

## THE POTENTIAL OF ALGINIC ACID AND POLYAL FOR SOIL STABILIZATION

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### ABSTRACT

The potential of two carbohydrate polymers, alginic acid and polygal for soil stabilization is examined in the light of soil gradation, clay mineralogical type and additive type and content. It is found that in line with their strategic occurrences in nature both alginic acid and polygal can improve the strength of (i.e. stabilize) some soils. Their ability to do so increases with the surface activity of the clay mineralogy and best results are achieved with clays which are weathered. However this ability is rapidly lost with soils containing increasing quantities of sand or on immersion of the stabilized soil samples in water at normal atmospheric conditions. The additives are thus best used with soils containing nearly hundred percent clay and the finished products should be protected from direct contact with water. The advantage of polysaccharides over other soil additives is advanced and stressed.

### 1. INTRODUCTION

No one soil additive known can possibly satisfy all the requirements for civil engineering purposes. For road and building constructions two of the basic requirements are weather ability (i.e. amount of resistance to disintegration on exposure to moisture) and adequate bearing (compressive) strength. In many cases these two requirements are achieved together

[1,2,3,4]. The results obtained are generally dependent on both the soil type and the quantity and kind of additive used [5,6].

The physico-chemical characteristics of clays are fairly well-known [7,8]. The particles exist in aggregates (or domains or peds) [9, 10]. The smallest aggregate or cell-layer consists of parallel, face-to-face stacks of tightly-bound layer planes. The cell inter-layer bonds are not accessible to normal exchange reactions but the inter-ped bonds are usually influenced by the surrounding fluid medium [11, 9]. The two more common clay minerals are the kaolinitic and montmorillonitic clays. Kaolinitic clays (e.g. kaolinite) reveal minor distortions in their crystal

structural arrangements and so are larger in size and more stable than the montmorillonitic clays (e.g. montmorillonite) which are very hygroscopic and extremely surface active.

Most engineers define all particles whose equivalent spherical diameter

is less than 0.002 mm as clay particles but not all clay-size particles are pure clays, for example quartz. The following discussions pertain to pure clays when compacted. The theory of the structure of compacted clays has been discussed widely [3, 7, 12, 13]. Lambe [2] showed that soil particles are relatively more dispersed, above the optimum moisture content than below it when compacted. Other workers [10,11,3,16] have also shown that the soil peds (structural elements) can assume relative positions with each other. Thus the fabric of a compacted clay varies with both the clay particle arrangements within the ped and ped orientations relative to one another. For a given compaction effort and moisture content the clay with a flocculated fabric has lower dry density, higher strength and higher suction than that with relatively dispersed fabric. Since the Atterberg limits are indications of a soil's strength, changes in the ped-size and structure also reflect in the liquid and plastic limits of the soil. Such a change can be caused by mixing the soil with an additive [8,9] such as the alginic acid and polygal and the results of such an investigation are reported in this paper. Atterberg limits, compaction and strength properties are presented and the changes in the engineering properties of the soils with additives admixed are discussed. The possibility of using alginic acid and polygal as additives for the

stabilization of soils for civil engineering purposes has so far not been reported in the literature.

## 2. THEORY

Alginic acid and some other insitu generated, long-chain carbohydrates (polymers with simple sugars as the repeating units) have been used to increase the aggregation and aggregate stability of agricultural soils [14,15, 16]. But an aggregated soil behaves like a granular material and it is believed that a soil that is granular exhibits both lower plasticity index, PI and greater compressive strength,  $q$  than similar but fine-grained variety [3,13]. Thus sand has lower PI and higher  $q$  than clay-similarly prepared. The possibility of a soil with alginic acid or polygal admixed showing better engineering characteristics than the raw soils is thus endorsed. Also since the soil-alginic acid mixture exhibits increased aeration factor (A.F.) then this implies that such a soil mixture should possess greater porosity than the raw soils (14). This suggests that the soil may exhibit greater void ratio and possibly greater compressibility than the untreated soil. Recently, Atkinson and Bransby [17] have shown that the soil compressibility,  $x$  and plasticity index, PI are related as:

$$x = 0.006 \text{ PI}$$

It is also shown that:

$$q = M \exp. \frac{T - r}{x} \quad (2)$$

where  $M$  = flow constant;  $q$  = unconfined strength;  $T$  = constant;  $r$  = specific volume. Thus PI and  $q$  are related and small decrease in PI can lead to a large increase in  $q$  [18] It is reported, however, that both decrease and increase in Atterberg limits have yielded decrease and increase in  $q$  [19]. Also in nature, both alginic acid and polygal are identified as major components of connective tissues (cartilages and bones) in vertebrates [20]. Thus, these polysaccharides show natural evidences that they can stabilize soils. They are stable under normal experimental conditions, are nontoxic and possess physico-chemical characteristics which make them safe to handle. Relevant details pertaining to the structure and physico-chemical properties of alginic acid, polygal and other polysaccharide types are available elsewhere [21].

