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Chemical Stabilisation of Sand—Part IX : Orthophthalate-type Unsaturated Polyester Resin for Inducing Fast Setting Behaviour and High Strength

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ABSTRACT

Polymer concrete composites have been made from orthophthalate-type unsaturated polyester resin, methyl ethyl ketone peroxide as initiator, cobalt naphthenate as accelerator and desert sand as filler. Composites preferred using resin (10-25 per cent), initiator (4 per cent) and accelerator (2 per cent) with representative desert sand samples of different particle sizes (0.2-0.02 mm, 2-0.2 mm and 4-2 mm) as filler recorded unconfined compression strength ranging from 4 to 442 kg/cm^2 after curing at 50 °C in an oven for 0.5-24 h. Using coarse and fine sand samples with 10 and 15 per cent resin systems the maximum strength of 391 and 326 kg/cm^2 respectively was attained after 2 h of curing at 50 °C. The fast setting resin system with strength in this range is quite adequate for the construction of chemically stabilised surfaces, which withstand trafficability of vehicles, operation of helicopters and aircrafts requiring a maximum strength up to 275 kg/cm^2. These composites may prove useful for rapid repair of roads, helipads and runways damaged during operational activities. A mathematical model has been developed for predicting resin percentage needed for obtaining composite material of requisite strength. The observed and model predicted values have been found to show close agreement.

1. INTRODUCTION

Polymer concrete composites are known[1-3] for their rapid strength gain, fast curing behaviour, adhesion, good mechanical strength, chemical resistance, heat resistance, water tightness, abrasion resistance and fatigue resistance. The composites are being used extensively in advanced countries for the construction and repair of roads, bridges, airfields and underground structures.

The present study forms part of our R&D work on the development of resin-catalyst systems for consolidation of sand for different military applications. Although phenol-formaldehyde[4], urea-formaldehyde[5,6] sodium silicate[5,6], furans[7] and natural resins[8,9] studied earlier attain good strength, but for rapid cure and high strength, their use is restricted to certain applications and these cannot be used for making damaged surfaces operational in a short time to attain the required strength.

Polymer concrete is a composite prepared by mixing a synthetic resin as a binder with an aggregate/filler followed by polymerisation in the presence of a suitable catalyst. In the present study, orthophthalate-type unsaturated polyester resin as a binder and different types of sand from desert areas have been polymerised in the presence of methyl ethyl ketone peroxide (initiator) and cobalt naphthenate (accelerator), which gave a highly exothermic cure. This property of exothermic heat of reaction could be utilised for fast setting of sand in desert areas during emergencies. This system yields a highly crosslinked polymer concrete composite characterized by high chemical and mechanical resistance.

Construction of airfields, roads, helipads, bunkers and other military structures by conventional methods require considerable time, large quantities of cement, concrete and bitumen, good quality water, construction equipment and skilled manpower. In the operational

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desert areas, construction and repair of these military structures cannot be achieved in a short time due to non-availability of the above resources. Polymer concrete composites based on unsaturated polyester resin system could meet all the above requirements giving required high strength and rapid cure. These chemically stabilised surfaces besides enhancing trafficability of service vehicles and operation of aircrafts would improve safety during operations.

2. EXPERIMENTAL DESIGN

2. Materials

Commercially available orthophthalate-type unsaturated polyester resin (AMSILITE-2113) was used as the binder. The physico-chemical characteristics of the resin are given in Table 1. The styrene monomer (36 per cent) was employed as the diluent to improve workability of the resin.

Methyl ethyl ketone peroxide (MEKPO) of Fluka-make (50-60 per cent plasticizer containing phosphoric acid and phthalic acid ester) was used as the initiator and cobalt naphthenate of Fluka-make (containing ~ 8 per cent *Co*) as the accelerator.

The fillers used were locally available desert sand samples of particle size 0.2-0.02 mm (dune sand), 2-0.2 mm (coarse sand from river belt) and 4-2 mm (gravel).

