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IISc THESES ABSTRACTS

Thesis Abstract (Ph.D.)

Studies on silica and zircon sands bonded with silicate-ester systems by K. G. Chandrappa.

Research supervisors: S. Seshan and R. M. Mallya.
Department: Mechanical Engineering.

1. Introduction

Cold-set processes have revolutionised mould and core making techniques and have lead to reduced need of skilled labour. Chemical binders have made a steady progress in the production of moulds and cores for small, medium and big castings. A study of published data indicates that cold setting systems may be broadly classified under organic, inorganic and miscellaneous binder systems.

Under organic binder systems phenolic, furan, alkyd, lignin and free radical systems are the popular ones.

In inorganic systems, sodium silicate-bonded sands are the most widely used. The hardening effect in these systems is brought about by a hardener which may be a solid, liquid or gas. Ferrosilicon, dicalcium silicate and CO_2 gas are some of the commonly used hardeners with sodium silicate. Organic esters were introduced some years back as hardeners, but it is observed from the literature that the use of such esters has not yet been fully exploited, probably due to the lack of adequate information on the materials and the process. Therefore an investigation was taken up to study the properties of sand systems bonded with sodium silicate and hardened by esters.

2. Details of investigation

Two grades of commercially available sodium silicates and two types of esters were made use of in the investigation. Initially, using thin layer chromatography (TLC), infrared spectroscopy (IR) and nuclear magnetic resonance spectroscopy (NMR) the characterisation of the ester was completed; ester E_1 was found to be ethylene glycol diacetate (EGDA) of about 99% purity. The other ester E_2 has been found to contain about 90% of glycerol diacetate (diacetin), the remaining 10% being accounted by triacetin and impurities. Naturally, the properties of the sand systems hardened by these two esters will be slightly different from each other.

Subsequently, experiments were carried out using respectively silica sand and zircon sand as base moulding materials, sodium silicates B_1 and B_2 as binders and the above esters E_1 and E_2 as hardeners (B_1 with E_1 and B_2 with E_2). With different combinations of binder and hardener contents, investigations were carried out to study the setting characteristics, strip time, pour time, setting time and permeability. From the findings of these trials, the compositions which gave the best possible properties for each sand system were optimised. By means of scanning electron microscopic technique and X-ray diffraction technique, the nature of bond formation on the sand particles was analysed and justification for optimum composition made. Differential thermal analysis was adopted to study the thermal stability of these optimised mixes.

The compositions optimised in each system was used for further investigations on the other aspects as briefed below:

i) *Thermal properties*: The line heat source method and the melting and casting technique were adopted to assess the properties of thermal conductivity, heat diffusivity and temperature diffusivity of the four sand systems at different temperatures. Proceeding further, the rate of heat extraction and the quantity of heat extracted from the moulds were calculated and the mould constant for each system computed. A comparison of the above thermal properties of the systems for the two base sands *viz*., silica and zircon was then attempted. In general, the thermal properties of the above sands were seen to be satisfactory for foundry applications.

ii) *Knockout property*: Realising that the casting trial method yields more realistic inferences on the knockout property than the measurement of retained strength, casting trials were conducted on all the sand-binder-hardener systems using aluminium, aluminium-12% silicon alloy, copper and grey iron. The knockout property of each system has been quantified and compared with the other systems as well as with conventional green sand. Knockout property of the ester hardened sands were found to be very good.

iii) *Friability*: Experiments were planned to study the property of friability of the different systems mentioned above. The mouldability tester was made use of in the assessment of the above property. It was established through this investigation that the friability of the above sand systems is not higher than the other conventional sands in common use.

iv) *Surface finish and mechanical properties of castings made*: In order to compare the surface finish and mechanical properties of castings produced in moulds made of the above sands, casting trials were completed with aluminium, aluminium-12% silicon alloy, copper and grey cast iron. Zircon sand systems obviously result in better surface finish and marginally superior mechanical properties. However, all the sand systems result in acceptably good surface finish and more than the minimum of specified mechanical properties.

Through the above investigations, a comparative study of the properties of sand systems comprising of silica and zircon sand with sodium silicate binders and ester hardeners has been completed. The sand systems with the above ingredients develop adequate mould properties and result in acceptably good castings. The variation in properties of the systems from one another is due to the difference between the esters and the resulting difference in chemical reactions.

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Thesis Abstract (Ph.D.)

Studies on cracking of reinforced concrete and ferrocement flexural members and fracture behaviour of ferrocement by N. Ganesan.

Research supervisor: Prakash Desayi.
Department: Civil Engineering.

1. Introduction

In the limit state design of concrete structures, cracking is one of the limit states which the design has to satisfy to ensure serviceability of the structure. Limiting the width of crack is important from the aesthetic point of view, to ensure water tightness and to safeguard the reinforcement against corrosion[1-3]. For this purpose, suitable methods of estimating the maximum width of crack and better understanding of the cracking of reinforced concrete structures are required. As the width of cracks is subjected to a large degree of scatter, methods based on statistical analysis using a large number of test results, probably, are better suited. While a number of studies on cracking of reinforced concrete have been reported, very few investigations are available for the determination of spacing and width of cracks in ferrocement members. In the few studies related to cracking in ferrocement reported so far, the cross-section of the specimen was rectangular and the reinforcement consisted of only mesh wires. In practical cases, as ferrocement structures are normally 15 to 30 mm thick and owe their strength and stiffness to their form, members with undulated cross-section and additional skeletal steel to take care of tensile forces are used. However, no attempts have been made to predict the spacing and width of cracks occurring in such ferrocement elements. Another important aspect in the field of cracking is the application of the concepts of fracture mechanics to characterize the fracture behaviour of cementitious materials. The review indicates that no attempts have been made to determine the fracture properties of ferrocement.

Taking note of the above points, the aim of this investigation has been: (i) determination of the spacing and width of cracks in (a) reinforced concrete flexural member, and (b) ferrocement flexural members with different types of cross-sections *viz.*, channel section, trapezoidal section and built-up I-section, and (ii) the study of the fracture behaviour of ferrocement.

2. Spacing and width of cracks

2.1 *Reinforced concrete flexural members*

A method is proposed to determine the spacing and maximum width of cracks in reinforced concrete flexural members. The constants appearing in the proposed method are determined from a statistical analysis of 732 maximum crackwidth data collected from literature. From the above studies, the following equation is arrived at to determine the maximum crackwidth in reinforced concrete flexural members:

$$W_{bt} = \frac{k_t f_{ct} A_e \varepsilon_s}{k_b (M_{cr}/M_u)^n f_{bu} \Sigma \pi \phi} \left(\frac{h-x}{d-x}\right) \tag{1}$$

where $k_t = k_b = 2/3$ and $n = 0.33$.

The computed values of spacing and maximum width of cracks are found to compare satisfactorily with the experimental values. Figure 1 shows a typical plot of calculated maximum crackwidth values *versus* experimental maximum crackwidth values of Base[4] *et al.* It can be seen from the figure that most of the points lie within ± 45% lines of agreement. Noting the difficulties involved in the experimental and analytical determination of crackwidth, this agreement is considered satisfactory.

2.2 *Ferrocement flexural members*

The method proposed for reinforced concrete flexural members has been extended to ferrocement flexural members having different types of cross-sections, *viz.*, (i) channel section, (ii) trapezoidal section and (iii) built-up I-section with appropriate modifications introduced to account for the presence of wire meshes. Figure 2 shows the details of different cross-sections of ferrocement members studied. In the case of ferrocement channel elements 107 maximum crackwidths have been used to determine the constants appearing in the proposed method. The equation for the maximum crackwidth, thus obtained is

$$W_{bt} = \frac{k_t f_{ct} A_e \varepsilon_s}{k_b (M_{cr}/M_u)^n \Sigma \left[f_{bu} \left(\frac{d_1 - x}{d-x}\right) \pi \phi \right]} \left(\frac{h-x}{d-x}\right) \tag{2}$$

where $k_t = k_b = 2/3$ and $n = 0.4$.

The spacing and width of cracks predicted by the proposed method have been found to compare satisfactorily with the experimental values. Figure 3 shows typical variation of the spacing of cracks obtained theoretically and experimentally with the factor 'm' for the channel specimens F_8 and F_9. Also the crackwidths calculated using the proposed method are found to compare better with the test results than those given by other methods[5-7] (Table I).

In the case of trapezoidal-sectioned roofing elements and built-up I-joists computations indicated that the presence of flange on the tension side influenced the strain and hence the crackwidth. A correction factor to that effect was introduced in the proposed method and determined from a regression analysis. The equation for the maximum crackwidth in the case of (a) trapezoidal-sectioned roofing element is,

$$W_{ma'} = \frac{k_t f_{ct} A_e \varepsilon_{a'} F_1(t)}{k_b (M_{cr}/M_u)^n \Sigma \left[f_{bu} \left(\frac{d_1 - x}{d-x}\right) \pi \phi \right]} \tag{3}$$