## 3. LABORATORY INVESTIGATIONS

Kaolinite was chosen to represent the lower bound of clay reactivity while montmorillonite represented the upper bounds. Both of these clays possessed

$\text{Ca}^{2+}$  (calcium ion) as the dominant exchangeable (surface) cations and were blended also with the same graded fine sand fraction to produce soils with wide range of particle size distribution. A red weathered London clay called "brick-earth" whose clay mineralogy was not verified was also chosen as a naturally occurring material. It was hoped that its surface activity would be possibly intermediate between those of montmorillonite and kaolinite. The montmorillonite and kaolinite were commercially prepared ready for laboratory use and were supplied by the Berks Limited of London and the E.C.C. Int. Limited of Cornwall, respectively. The brick-earth was collected from its natural site, 1.km North of St. Peter's Cathedral, London and the sand was supplied by the Leighton Buzzard Company, England. Only the brick-earth needed to be sieved and fractionated before use, adopting the BS 1377 (22) as a guide. The hydrosopic moisture contents of all the soil samples were pre-determined. The sand-clay mixtures were prepared by blending together appropriate quantities (by weight) of sand and kaolinite or montmorillonite. In all, six sand-clay blends were produced by mechanical mixing. With each clay, blends were prepared with a dry-mass ratio for sand-to-clay of 1: 3, 1: 1, 3:1. The blends were prepared in batches as required and the particle size distribution of each batch was determined to ensure correct proportioning. The soils were classified in accordance with the procedures described in BS 1377, section 2 and 3 and Tests 7(A) and 7(B). The organic matter content, the cation-exchange capacity (c.e.c) [23,24) and pH [22, section 3.4.1] of each soil batch were also determined. Each batch was then compacted with a standard effort at different water contents encompassing the moisture contents for maximum dry density and maximum unconfined compressive strength. The alginic acid and polygal used were both charged polysaccharides (i.e. they produced electrolytic solutions with water)

supplied by the Kochlight Laboratories Limited, Bucks. England, as fine powder flakes in sealed containers. They had been commercially purified ready for laboratory use. For the raw soils used, a modification of the BS 1377 procedures was unnecessary. However, for the soil-polysaccharide mixtures, the following modifications were made: the water was mixed with the raw soil and the resultant paste allowed to stand in a sealed container for 24 hours to moisturise. The required mass of the polysaccharide was then admixed as a powder to the pre-conditioned soil. Immediately after mixing the soil polysaccharide sample was compacted except where otherwise specified for specific studies. The polysaccharide content,  $C_p$  was defined as

$$C_p = 100 \frac{W_p}{W_s}$$

Where  $W_p$  = mass of polysaccharide powder  
 $W_s$  = mass of dry soil

Selected compacted samples were dried and their durability in water verified. The details of the procedures adopted in the test are described in [22]. Above 400 samples were successfully examined for weatherability. All the test results were collected and analysed using the optimum parameters of compaction and strength

#### 4. RESULTS AND DISCUSSIONS

Tables 1 and 2 show the classification and other index parameters of the raw soils examined. The values of the specific gravity,  $G_s$ , cation exchange capacity and pH obtained were within the range anticipated for the soils [8, 13]. The gradations and the Atterberg limits of the soils cover a wide range as planned thus representing a wide spectrum of the soil reactivity. Also, the activity indices generally lie below 1.70 and so within the range defined for soils of normal activity by Skempton [25]. The organic matter contents are much more lesser than 1 percent and can be neglected [26]. In general, the soils used were free from organic interference and varied from non-

plastic to highly plastic varieties. One of the major aims of the study was thus satisfied.

The specific gravity, Atterberg limits and the activity index all varied with the sand contents of the soils as shown in figure 1. It is seen that while both the specific gravity and the Atterberg limits decrease progressively with increasing sand content, the activity of the soils remain almost unaffected until the sand proportion has exceeded 50 percent. Beyond this sand content the activity of the soils increases slightly (by between 30 percent and 40 percent for the pure clays (kaolinite and montmorillonite). From these results it is possible that the presence sand does not destroy the surface effects of the clay particles but may enhance them when it is present in high proportions.