Table 1 Physico-chemical characteristics of orthophthlate-type unsaturated polyester resin (AMSILITE-2113*)

Parameter	Characteristics
Appearance	A clear colourless to pale yellow liquid
Viscosity	700-1200 cp at 25 °C
Specific gravity	1.12 ± 0.02 at 25 °C
Solids content	64%
Acid value	25 mg *KOH*/g
Stability	5-6 months at 25 °C
Styrene content	36%

* Manufactured by Reichhold Chemicals India Ltd., Madras.

2.2 Mechanism of Unsaturated Polyester Resin Formation and Its Polymerisation

Unsaturated polyesters usually consist of phthalic anhydride and maleic anhydride in varying proportions esterified with diols (viz. propylene glycol, dipropylene glycol, diethylene glycol or a mixure of glycols). The reaction is shown in Fig. 1.

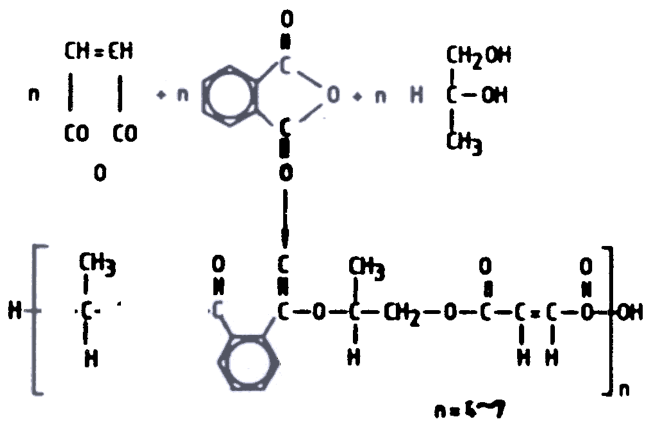

Figure 1. Orthophthalate-type unsaturated polyester resin.

This resin is a soluble, linear and low molecular weight macromolecule. It is diluted with 36 per cent styrene. This diluted resin is capable of undergoing rapid copolymerisation to produce a strong solid. The mixing of resin and styrene gives rise to a free radical initiated reaction which proceeds via an addition mechanism involving double bonds of both the materials and further leads to the formation of a highly crosslinked structure (Fig. 2).

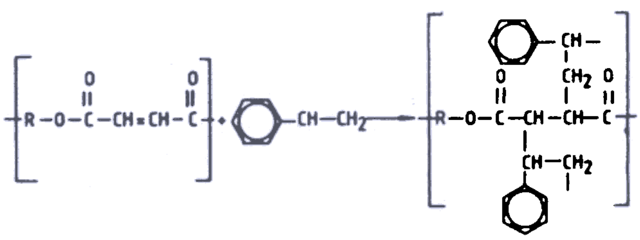

Figure 2. Crosslinted 3-D polymer network.

For making polymer concrete composites, it is required to convert rapidly the unsaturated polyester resin from a fluid state to a completely cured solid. Thermal polymerisation of the resin proceeds very slowly and it is necessary to accelerate curing at room temperature by adding unstable substances that produce free radicals, normally peroxides, e.g. methyl ethyl ketone peroxide. The initiatiing radicals are consumed and become an intergal part of the cured polymer. MEK peroxide is used in conjunction with an accelerator (cobalt naphthenate) which induces decomposition of the initiator at a temperature lower than that required for the pure initiator.

Table 2. UCS and average bulk densities of dune/coarse sand and gravel specimens cured at 50 °C with different resin contents (Initiator : accelerator = 4:2 (PHR)

[Values are averages for the three determinations]

Resin (%)	Filler (particle size)	Unconfined compression strength (kg/cm^2) Curing period				Average bulk density (gm/cm^3)
		0.5 h	2 h	4 h	24 h	
5	Dune sand (0.2-0.02 mm)	a		a	6	1.76
10	"	4	9	31	39	1.79
15		222	326	363	382	1.94
20		370	439	442	442	2.02
25		360	363	371	380	1.82^b
10	Coarse sand from river belt (2-0.2 mm)	309	391	415	416	1.98
15	"	425	428	436	436	2.11
10	Gravel (4-2mm)	109	189	226	227	1.67
15	"	223	288	305	305	1.85

PHR: parts per hundred resin, a: specimens collapsed; strength could not be determined, and b: low density due to less compaction in the presence of high resin content.