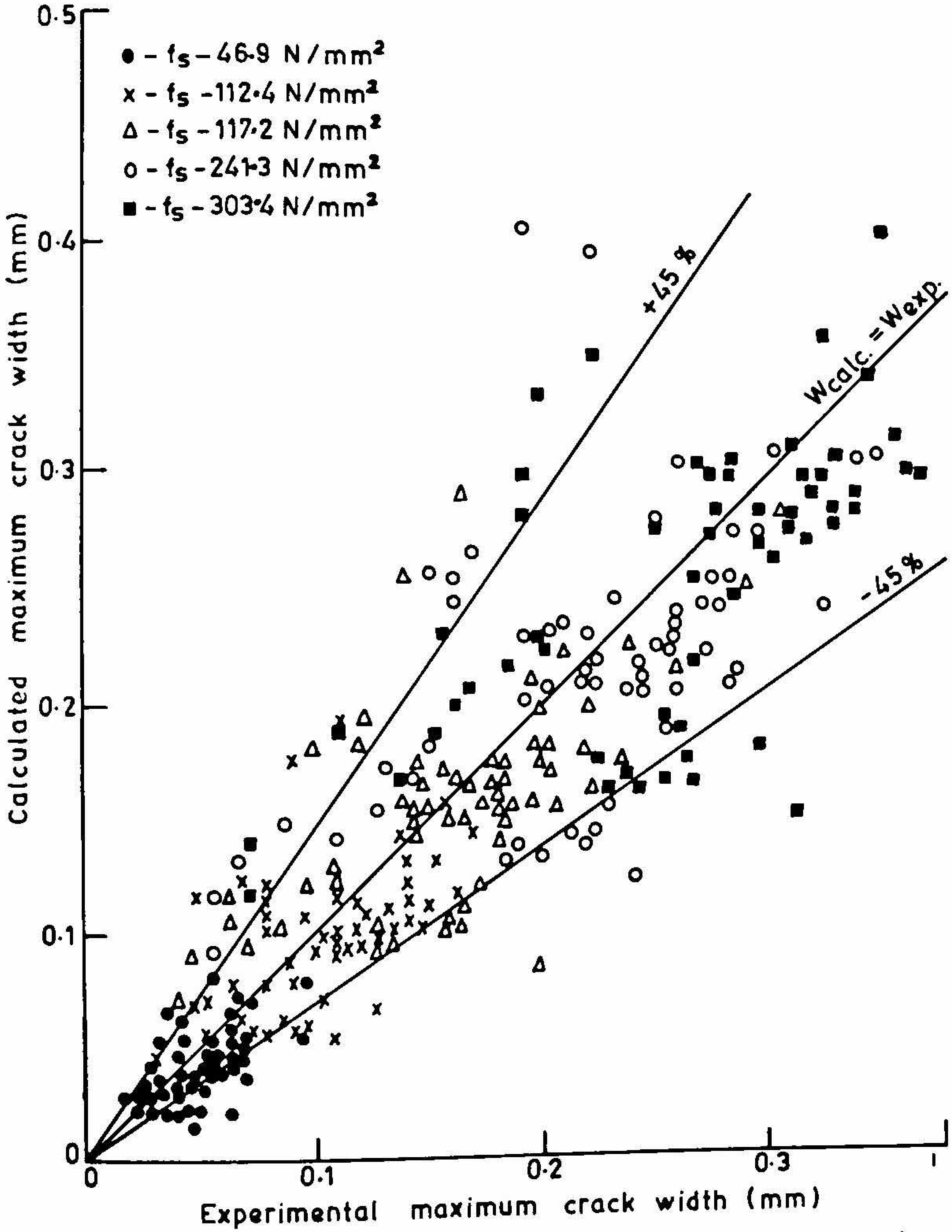

Fig. 1. Comparison of calculated crackwidths with the experimental crackwidths of Base *et al*[4].

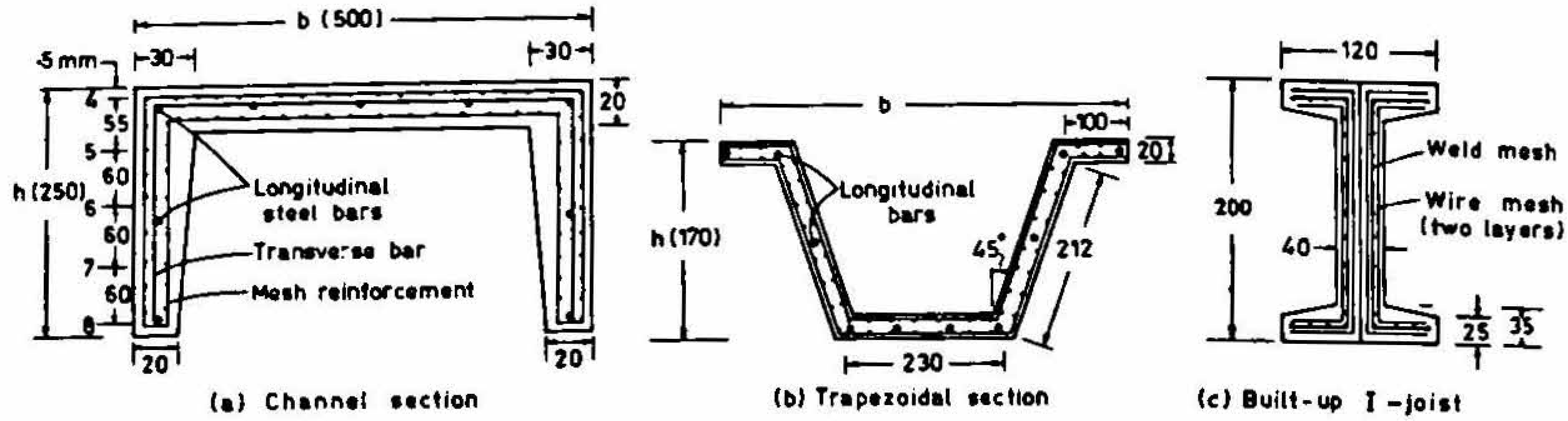

FIG. 2. Details of cross-sections of ferrocement flexural members (in mm).

where $k_t = k_b = 2/3$, n = 0.92, and

$$F_1(t) = 0.5903\ (T_{sf}/T_{cf}) - 0.0397. \qquad (4)$$

(b) built-up I section is,

$$W_{ma'} = \frac{k_t f_{ct} A_e \varepsilon_e F_2(t)}{k_b (M_{cr}/M_u)^n \Sigma \left[f_{bu}\left(\frac{d_1 - x}{d - x}\right)\pi\phi \right]} \qquad (5)$$

where $k_t = k_b = 2/3$, n = 0.4 and

$$F_2\ (t) = 0.2944\ (T_{sf}/T_{cf}) - 0.151. \qquad (6)$$

3. Fracture behaviour of ferrocement

An attempt is made to study the fracture behaviour of ferrocement using notched beam and double cantilever beam (DCB) specimens. Figures 4 and 5 show details of the notched beam and DCB specimens tested in this study.

From the tests on 60 notched beam specimens it has been found that J-integral appears to be a useful fracture criterion for ferrocement. Using the test results of 30 DCB specimens, crackgrowth resistance curves (R-curves) were obtained using different methods available in

Table I
Comparison of calculated maximum crackwidths with experimental values

Sl. no.	Equation used	No. of test results	W_{calc}/W_{expt}	
			Average	Coefficient of variation (per cent)
1.	Logan and Shah[5]	32	0.842	51.43
2.	Balaguru *et al*[6]	32	0.056	44.29
3.	Balaguru[7]	32	0.357	36.69
4.	Proposed method	32	1.004	42.63

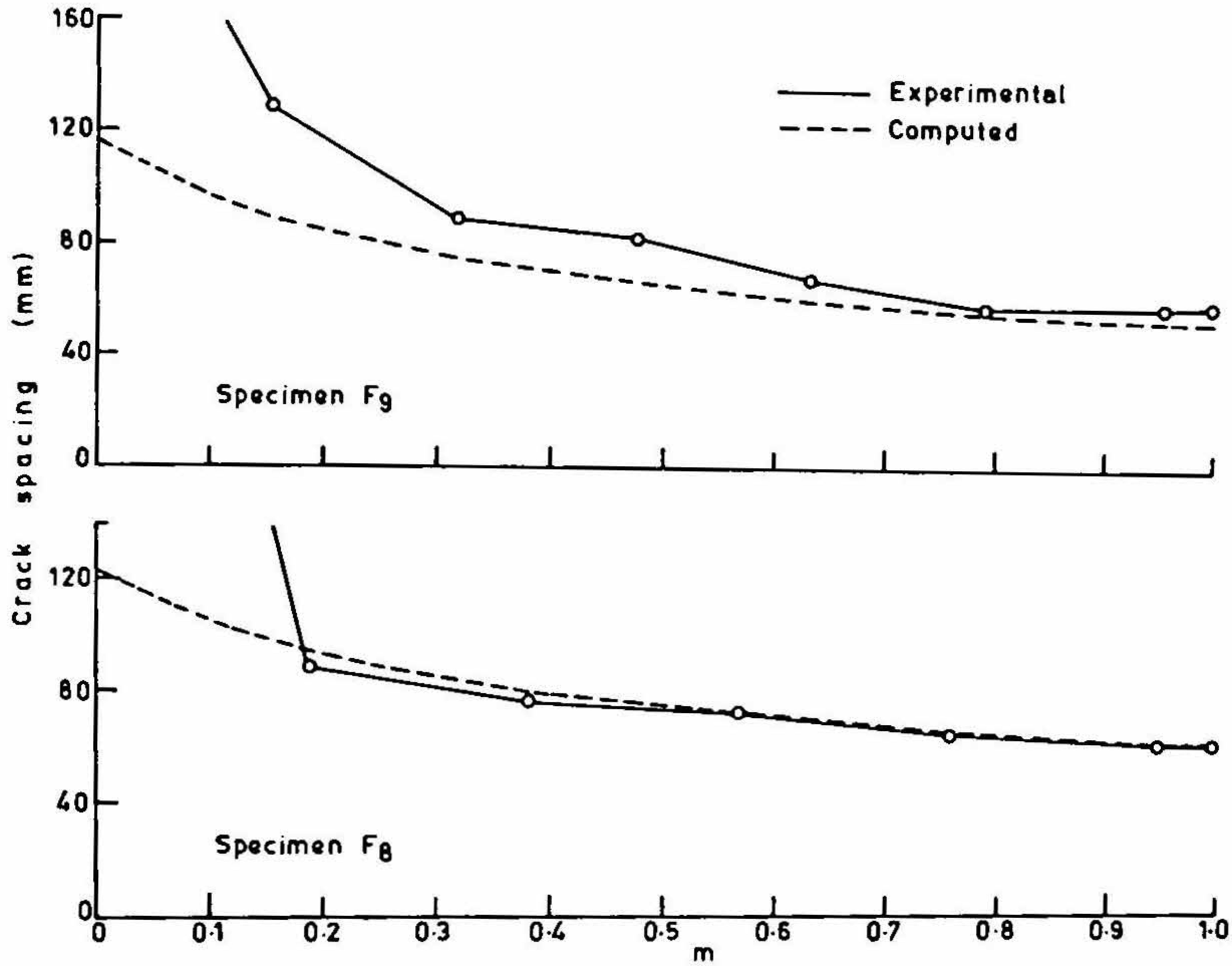

FIG. 3. Variation of crack spacing against the factors 'm' for specimens F8 and F9.

literature and compared. From these studies it has been found that (i) the R-curves obtained taking into account the effect of permanent deformation were dependent on the initial notch depth, (ii) the R-curves are influenced by the percentage of mesh reinforcement, and (iii) the values of strain energy release rate in R-curves increase with the increase of percentage of mesh reinforcement.