The influence of alginic acid and polygal on the Atterberg limits is presented in figure 2. It is seen that the positions of both kaolinite and montmorillonite are shifted downwards with increasing contents of both types of polysaccharide. Thus both the water adsorption capacity and the compressibility of the clays are increased and decreased respectively. However, the polygal produces a greater amount of decrease in compressibility and less of increase in water adsorption capacity than the alginic acid. On the other hand greater overall effects are demonstrated for montmorillonite with greater surface active particles than for kaolinite. It is also seen from figure 2 that with increasing sand content the soil-polysaccharide specimens demonstrate accelerated rates of increase of compressibility and water adsorption capacity. For the montmorillonitic soils, however, the increase in water adsorption capacity for a given increase in the amount of the polysaccharide admixed is always greater than that of the compressibility. For the kaolinitic soils, the trend changes for sand contents greater than 75 percent and both the compressibility and water adsorption capacity of the soils increase

Table 1.0: Classification and Index Properties of the Clay

INDEX PARAMETERS			SOIL TYPES				
			KAOLINITE	MONTMORILLONITE	BRICK - EARTH B	SAND S	
GRAIN DIAMETER CONTENT PER CENT	0.002M - M	CLAY	97.0	86.0	80.0	0	
	0.002M - 0.06MM	SILT	fine	2.0	4.0	5.1	0
			medium	1.0	4.0	2.9	1.2
			coarse	0	3.0	3.	2.6
	0.06MM - 2.00MM	SAND	fine	0	2.0	4.0	96.2
			medium	0	1.0	3.0	0
			coarse	0	0	2.0	0
ORGANIC CONTENT (%)			0.40	0.30	0.65	0.10	
SHELL POTENTIAL			HIGH	VERY HIGH	LOW	0	
ACTIVITY INDEX (RATIO)			0.45	1.16	0.27	0	
PH (ACIDITY)			5.0	6.0	8.5	6.9	
CATION EXCHANGE CAPACITY (Meg/100 gm)			7.90	85.2	8.03	0	
SPECIFIC GRAVITY, Gs			2.66	2.94	2.76	2.40	
LIQUID LIMIT LL (%)			66	165	39	NP	
PLASTIC LIMIT PL (%)			27	77	19	NP	
PLASTIC INDEX PI			39	88	20	Non Plastic	
CLASSIFICATION	PUBLIC ROADS SYSTEM		A-7-5 (20)	A-7-5 (20)	A-7-5 (6)	A-3 (0)	
	UNIFIED SYSTEM		CH	CH	CI	SU	

TABLE 2.0: Classification and Index properties of different clays with varying gradations

INDEX PARAMETERS			SAND – CLAY TYPE						
			SAND: KAOLINITE RATIOS			SAND NONTMORLIONITE RATIO			
			SK = 1:3	SK = 1.1	SK = 3:1	SK = 1:3	SK = 1.1	SK = 3:1	
GRAIN DIAMETER CONTENT (PERCENT)	0.002MM	CLAY	73	47	22	72	52	22	
	0.002MM-0.06MM	SILT	FINE	1	2	1.0	2.0	1	1
			MEDIUM	1	1	1.0	1	1	2
			COARSE	2	1	2.0	1	1	74
	0.06MM-2.0MM	SAND	FINE	23	49	74	14	45	0
			MEDIUM	0	0	0	0	0	0
COARSE			0	0	0	0	0	0.07	
ORGANIC CONTENT (%)			0.24	0.24	0.08	0.21	0.16	0.07	
SHELL POTENTIAL			LOW	LOW	0	MEDIUM	HIGH	LOW	
ACTIVITY INDEX (RATIO)			0.30	0.35	0.50	1.03	1.00	1.83	
PH (ACIDITY)			5.1	5.0	4.9	6.0	6.0	6.0	
CATION EXCHANGE CAPACITY (Meg/100 gm)			7.1	6.4	5.8	78.7	50.8	23.6	
SPECIFIC GRAVITY, Gs			2.63	2.55	2.48	2.84	2.70	2.55	
LIQUID LIMIT LL (%)			39	25	12	120	80	40	
PLASTIC LIMIT PL (%)			20	12	6	56	38	18	
PLASTIC INDEX PI			19	13	6	64	42	22	
	PUBLIC ROADS SYSTEM (1945)		A-7-6 (10)	A-6 (8)	A-24 (10)	A-7-5 (20)	A-7-5 (18)	A-2-7 (4)	
	UNIFIED SYSTEM (1942)		CI	CI	CS	CH	CH	CI	

