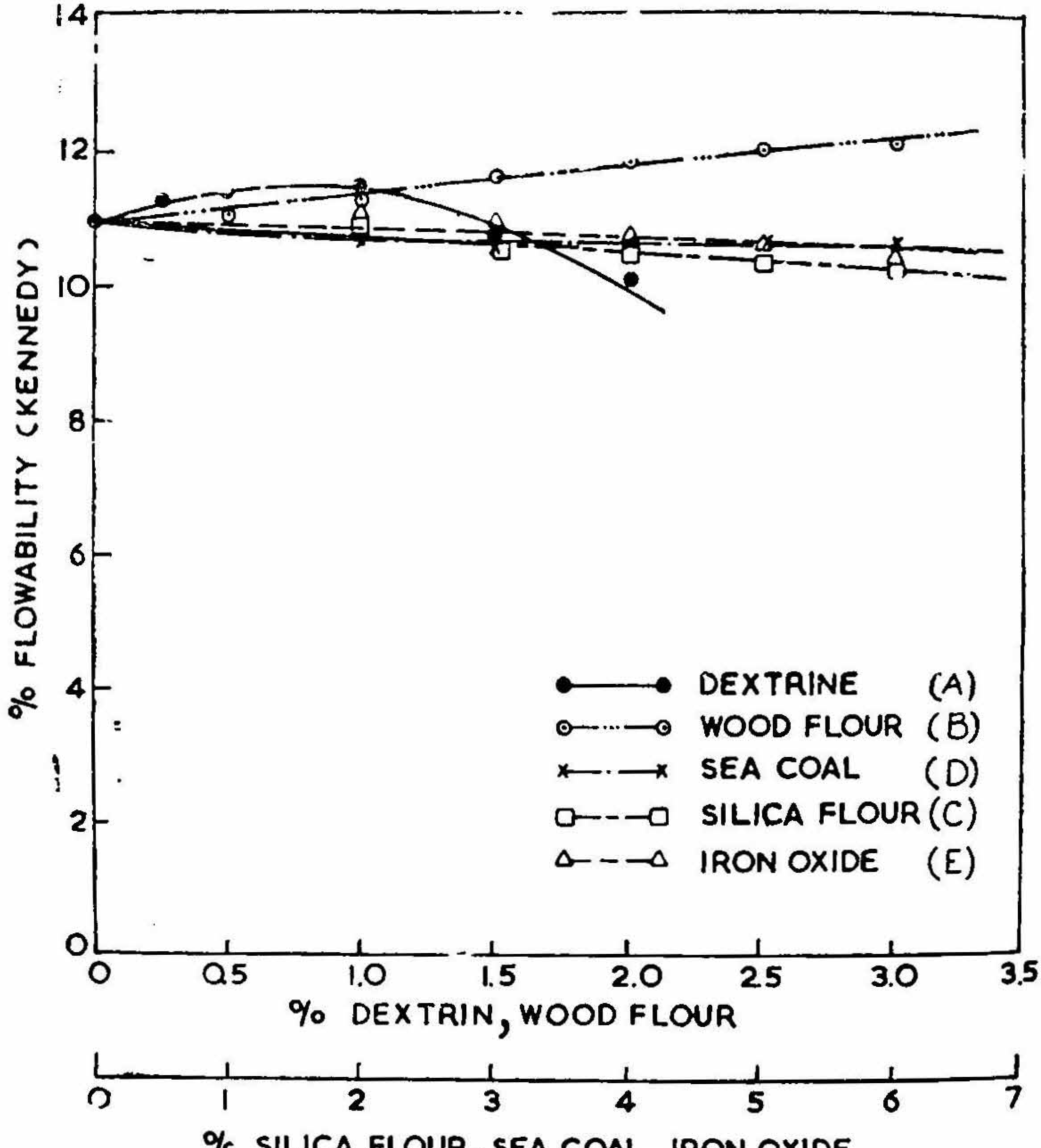

FIG. 12

Effect of Additives on the Flowability of 6 % Bentonite 4.5 % Water Bonded Silica Sand Mulled for 8 Minutes.

Wood flour also absorbs water but it does not act as a bond, so with each addition of wood flour more and more water is obsorbed by it thereby increassng the bentonite water-ratio and hence flowability (Fig. 12B).

Additions of silica flour, sea coal and iron oxide to the sand mix decrease the flowability (Fig. 12C, D and E). These additions also absorb a part of water added. The increase in flowability due to this effect is counteracted by decrease in flowability due to increase in compressive strength and per cent fines in the sand and the net effect shows a decrease in flowability.

4. Conclusions

(i) AFS, +GF+ and analytical methods show considerable amount of scatter in results when compared with the values of flowability obtained during actual mould preparation (jolt-squeezing).

(ii) Kennedy method shows linear relationship over a specific range with the flowability values obtained using test patterns and amount of scatter is less and therefore it was selected for subsequent use. The next best method was +GF+ method.

(iii) The test patterns show similar behaviour during mould preparation within the limit of experimental and human error.

(iv) Increase in bentonite-water ratio increases flowability for a given bond content and for a given bentonite water ratio flowability decreases with increase in bond content.

(v) At higher bentonite-water ratios, the decrease in flowability is considerable at bond content of about 12-14.

(vi) Upto 1% of dextrin addition an increase in flowability is noticed. On further addition of it flowability decreases.

(vii) Wood flour increases the flowability whereas silica flour, sea coal and iron oxide decreases it. Silica flour shows the maximum decrease in flowability.

(viii) Kennedy test is most suitable for measuring flowability of sands containing additives also.

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