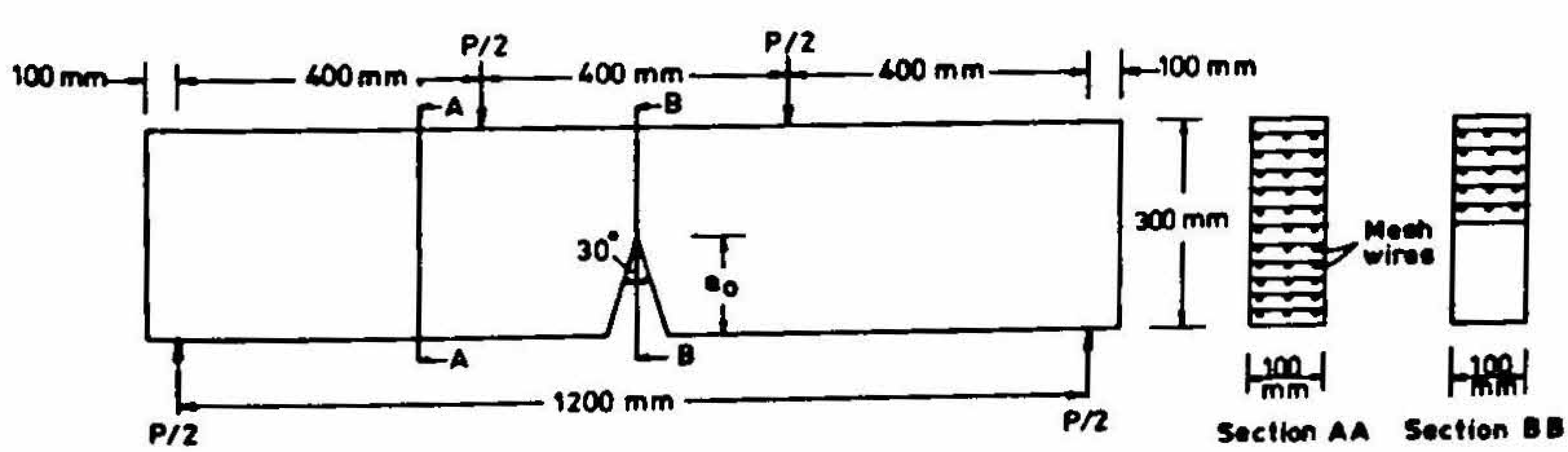

FIG. 4. Dimensions of ferrocement notched beam specimen.

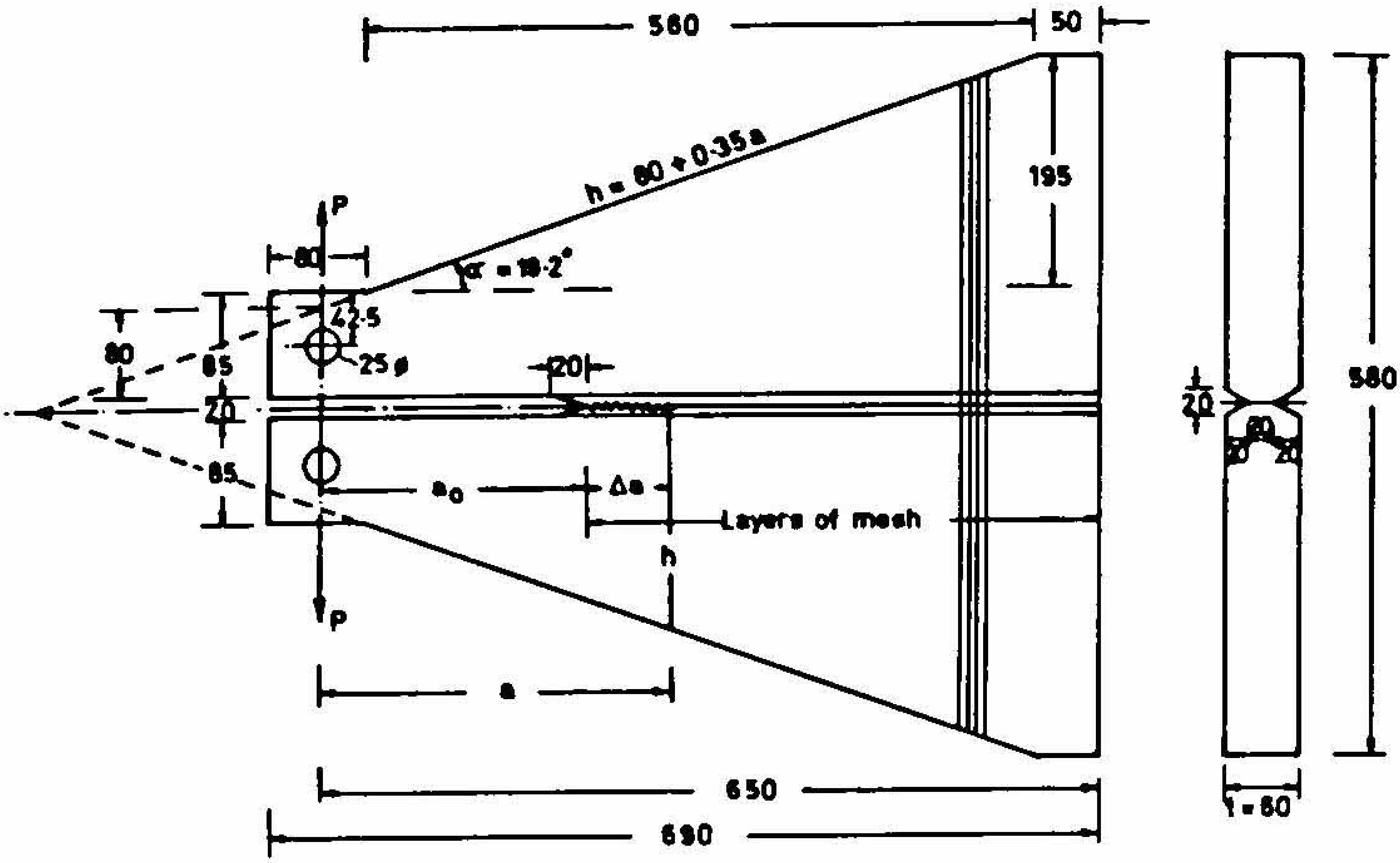

FIG. 5. Dimensions of ferrocement double cantilever beam specimen (in mm).

4. Conclusions

From the above studies the following conclusions are arrived at.

(i) The methods proposed for reinforced concrete and ferrocement flexural members for the determination of spacing and maximum width of cracks have given satisfactory results.

(ii) From the fracture studies on ferrocement, it has been found that the elastic-plastic fracture mechanics approach, J-integral, seems to be a useful fracture criterion for ferrocement.

(iii) The tests on double cantilever beam specimens indicate that the R-curves obtained taking into account the effect of permanent deformation were dependent on the initial notch depth and the R-curves are influenced by the percentage of mesh reinforcement.

Notations

A_e effective area of concrete or mortar in tension
a crack length
a_q initial crack length or notch depth
a distance from the compression face to the point at which crackwidth is being calculated
d effective depth in RC members and depth to bottom layer of tension steel in ferrocement specimens
d_1 depth to any layer of mesh wires or bars
h overall depth of the cross-section
f_{bu} ultimate bond stress
f_{ct} split tensile strength of concrete or mortar
k_b factor giving average bond stress
k_t factor giving average tensile stress

M bending moment
M_{cr} Moment at cracking
M_u ultimate moment
m ratio $(M - M_{cr})/(M_u - M_{cr})$
n a constant
P applied load
R crack growth resistance
T_{cf} tensile force in mortar in tension flange
T_{sf} tensile force in steel and mesh wires in tension flange
W_{bt} maximum crackwidth at the lower extreme tensile fibre
$W_{ma'}$ maximum crackwidth at a depth a' from top compression face (a' > x)
x neutral axis depth of cracked section
$\varepsilon_{a'}$ surface strain at a depth a'
ε_s strain in reinforcement
Δ_a crack extension
ϕ diameter of bar/wire

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Thesis Abstract (M.Sc. Engng)

Studies on the properties of synthetic moulding sands through the application of statistical design of experiments by S. P. Gadag.

Research supervisors: Malur N. Srinivasan, K. S. Subba Rao, and S. Seshan.
Department: Mechanical Engineering.

1. Introduction

This thesis highlights the application of statistical design of experiments in foundry to understand the adverse effect of dead clay built up gradually on repeated recycling of the moulding mix. The regression equations developed in this investigation have been effectively analysed by constructing nomograms in search of optimal composition of the moulding mix to achieve satisfactory sand control on the foundry floor. The usefulness of liquid limit in the control of foundry sands is also highlighted in the thesis.

Green sand moulding has been the basic moulding medium of foundry industry for years. It consists of the basic ingredients like base sand, binder, temper moisture and, if necessary, additives. The most commonly used base sand is 'silica sand', and the binder is 'clay' which is a common term for group of minerals called hydrous aluminium silicate. All clays when heated to 800°C, will have no bonding power, losing their plasticity due to structural breakdown. In such a state they are known as dead clays[1,2].

Whenever molten metal is poured into sand mould, some clay is heated to a temperature at which it breaks down, resulting in some amount of dead clay being formed. In a sequence of operations of recycling of moulding sand, the amount of dead clay goes on building up. The presence of dead clay has adverse influence on the physical properties as well as on the workability of moulding sands, causing various types of sand casting defects like scabbing, rat-tail, blow holes and so on. There is no way of removing dead clay without removing at the same time the active clay and other fine-grained materials. However, it has been suggested in the literature[1] that a small amount of any one of the organic additives namely, starch, dextrin and molasses, could be employed to counter the increasing trend of green strength and decreasing trend of shatter index due to the effect of dead clay.

A survey of literature indicated that no systematic work seemed to have been done earlier to evaluate the relative effectiveness of these organic additives in minimizing the detrimental effect of dead clay. Yet another aspect hitherto ignored is the potential of liquid limit as a measure of bonding properties in the control of foundry sand. Systematic investigations were, therefore, taken up to study the above aspects.

2. Experimental programme

2.1 Materials used

In the systematic design of statistical experimental programme, foundry clay-bonded moulding sand was chosen to have the following ingredients: silica sand, procured from Mangalore sea coast, as base refractory material, foundry grade bentonite clay as the binder, and commercially available organic additives namely starch, dextrin and molasses in addition to temper moisture. The base sand had fairly uniform grain size distribution with uniformity coefficient of about 2, AFS GFN 56 and AFS clay of 0.4%.

2.2 Sand preparation

Sand mixtures were prepared in the laboratory type sand muller having a batch capacity of 5 kg. The silica sand with bentonite were dry mixed for about 1 minute and after the addition of water, wet mulling cycle was carried out for about 6 minutes. The mixtures were discharged into polyethylene bags and tested immediately for green sand properties.

The optimum levels of clay and moisture contents were established from the functional graphs based on the criteria that green compression strength is $\geqslant$ 5 psi (or 352 gm/cm^2) and shatter index is $\geqslant$ 80%.

2.3 Sand with dead clay

In order to prepare sand with known amount of dead clay and to simulate the conditions of reused moulding sands on foundry floor, silica sand with known amount of active clay and corresponding optimum moisture, were first mixed according to mixing procedure as mentioned in section 2.2. Subsequently, this mixture was fired at 800°C in an electric furnace using graphite crucibles, for a duration of three hours, to ensure the conversion of all active clay to dead clay form.