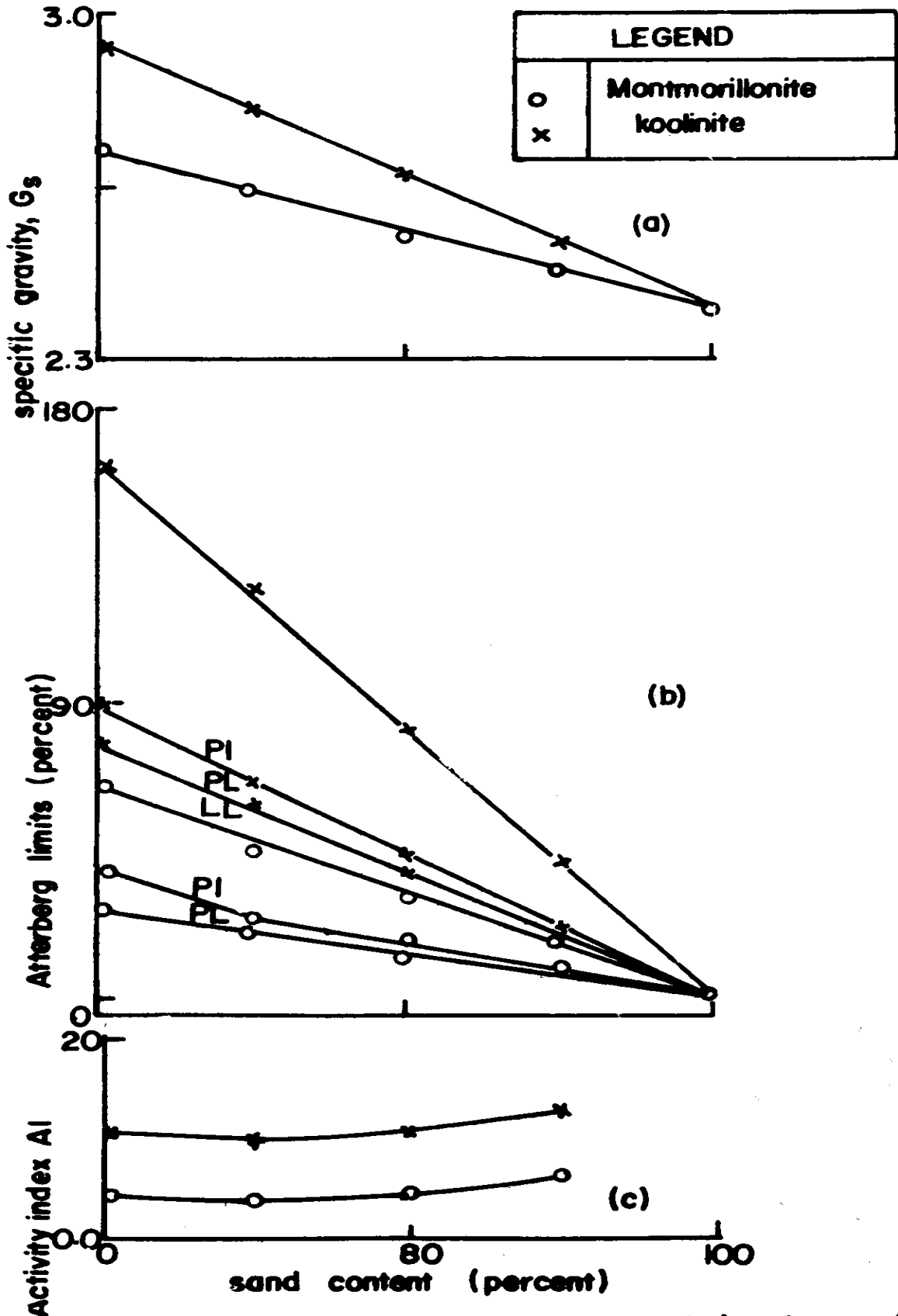


FIG. 1.0 Influence of sand content (gradation) on the specific gravity, Atterberg limits and activity of the soils.

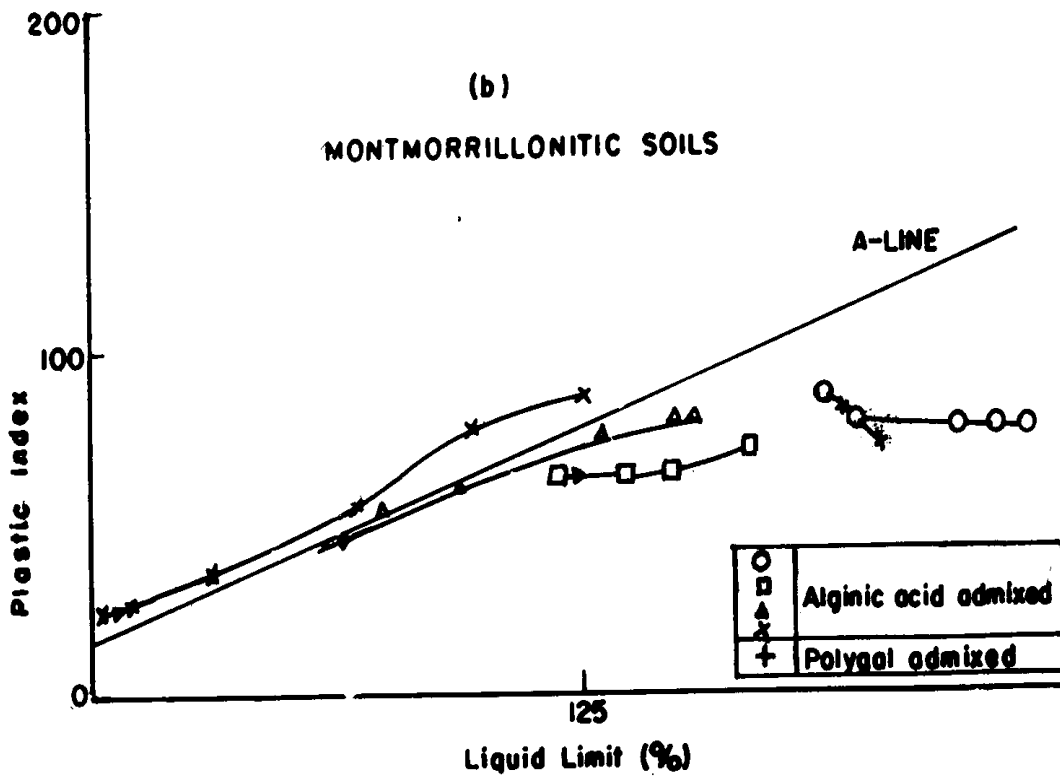
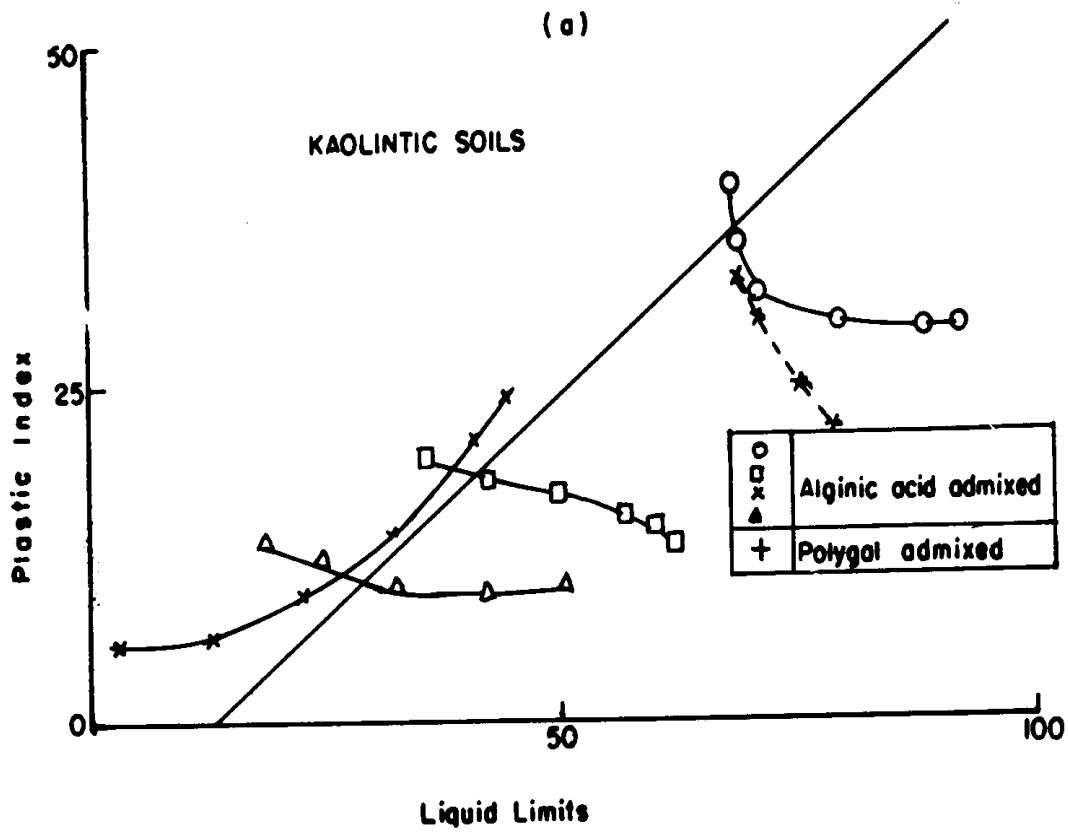


Fig. 2-0: Changes in the classification of soils with increasing Polysaccharide content. (a) Kaolintic soils (b) Montmorillonitic soil

at equal rates. It was mentioned earlier that the compressibility of a soil is related to its strength (equations 1 and 2).