The same mixing and mulling procedure was adopted even with the addition of organic additives to clay-sand-water system.

2.4 Evaluation of physical properties

Standard AFS cylindrical specimens of 50 × 50 mm were prepared using AFS rammer. Green compression strength, shatter index and bulk density measurements were made using + GF + make universal sand-testing equipment, Ridsdale shatter test apparatus and sensitive laboratory balances respectively. In the second part of the experimental programme, liquid limit tests of clay-bonded foundry sands with and without the addition of organic additives were performed using Casagrande as well as Cone Penetrameter liquid limit devices.

2.5 Statistical design of experiments

After establishing the optimum values of clay and moisture contents, the main experimental programme involving factorial design of experiments was performed in two parts for each of the three additives. The composition variables in both the parts were varied at two levels namely upper level designated as (+), and lower level designated as (−) as shown in Table I.

2.5.1 2^4–Factorial design of experiments: The bulk of the experimental programme constituting the first part was performed in the foundry laboratory using 2^4 factorial design of experiments to study the response of properties *viz.*, green compression strength, shatter index and bulk density to variations in dead clay, active clay, moisture and additive. Typical non-linear regression equations developed in case of starch additive (using the data in Table II) are as shown below:

$$Y_{1g} = 733.64 - 39.06X_1 + 165.63X_2 - 53.13X_3 + 54.06X_4 - 56.25X_1X_2 - 31.56X_2X_3 - 21.25X_2X_4 - 16.88X_3X_4 - 75.3X_1X_2X_3 - 21.56X_1X_2X_3X_4. \quad (1)$$

Table I
Levels, codes and intervals of variations of variable factors (in %) in the case of 2^4 matrices

Sl no.	Factors	Codes	Upper level + 1	Base level 0	Lower level − 1	Interval of variation
1.	Dead clay	x_1	24	16·	8	8
2.	Active clay	x_2	10	8	6	2
3.	Moisture	x_3	11	9	7	2
4.	Additives	x_4				
	i) Starch		2.63	1.73	0.83	0.9
	ii) Dextrin		1.5	1	0.50	0.5
	iii) Molasses		3.38	2.255	1.13	1.125

Table II
Results of the experiments (for I. starch)

Sl no.	Experiments	Bulk density (g)			Green compression strength (g/cm²)			Shatter index (%)		
		Trial (I)	Trial (II)	Mean $\bar{y}$	Trial (I)	Trial (II)	Mean $\bar{y}$	Trial (I)	Trial (II)	Mean $\bar{y}$
1.	(+ + + +)	156.27	156.30	156.285	655	655	655	85	86	85.5
2	(+ + + −)	161.52	161.10	161.310	630	625	625.5	77	79	78.0
3.	(+ + − +)	147.66	147.49	147.575	1010	1005	1007.5	62	68	65.0
4.	(+ + − −)	148.53	148.40	148.465	940	910	925	58	59	58.5
5.	(+ − + +)	162.68	162.40	162.540	760	740	750	65	64	64.5
6.	(+ − + −)	160.85	160.53	160.690	520	525	522.5	47	48	47.5
7.	(+ − − +)	150.13	150.23	150.180	570	575	572.5	51	52	51.5
8.	(+ − − −)	152.30	151.88	152.090	480	510	495	44	40	42.0
9	(− − − −)	155.75	155.38	155.565	570	580	575	65	66	65.5
10.	(− − − +)	156.08	155.65	155.865	710	720	715	73	69	71.0
11.	(− − + −)	162.29	162.82	162.555	380	375	377.5	59	61	60.0
12	(− − + +)	163.98	163.66	163.820	540	530	535	75	76	75.5
13.	(− + − −)	151.61	151.95	151.780	1000	1005	1002.5	64	68	66.0
14	(− + − +)	153.57	153.90	153.735	1000	1000	1000	48	50	49.0
15.	(− + + +)	162.07	161.93	162.000	1060	1070	1065	95	95	95.0

$$Y_{1s} = 66.72 - 5.16X_1 + 7.03X_2 + 8.16X_3 + 2.91X_4 + 3.16X_1X_2 + 2.15X_1X_4 + 5.96X_2X_3 + 3.03X_2X_4 + 2.34X_3X_4 - 3.28X_1X_2X_3 + 1.46X_1X_2X_4, \quad (2)$$

$$Y_{1b} = 156.76 - 1.88X_1 - 1.15X_2 + 4.86X_3 - 0.27X_4 - 0.34X_1X_2 + 0.45X_1X_3 - 0.48X_1X_4 + 0.37X_2X_3 - 0.46X_2X_4 - 0.19X_3X_4 - 0.29X_1X_2X_3 - 0.79X_2X_3X_4 - 0.29X_1X_2X_4 - 0.19X_1X_2X_3X_4, \quad (3)$$

where X_1, X_2, X_3 and X_4 are in coded form (Table I) and Y_{1g}, Y_{1s} and Y_{1b} respectively represent the green strength, shatter index and bulk density for the case of i) starch additive.

The nonlinear regression equations were also developed in the case of ii) dextrin and iii) molasses additives. The regression equations so developed were used for optimisation of the composition of a given moulding sand mixture by constructing nomograms (figs 3 and 4) to realise the required properties of the sand mixtures on the foundry floor.

2.5.2 2^3–Factorial design of experiments: The other part involved 2^3 factorial design of experiments in the study of liquid limit as a response variable and was carried out separately in the Soil Mechanics Laboratory. The three variable factors *viz.*, dead clay, active clay and additives were also varied at two levels as cited already. The linear regression equations developed relating the liquid limit (W_L) with the variables are as follows:

$$W_{1L} = 42.96 + 0.54X_1 + 4.54X_2 + 0.68X_3, \quad (I)$$

$$W_{2L} = 40.90 + 0.95X_1 + 4.38X_2 - 0.68X_3, \quad (II)$$

$$W_{3L} = 28.71 - 0.04X_1 + 1.50X_2 - 0.76X_3, \quad (III)$$

where X_1, X_2 and X_3 are in coded form (Table I) and W_{1L}, W_{2L} and W_{3L} are liquid limits of starch, dextrin and molasses respectively.

2.6 Qualitative assessment

The two sets of regression equations so developed (in sections 2.5.1 and 2.5.2) were analysed in the light of existing literature on clay-bonded sand system and an excellent validity of these linear and nonlinear regression equations was observed on comparing the experimental and calculated values of the response variables for a given set of composition variables. The relative effectiveness of the organic additives was studied from their qualitative assessment in counteracting the detrimental effect of dead clay on the mounding mix.

3. Conclusions

The major conclusions from the two parts of the above experimental investigations are as follows:

3.1 Critical points of transition in strength and density occur at about 33% of water : clay ratio thereby confirming rigid water layer theory as proposed by Grim & Cuthbert[3], in the case of calcium-based bentonite-bonded sands as shown in figs 1 and 2.

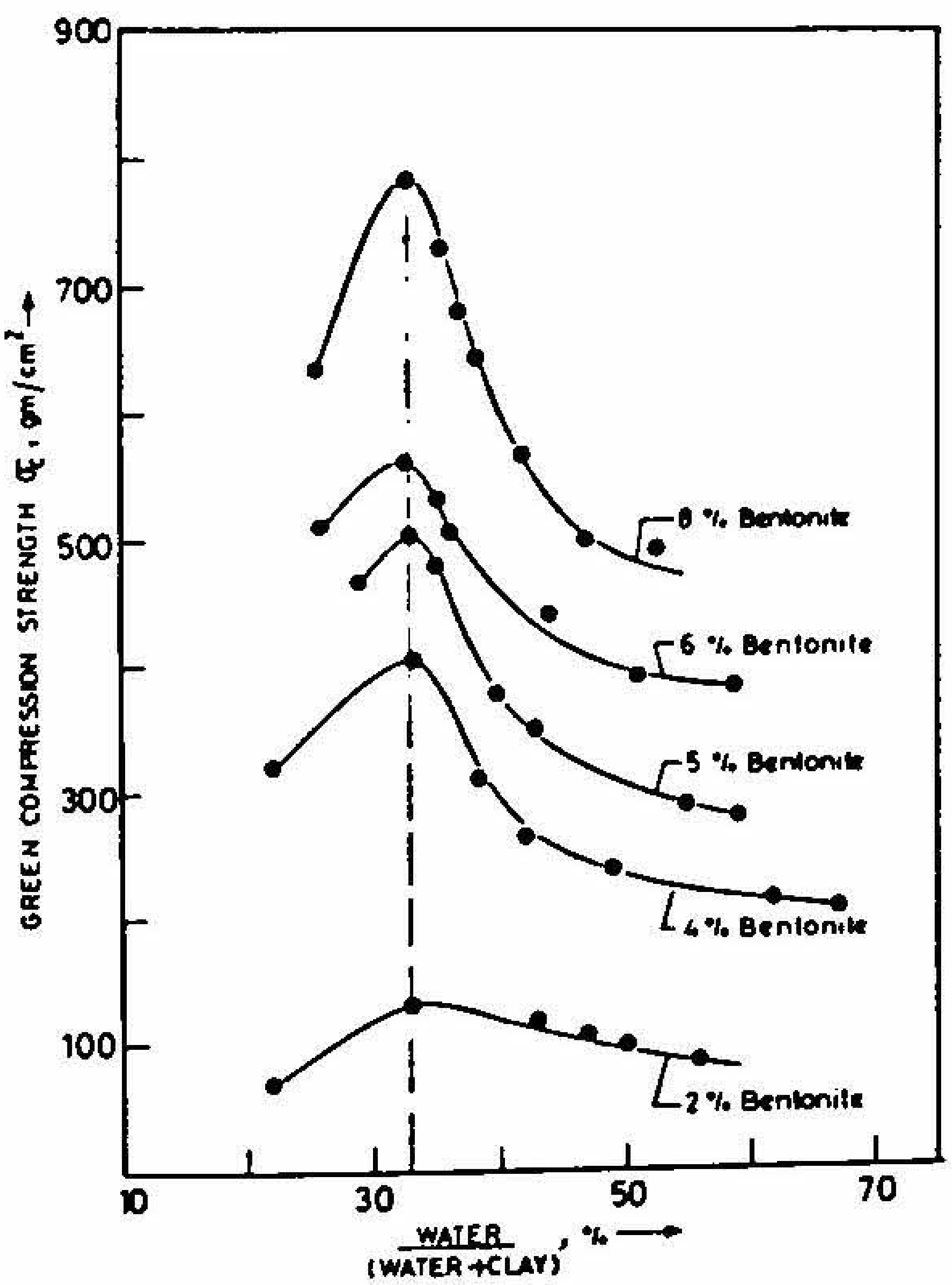

FIG. 1. Influence of water: clay ratio and bentonite content on green compression strength.