In the present study the pure clays with either Alginic acid or polygal admixed exhibit reduced compressibility. An increase in undrained shear strength is therefore predicted (equation 2). The equations (1) and (2) also suggest that the gain in strength will be adversely affected by the addition of sand fractions. Additionally increased surface adsorption capacity suggests increased resistance to deterioration in water. However, it is difficult to quantify this change because the contributions of M, T and r for the different soil types are difficult to determine [17].

The maximum compaction and strength parameters of the pure clays examined are presented in figure 3. It is seen that independent of the polysaccharide type, the lowest optimum moisture content (OMC) and the highest maximum dry density (MDD) are always exhibited for the brick-earth for any content of the polysaccharides used. The direct opposite is true for the montmorillonite. The compaction parameters for kaolinite are always intermediate between those of the brick-earth and the montmorillonite. The relative positions one to another of the above parameters reflect the surface activities of the clays, montmorillonite with the highest and brick-earth with the lowest surface activity (see also table 1). It follows therefore that admixing charged polysaccharides of any kind with soils does not alter the compaction characteristics to such an extent that they no longer reflect the clay mineralogy, hence the surface activity of the dominant clay type. Thus the clay with a greater surface activity is always more flocculated than that with lower surface activity with alginic acid or polygal admixed [27,10]

The strength increase obtained for kaolinite with the polysaccharides admixed is negligible when compared with those for montmorillonite and the brick-earth - very high and very low surface active materials

respectively. It follows therefore that high surface activity is not the only pre-requisite for strength development in soils with the polysaccharides studied admixed. If an economic factor of utility,  $F_u$  is defined such that

$$F_u = \frac{q_u}{C_p}$$

Where  $q_u$  = incremental strength

$C_p$  = incremental polysaccharim content (%) then it can be deduced that alginic acid is economically preferred to polygal as an effective potential soil stabilizer.

Also some regression analyses carried out gave the following linear regression equations

a) Montmorillonite:  $q_u = 1500 - 1600 (MDD) r = 0.59$

b) Kaolinite:  $q_u = 1284 - 564 (MDD) r = 0.62$

c) Brick - earth:  $q_u = S175 - 2750 (MDD) r = 0.33$

d) All clays studied:  $(MDD) = 1.9 - 0.02 (OMC)$

e)  $MUCS = 0.96 (SMDD) + 23$   
 $r = 0.97$

$(OMC) = 0.85 (MCMS) + 0.1 r = 0.89$

$(OMC) = 0.4 (PL) + 5$

$r = 0.57$

Thus although the changes in strength and dry density shown (figure .3) seem anomalous, they still have some, though poor, correlation. It is seen that the MDD and OMC, maximum compressive strength (MUCS) and strength at the maximum dry density (SMDD) optimum moisture content and plastic limit of the clays with the polysaccharides admixed are also related. For the sand clay polysaccharide mixtures figure 4) strength decreases very rapidly with both increase in polysaccharide and sand contents. Also, the mixtures exhibit the optimum moisture contents for maximum dry density and strength. Both the maximum compressive strengths and strength corresponding to the maximum dry density and the optimum moisture content/moisture content corresponding to the maximum compressive strength show good correlation:



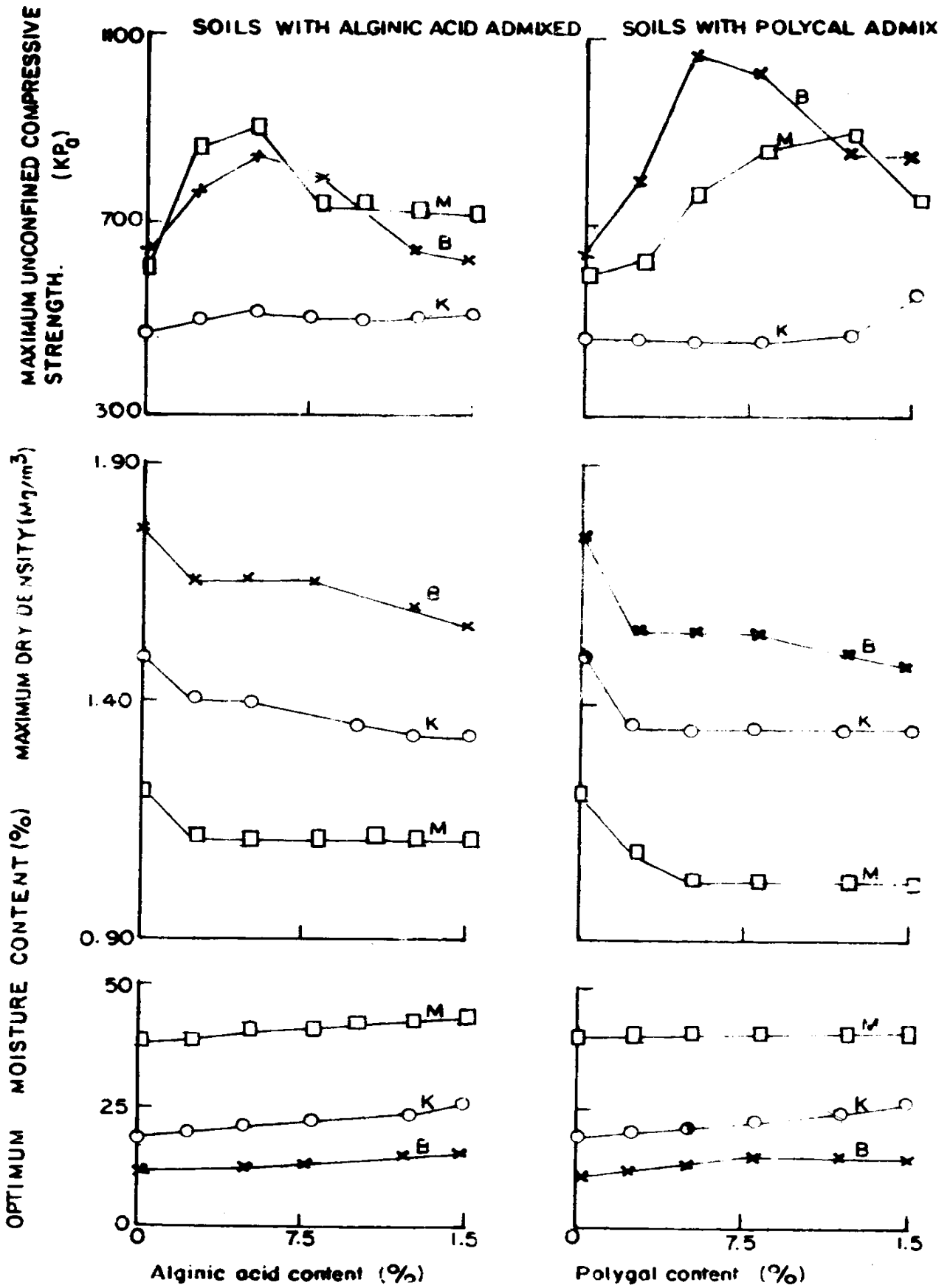


Fig. 3.0 Compressive strength Versus additive content for different mineralogical Soil types.