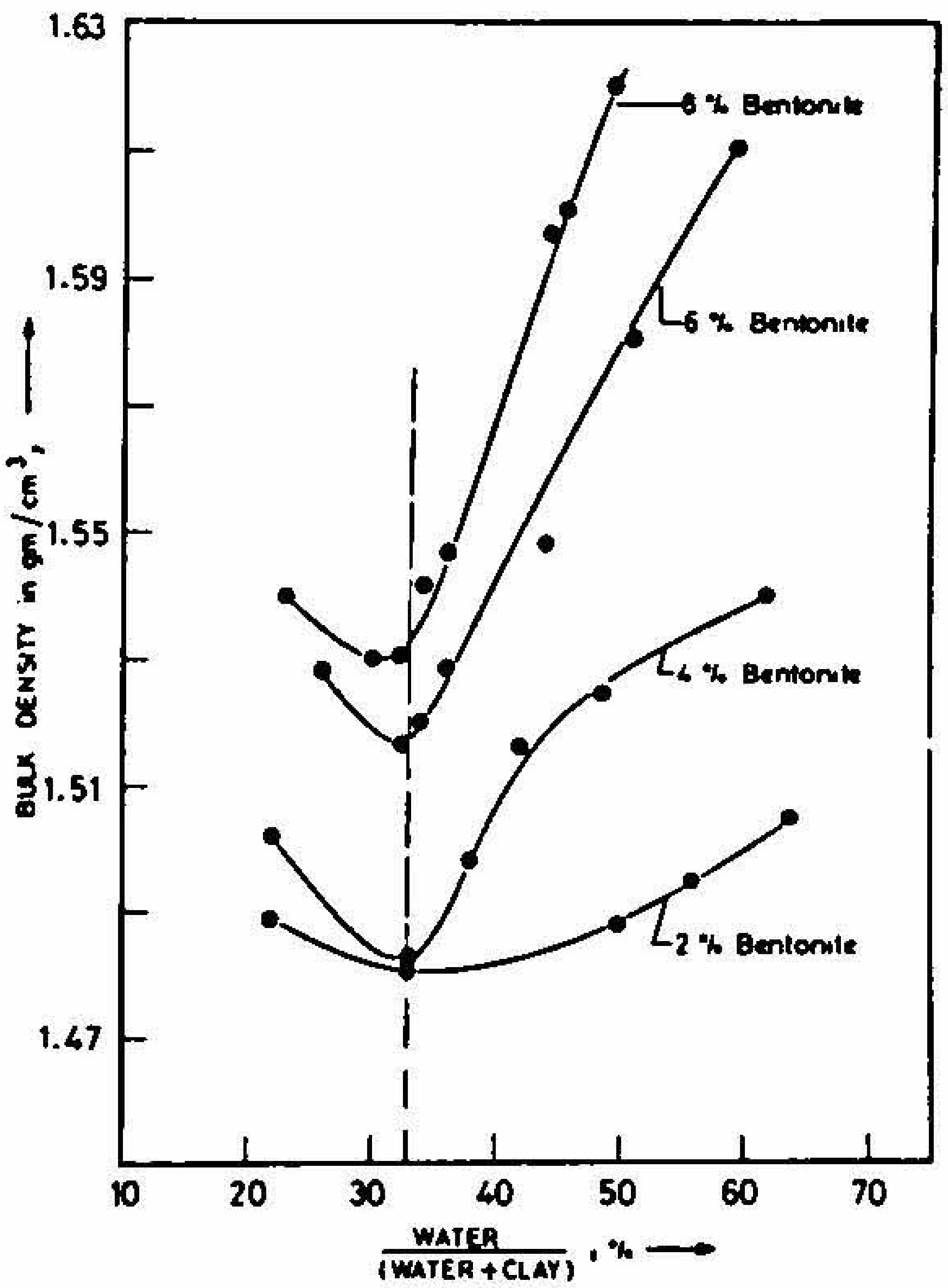

FIG. 2. Influence of water: clay ratio and bentonite content on bulk density.

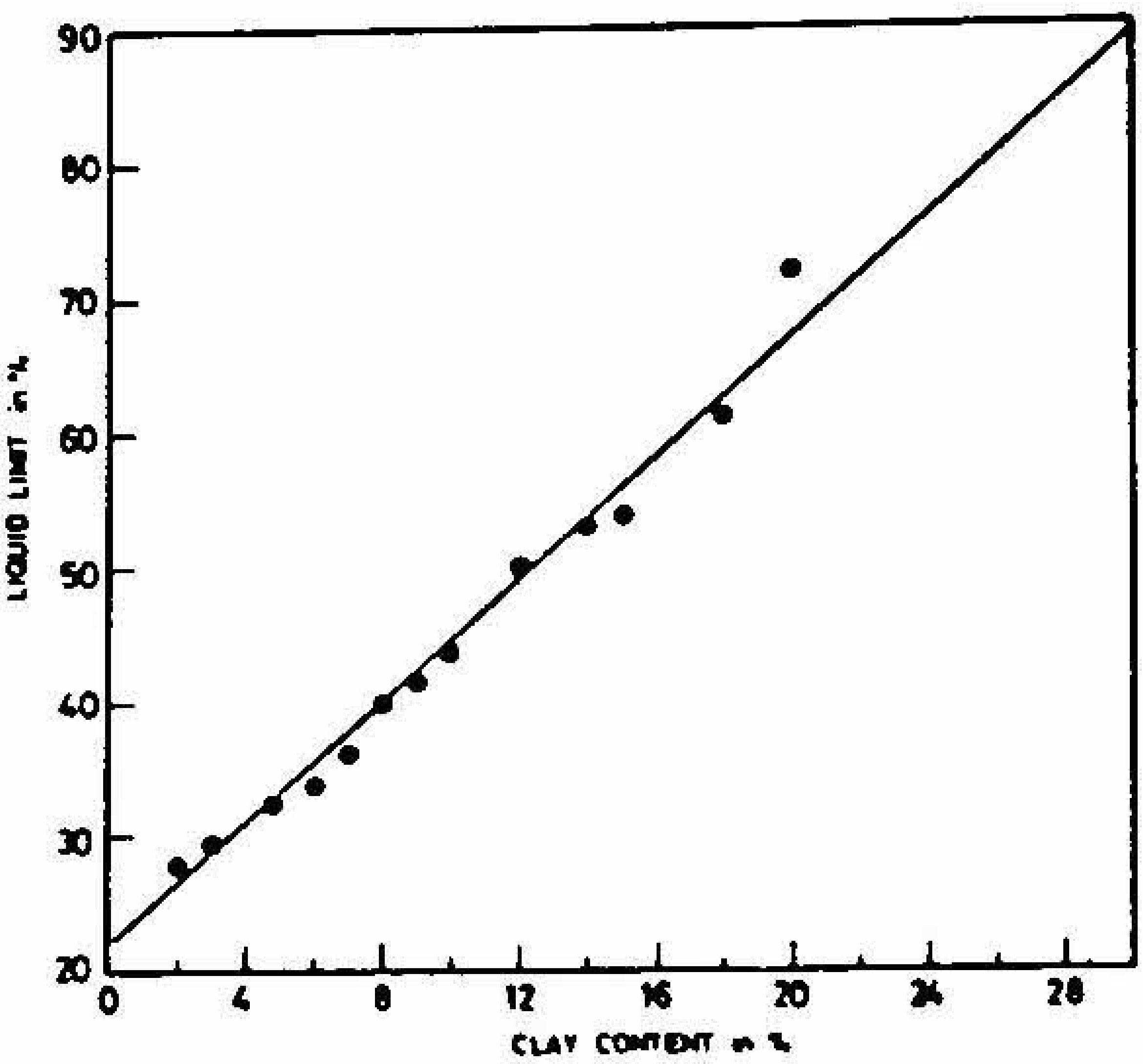

Fig. 3. Relationship between clay content and liquid limit

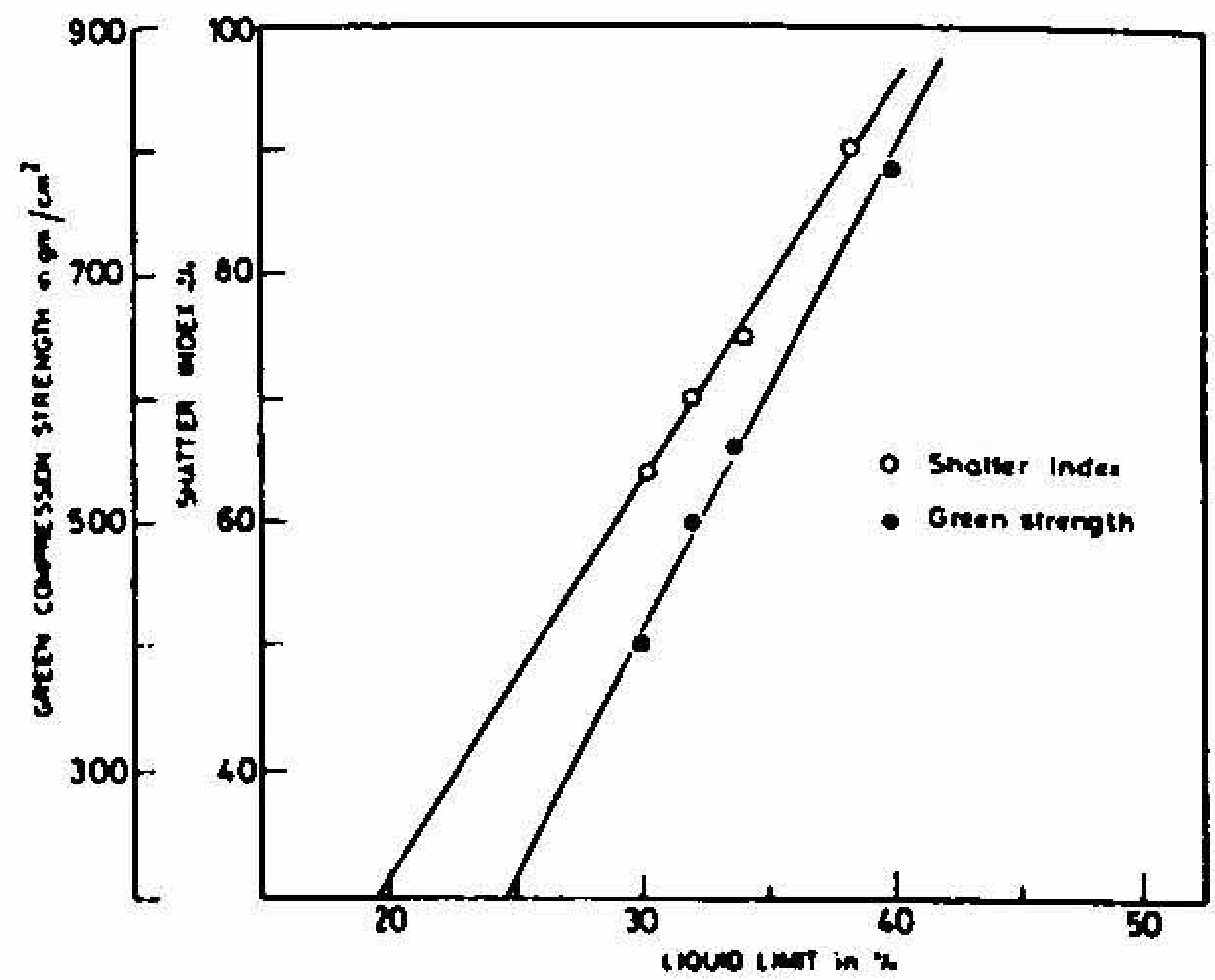

Fig. 4. Relationship of liquid limit with green compression strength and shatter index.

3.2 On the whole, starch seems to be a relatively more effective additive than dextrin on molasses in imparting better strength, higher toughness and liquid limit and hence, in counteracting the adverse effect of dead clay on the moulding sand, in the range of variations considered.

3.3 Nomograms have been constructed to optimise the composition of moulding mixtures on the foundry floor with a view to facilitate easy selection of the composition variables leading to satisfactory sand control (figs 3 and 4).

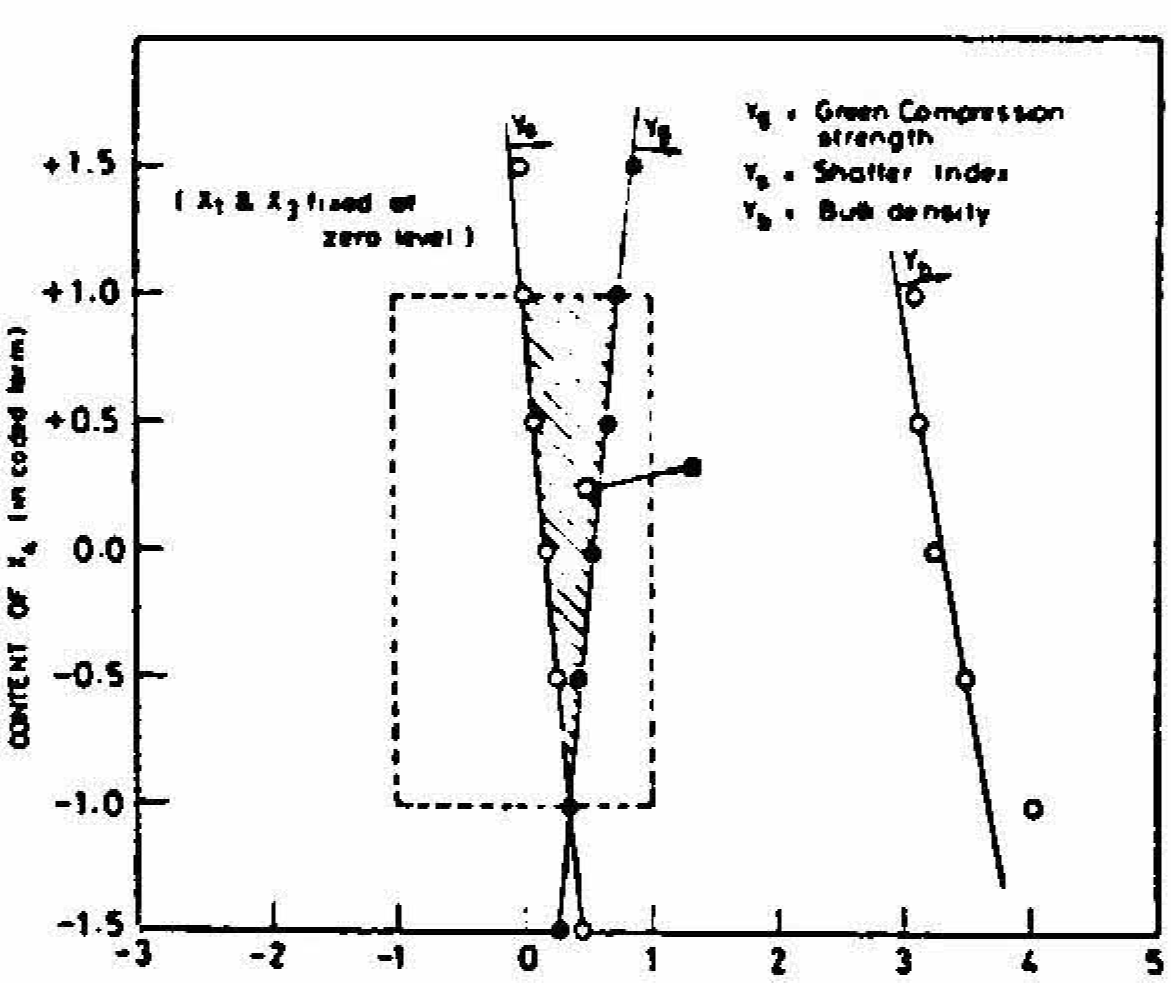

Fig. 5. Nomogram for optimising sand composition (Additive: Molasses).

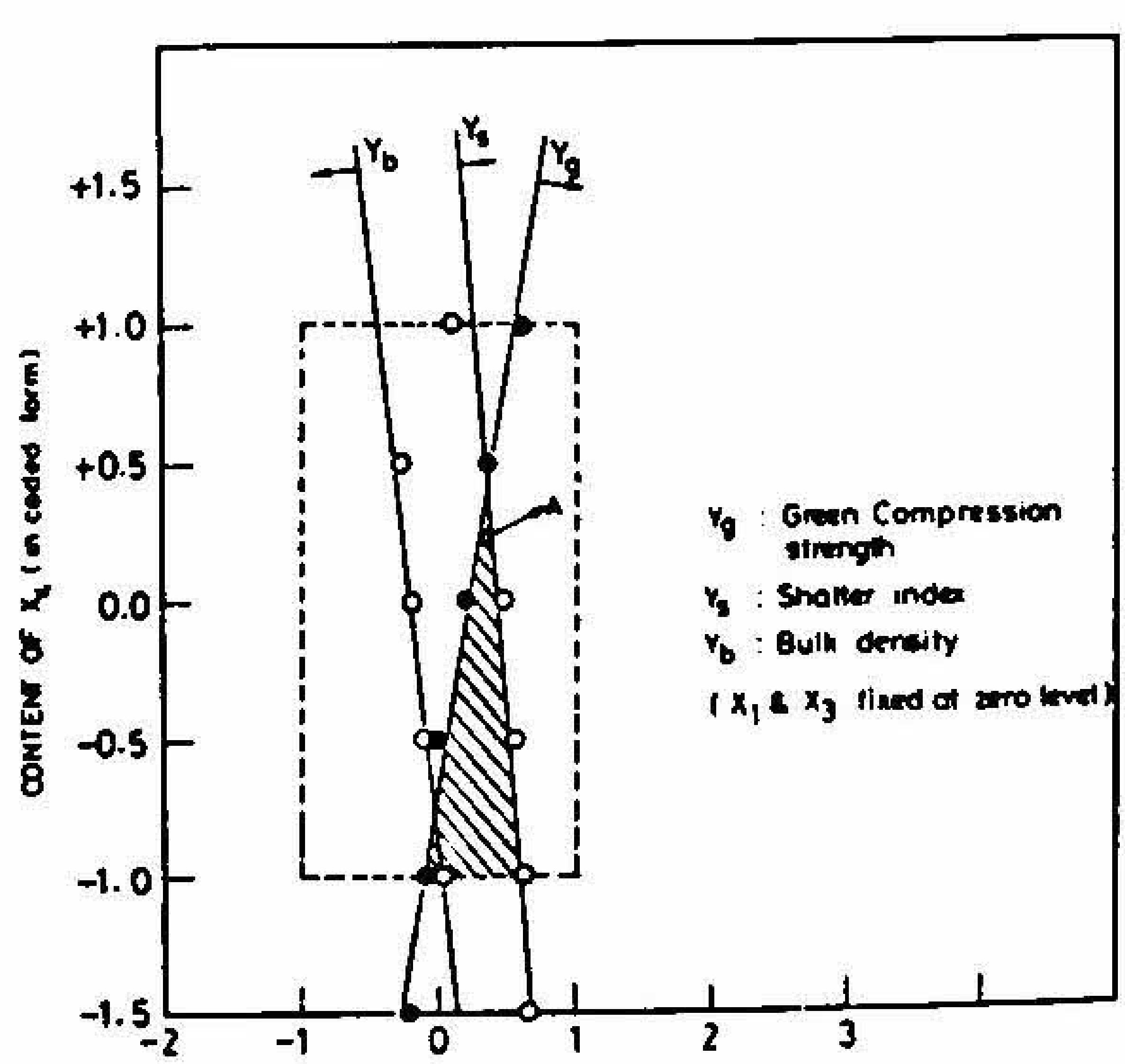

Fig. 6. Nomogram for optimising sand composition (Additive: Starch).

3.4 Liquid limit bears a linear relationship with clay content, maximum green compression strength and shatter index as shown in figs 5 and 6. A good moulding sand should have a liquid limit of about 40% to obtain maximum green strength of about 700–800 g/cm^2 and shatter index of about 90%.

3.5 It is possible to predict the properties of green moulding sand by the liquid limit test which is very simple to perform. The same test provides information on the amounts of active clay and dead clay present in any moulding sand.

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Thesis Abstract (M.Sc. Engng)

Design and development of a microprocessor-based test bench for protective relays by U. Jayachandra Shenoy.

Research supervisor: K. Parthasarathy.
Department: Electrical Engineering.

1. Introduction

Protective relays are intended to protect expensive electrical equipment in power systems. Since a high degree of reliability, sensitivity and selectivity are expected in protection schemes, it is becoming necessary that these schemes should be tested rigorously under simulated conditions which are close to those with which the protective relays may subsequently encounter in service. The test procedure must be able to simulate realistic relaying signals corresponding to both steady state and transient power system operating conditions. Conventional test procedures based on analog test benches such as those devised by Hamilton and Ellis[1] and G. W. Swift *et al*[2] suffer from the limitations that they are time consuming, uneconomical and lack flexibility. The advent of digital computers has increased the scope of protective relay testing drastically. The minicomputer-based relay test equipment developed by Webb[3] is found to be bulky and expensive. A low-cost and small size dedicated microprocessor-based relay testing scheme could provide the feasible solution to the problem of protective relay testing.