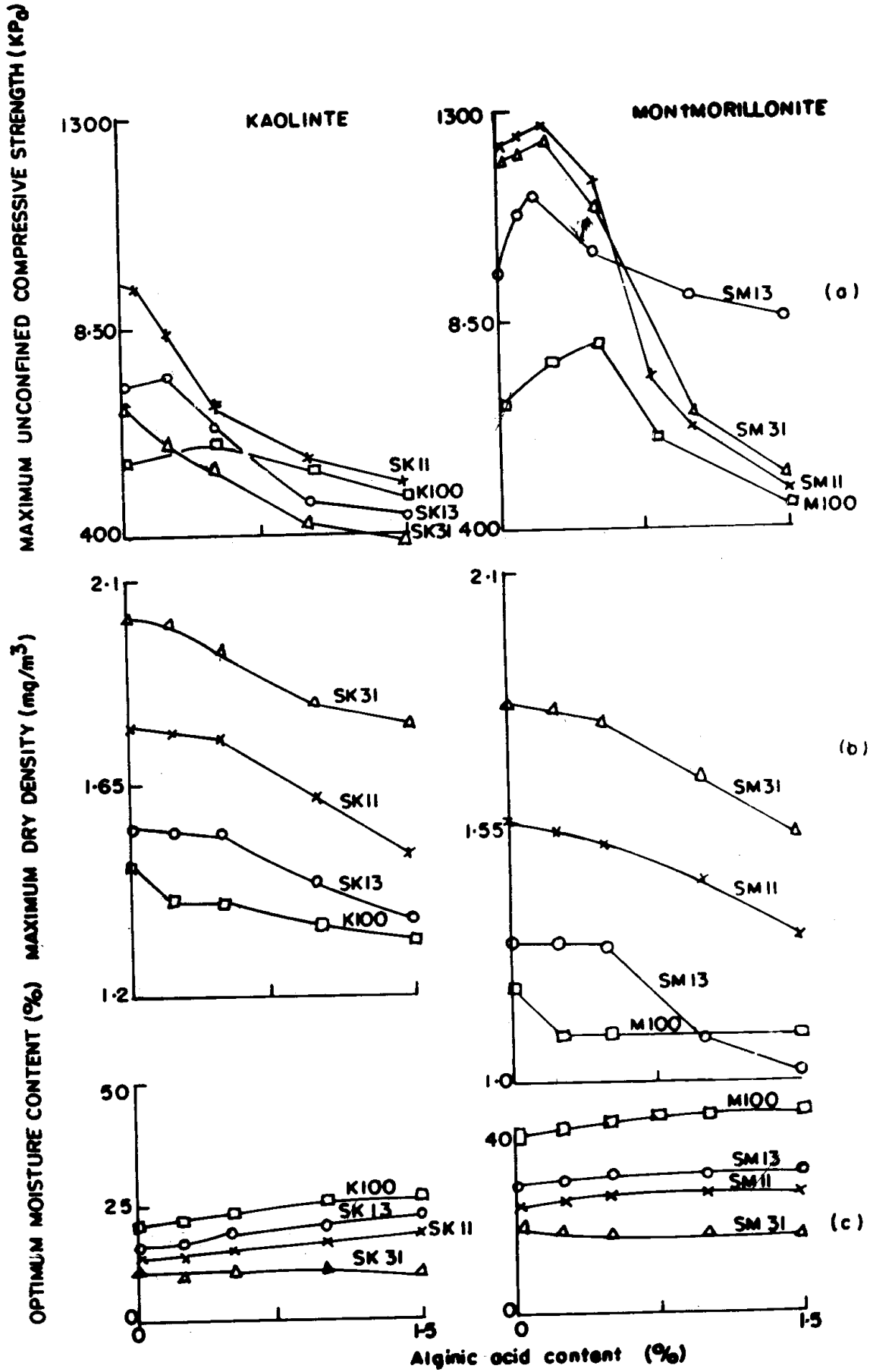


Fig. 4.0 Strength and compaction parameters versus additive content for different gradation of the soil.

Thus,

$$\text{MUCS} = 0.98 (\text{SMDD}) + 19$$

$$r = 0.95$$

$$\text{OMC} = 0.91 (\text{MCMS}) + 0.1$$

$$r = 0.90$$

However neither the strength and dry density nor the optimum moisture contents and plastic limit are related. Out of about 400 normally prepared soil-polysaccharide samples examined, it was found that independent of the dominant clay mineralogy and gradation all the soils with any of the polysaccharides admixed resisted the collapse in water by between 10 and 15 minutes longer than the raw soil equivalents of the pure clays. Those with 5 percent of alginic acid were most durable. Although the static immersion test is not reliable [28] it has given an indication of the improved properties of the polysaccharide - treated soils in water. The results are comparable to those presented for soils with known organic polymer stabilizers admixed [9]. Yet the polysaccharides studied seem to have some advantages over those other soil organic additives. Thus, the polysaccharides can be produced from organic matter and organic wastes of all sorts and so can be generated in large quantities easily and cheaply by improved methods. Also no special technique is required for their use by the common man.

## 5. CONCLUSION

The ability of alginic acid and polygal both charged carbohydrate polyers to improve the strength of (i.e. stabilize) soils have been examined. The polysaccharides have the ability to stabilize clays which are either weathered or possess high surface activity. Independent of the polysaccharide type used the gain in strength is rapidly lost completely when sand-clay soils are used. The polysaccharides are, therefore, best used with soils containing nearly 100 percent clay. The soil-polysaccharide mixtures exhibit characteristics normal for most soils like lower maximum dry density and higher optimum moisture content for soils with greater surface activity than otherwise. The maximum dry density and optimum moisture content for the soil-polysaccharide mixtures are always correlated by definite

regression correlation equations. The unconfined compressive strength and the Atterberg limits of the soil polysaccharide mixtures do not exhibit any statistical relationships. The integrity of the dominant clay mineralogy present is maintained in a soil with the polysaccharide admixed.

By using improved methods to produce alginic acid and polygal from various types of organic wastes, the cost of soil stabilization using these additives can be greatly reduced.

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