2. Experimental programme

The general hardware scheme for testing protective relays has been built around Intel 8085 microprocessor. The microcomputer-based hardware set up comprises of modular cards. The memory card has been designed to provide 32 K bytes of directly addressable memory space of Intel 8085 A. The developed test program as well as the library of transient test data are stored in Erasable Programmable Read Only Memories (EPROMs) which are available on the memory card.

The test data are generated as a series of numbers corresponding to the instantaneous values of the test signals and they are presented to digital to analog converters (DACs) where they are reconstituted into low-level relaying signals. The reconstructed waveform will be a stepped wave with a number of steps per cycle equal to the number of samples output per cycle. To smoothen the waveform and to remove the harmonics introduced into the waveform due to the reconstruction by discrete samples, the resulting waveform is filtered by a low-pass filter. The signal after filtering does not possess a power level adequate to drive the CT/PT and the relay input circuitry. These low-level signals are then used to drive the power amplifiers which produce the necessary test levels of voltage and current signals. The amplified outputs are fed to the relay under test. At the same time, the microcomputer monitors the relay trip status which is connected to one of the input/output ports of the microcomputer system. A video terminal interfaced to the processor system, automatically displays the test results. The operator can also communicate with the microcomputer through this video terminal.

Based on the proposed hardware, various performance evaluation tests have been conducted on commercially available relays such as directional over-current relays, transformer differential relays and distance relays.

The microprocessor simulates the relaying signals for test purpose and monitors the relay performance. The relaying signals for the steady-state tests have been computed by the processor using a floating-point software package. Transient relaying signals have been simulated using the library of transient data stored in the system memory.

A 3-phase static directional overcurrent relay has been tested for various tasks like pick-up, drop-out, reset time, time-current characteristic, mechanical endurance, directional property and sensitivity, making and breaking capacity of relay contacts and overshoot. The relay performance at different frequencies ranging from 48 Hz to 52 Hz is also studied. Before commencing the test sequence on the relay, the microcomputer should be supplied with the following data: (a) relay settings such as plug setting, time-multiplier setting and maximum torque angle, (b) test signal parameters such as phase angle between voltage and current signals and frequency of these relaying signals (say 50 Hz, 49 Hz, etc.). The above tests are then carried out by the microcomputer and the results are displayed on the video terminal.

Steady-state and dynamic tests have been conducted on a static 3-phase distance relay. The steady-state test determines the trip characteristics of the distance relay for different relay reach settings. The microcomputer simulates the relaying signals for earth faults as well as phase-to-phase faults. The fault impedance determined for various impedance angles are recorded and displayed on the video terminal. The transient test data obtained from the off-line analysis of a typical power system model using Electromagnetic Transient Package (EMTP) are being used to conduct dynamic test on the relay. The dynamic test is carried out from the available test data for earth fault and phase-to-phase fault. These test data are obtained for different source-to-line impedance ratios and for fault inception angles at voltage zero and voltage maximum. Each set of transient test data consists of prefault data samples and transient data samples subsequent to the fault. The test program simulates these signals in a predetermined test sequence. The relay accuracy and the operating time obtained during the dynamic test are recorded and displayed.

The microcomputer-based test procedure for the static 3-phase differential relay, performs both steady-state and dynamic tests on the relay. The main objectives of the steady-state test are (i) to check the correctness of the relay pick-up settings and (ii) to obtain relay characteristic as a plot of current *vs* operating time. The dynamic test is conducted on the relay to assess the performance of the relay for stability against magnetising inrush currents. The processor computes the inrush data consisting of fundamental component of the signal and the percentage of second harmonic component. The second harmonic component has been varied from 0% to the value at which the relay restraint is obtained. Rectified sinusoidal signals with different on periods are also simulated to test the performance of the relay.

3. Main results and conclusions

The proposed programmable test procedure can be used for obtaining accurate performance evaluation of varieties of protective relays. Typical results of the tests conducted on over-current, distance and differential protection schemes clearly demonstrate the efficacy of the proposed technique for conducting the tests on commercial relays. The time taken by the microcomputer for conducting the tests on the relays is very much less compared to that taken by analog test bench methods. The transient relaying signals can be simulated with any desired level of harmonic and d.c. distortion, accurately. The proposed test scheme simulates wide range of test conditions and the test sequence can be repeatable.

The design and development of the Intel 8085 A-based hardware set-up for the testing scheme is rightly justified by the low cost of the processor and the availability of its wide range of peripheral components which can be interfaced to it with minimal hardware. The modular construction of the hardware set-up has simplified the hardware debugging during the development of the computer set-up. The test scheme has been found to provide a means for flexible, accurate and repeatable, rigorous testing of the protective relays.

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Thesis Abstract (M.Sc. Engng)

Environmental aspects in mining and processing of sulphide minerals by N. R. Mandre.

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Department: Metallurgy.

1. Introduction

Environmental pollution problems are invariably associated with the mining and processing of sulphide-bearing minerals. The major problems are associated with:

(i) Toxic reagents used in the beneficiation circuits
(ii) Generation of fines in the form of tailings
(iii) Acid-mine drainage and heavy-metal ion dissolution.

As such environmental problems facing the Indian mineral industries are significant and need to be tackled on an emergency footing. No systematic work in order to establish the pollution potentials of various sulphide ores, sulphide-bearing wastes as well as flotation tailings has been reported previously in India. Hence, it was felt that laboratory data need to be generated to assess the acid production capacities of sulphide-bearing minerals, heavy-metal ion dissolution from different sulphide-bearing materials and the role of microorganisms in acid generation and heavy-metal ion dissolution as well as to investigate the possible development of suitable pollution control techniques, with special reference to Indian conditions. The present research was hence undertaken with the above objectives. The following advantages can be claimed for the above process techniques:

(i) Efficient removal of hazardous metals and their easy disposal.
(ii) Separation of sulphide mineral particles from the oxide gangue, resulting in the recovery of valuables and removal of acid-producing sulphide constituents.
(iii) Relatively cheaper processes and better suited for low-grade ores and wastes.

Experimental investigations included the following aspects:

(i) Characterisation and mineralogical studies on Chitradurga copper ore and flotation tailings as well as on the gold tailings from Kolar Gold Fields and their acid buffering studies.
(ii) Environmental and acid leaching studies in the presence and absence of *Thiobacillus ferrooxidans* with the above samples.
(iii) Selective flocculation with various polymers to separate the sulphide minerals from oxide gangue as a potential control technology.

The above studies were done from an applied point of view and the experiments were oriented to be of practical relevance.

2. Experimental programme

Initially, the mineral samples were subjected to ore microscopic studies to assess the various mineral constituents present and their approximate percentages were estimated. The acid buffering capacities of the tailing samples, arsenopyrite concentrate and the copper ore fractions were determined by acid titration tests with 1N H_SO_4.

In the study of environmental leaching, initial sampling of the mine water for enumeration and isolation of bacteria is of vital importance. The bacteria being very sensitive to organic matter, isolation using solid media like agar and gelatin was found to be inadequate. To overcome this problem a special technique has been adopted. The isolated cultures were subcultured in an inorganic media (9 K). The bacterial growth was ascertained by direct microscopic examination and by the observation of change in colour of the 9 K media, development of turbidity as well as the change in Eh and pH. To study the selectivity of *T. ferrooxidans* towards various sulphide minerals, selective attachment studies were carried out with pyrite and chalcopyrite minerals.

Environmental leaching of sulphide minerals and wastes was carried out in columns and in shake flasks.

Pyrex glass columns (dimensions : length, 30 cm, diameter 6 cm, and thickness 0.2 cm) were used throughout the studies. The columns had a uniform diameter from top to bottom, fitted with two rubber corks, having a provision for recirculation of the leachant. Compressed air from an air compressor was continuously supplied to enable the recirculation of the leachant through the side tube. The bottom portion of the columns were fitted with a filter cloth to avoid any particles passing through the bottom tube. A requisite quantity of mineral samples were taken in the columns with distilled water. The test columns were inoculated with 80 ml of an active culture of *T. ferrooxidans* (72 hours old) whereas the controls were supplied with 10 ml of a 2% alcoholic thymol solution as a bactericide. Copper and ferric ion analyses were made when the pH of the leachant dropped considerably (pH 4).

Similarly environmental dissolution characteristics of the sulphide minerals and wastes were carried out in shake flasks. The studies were conducted on a rotary shaker maintained at 200 rpm. The copper and ferric iron analyses were made as in the case of environmental column leaching.

As a pollution-controlling technique, selective flocculation was studied with the help of various polymers, namely, polyacrylamide, starch xanthate and cellulose xanthate. The steps involved in the selective flocculation processes were as follows: (i) Dispersion of fines, (ii) Selective flocculation of fines, (iii) Separation of flocs from dispersed solids, and (iv) Redispersion and reflocculation of the flocs to release the entrapped particles.

3. Main results and conclusions

A prior understanding of the mineralogy of sulphide minerals and wastes used in this study helps in assessing their pollution potential and acid-consuming capacities. The mineralogy of copper ore, copper tailings, gold tailings reveals (Table I) the presence of various sulphide minerals. However, the sulphide minerals constitute only a small proportion, whereas the gangue minerals predominate. Based on the laboratory acid-titration studies, the pollution potential of the various samples used in this work can be assessed in the following order:

Copper tailings
Gold tailings
Copper ore (+ 100 mesh)
Copper ore (+ 60 mesh)
Copper ore (+ 44 mesh)
Copper ore (+ 10 mesh)

↓ Increasing pollution potential

The leaching studies on the sulphide mineral samples were separately carried out under environmental conditions. Environmental leaching refers to conditions in which mineral dissolution has been studied in the presence or absence of bacteria in contact with water at natural pH. This may better correspond with conditions existing in actual mining and processing operations. Sulphide minerals are the most susceptible to the oxidation when they are exposed to the atmosphere. Such oxidation of sulphide minerals has been considered to affect the environment in the form of water pollution problems which are associated with acid-mine drainage and heavy-metal ion dissolution. These are found to be enhanced by the presence of a particular group of microorganisms belonging to the genus, *Thiobacillus* which are invariably associated with many sulphide deposits. *T. ferrooxidans*, used in this study belongs to the genus *Thiobacillus*, consumes ferrous iron as its energy source; a major electron transfer takes place and the reaction could be given as follows:

$$Fe^{++} \rightarrow Fe^{+++} + e^{-}.$$

Table I
Mineralogical analyses of copper ore, copper tailings and gold tailings

Sample	Mineral	Percentage
Copper ore	Quartz	25–30
	Biotite and chlorite	55–60
	Calcite	5–7
	Pyrite	Traces
	Pyrrhotite	1–2
	Sphalerite	Traces
	Chalcopyrite	2–3
Copper tailings	Quartz	35–40
	Biotite and chlorite	50–55
	Calcite	4–5
	Pyrite	3–5
	Pyrrhotite	1–2
	Sphalerite	1
	Chalcopyrite	Traces
Gold tailings	Quartz	35–40
	Hornblende and tremolite	25–30
	Diopside and augite	15–20
	Biotite and muscovite	7–10
	Pyrite	1
	Sphalerite	1
	Pyrrhotite	1
	Chalcopyrite	Traces
	Arsenopyrite	1
	Magnetite	Traces

The percentage of copper leached from copper tailings, gold tailing and arsenopyrite concentrate was about 46, 65 and 43% respectively, in environmental column leaching (fig. 1). The environmental leaching studies were also carried out in shake flasks and the percentage of copper leached was relatively higher than that of environmental column leaching.

In all the above studies, the leaching followed a similar pattern as that observed in column leaching.

As a pollution control technology, the selective flocculation was carried out to selectively flocculate the sulphide minerals. Polymers of high molecular weight incorporating a sulphyhedryl or any other suitable chelate group are known to be selective towards sulphide minerals.

In this investigation, selective flocculation studies using natural chalcopyrite (67%), quartz (99%) and pyrite (54%)-quartz (99%) mixtures with flocculants such as polyacrylamide, starch xanthate and cellulose xanthate were carried out with the use of a moderate dispersing agent (sodium silicate) to disperse the gangue particles. An excellent selectivity for the pyrite-quartz mixture was obtained using starch xanthate in the presence of 5 kg/ton of sodium silicate (fig. 2), when it was found that the grade and the recovery of metal in the sand were about 32 and 70%, respectively. It is also evident that either too low or very high concentration of sodium

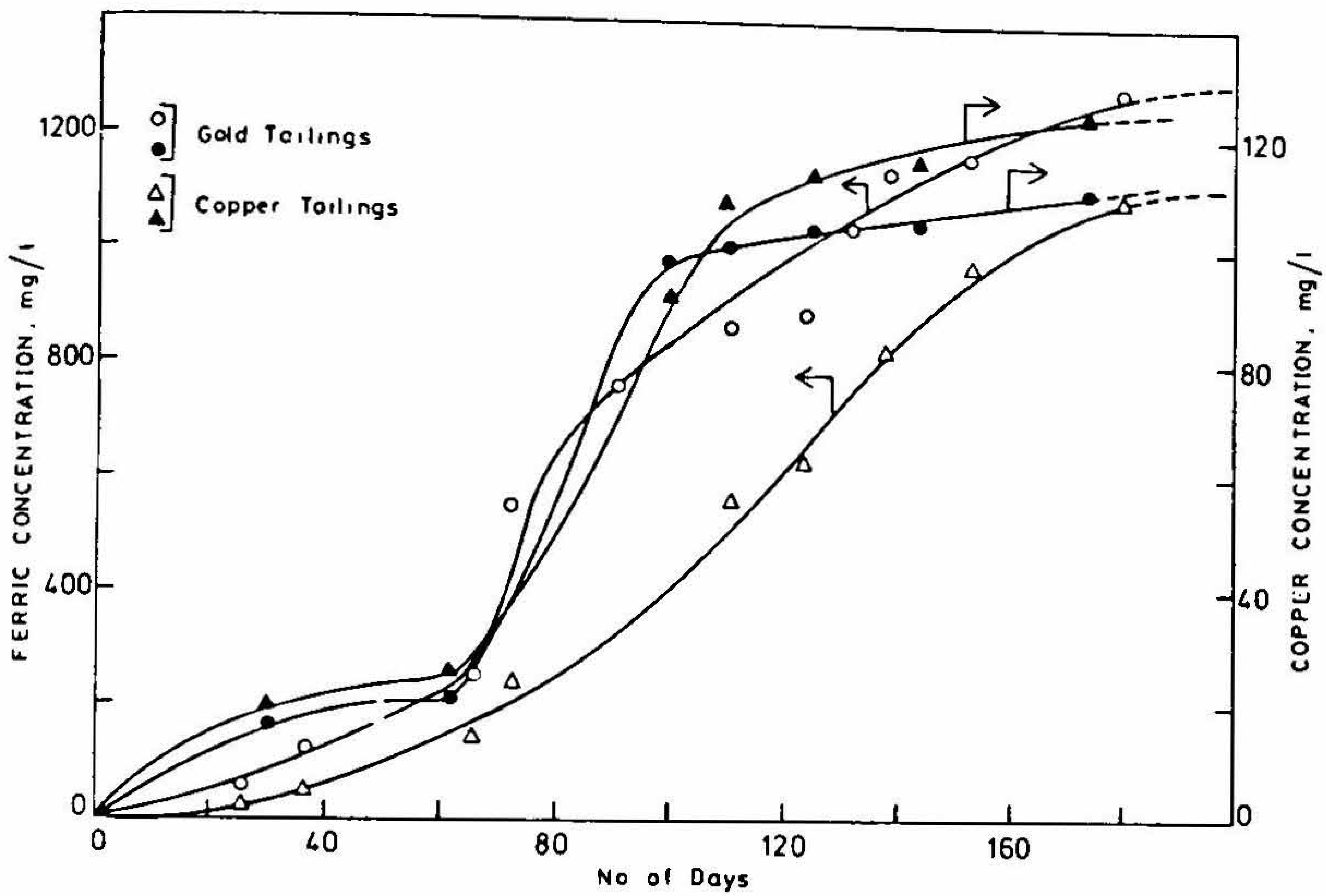

Fig. 1. Variations of ferric ion concentration and copper ion concentration with time in environmental column leaching of copper and gold tailings in the presence of bacteria.

silicate reduces the selectivity. Such an observation could be attributed to the relatively higher purity of pyrite (84%) sample used in this work.

Major conclusions arrived on the basis of this work are outlined below:

The acid production potential (pollution potential) of sulphide-bearing minerals and wastes is essentially dependent on their mineralogical characteristics and on the amount of sulphur present in the sample.

The presence of bacteria along with the sulphide-bearing materials, enhances the acid production and heavy-metal in dissolution. Higher pH levels retard bacterial oxidation as also the presence of a bactericide. These two factors may be useful in controlling the bacterial activity with respect to acid-mine drainage.

Flocculants such as, polyacryl amide, cellulose xanthate and starch xanthate can be effectively used to flocculate a sulphide mineral such as chalcopyrite and pyrite from an oxide gangue. The selectivity that could be achieved with the above polymers depends upon a number of factors such as, the presence and absence of a dispersing agent, nature of the functional group in the polymer, pH of the system as well as the number of deshming operations.

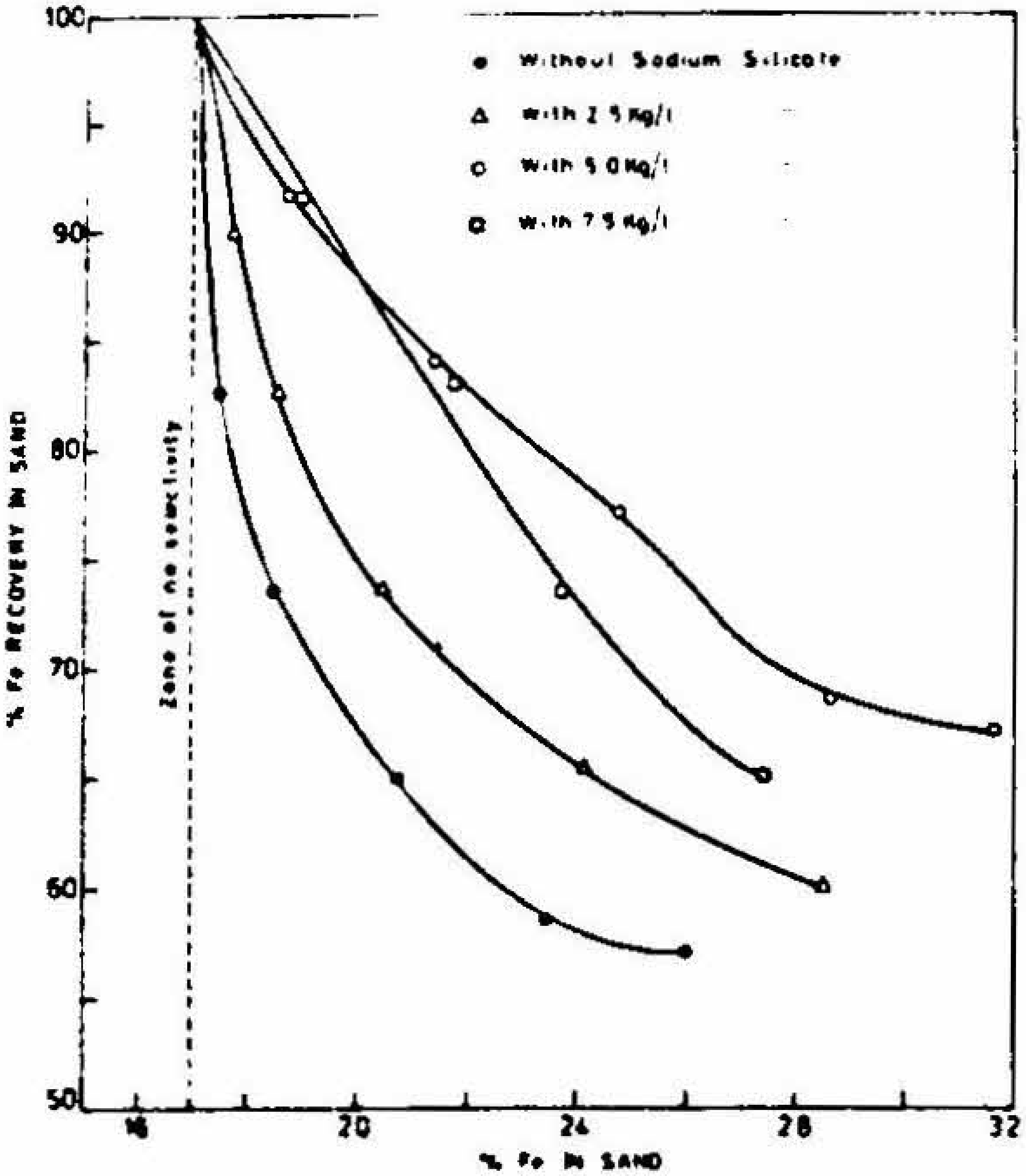

FIG. 2 Selective flocculation studies on mixtures of pyrite and quartz with starch xanthate (0.2 g) as a function of sodium silicate.

Though the laboratory techniques may not be entirely representative of actual conditions existing in a mining or a mineral processing operations, they are, however, useful in predicting mechanisms and also to portray acid production and metal-ion dissolution existing in a mine or a processing plant.