2.3 Preparation of Polymer Concrete Composites

Polymer concrete composites were prepared using varying percentages of unsaturated polyester resin (5-25 per cent), initiator (4 per cent) and accelerator (2 per cent) with the above mentioned desert sand samples (Table 2). The resin was weighed accurately and divided into two equal parts. One part was mixed with the initiator and the second with the accelerator separately so as to avoid the generation of excessive heat and formation of an explosive mixture. The two mixtures were combined and stirred thoroughly. The resin-initiator-accelerator composition was finally mixed with the respective sand sample. This polymer concrete composite was used for the preparation of standard specimens.

2.4 Preparation of Specimens and Evaluation of Data

Standard specimens of diameter 7.98 cm and height 6 cm were made using a standard mini-compactor[10]. Three sets of specimens were prepared and cured for 0.5, 2, 4 and 24 h at 50 °C in an oven. The curing temparature of 50 °C was chosen to match with the average maximum day surface temperature (45-50 °C).

Data on unconfined compression strength (UCS) of the specimens determined using standard equipment having a motorised load frame[11] immediately after curing for 0.5, 2, 4 and 24 h are given in Table 2. The bulk densities of the specimens measured prior to the determination of their UCS are also given in Table 2.

3. RESULTS AND DISCUSSION

3.1 Dune Sand Specimens

It is observed from Table 2 that the maximum strength of 442 kg/cm^2 is obtained at 20 per cent

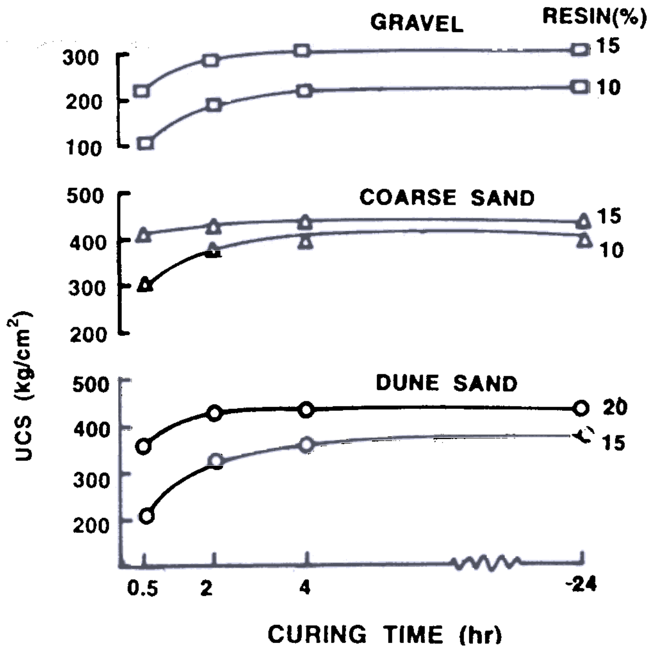

Figure 3. Effect of curing time on UCS.

concentration of the resin. It is also seen that the specimens are almost set after 2 h of curing (Fig. 3), the strengths attained with 15, 20 and 25 per cent resin system being 326, 439 and 363 kg/cm^2 respectively against 382, 442 and 380 kg/cm^2 observed after 24 h of curing. The UCS requirement for laying permanent tracks and runways is about 275 kg/cm^2. In making specimens with resin content 20 per cent and above, difficulty was experienced due to fast setting, excessive heat generation and improper compaction. Hence, it is concluded that adequate strength (275 kg/cm^2) for making damaged roads, helipads and runways functional is achieved after 2 h of civil work and the optimum quantity of the resin content for attaining this strength and easy workability is 15 per cent.

3.2 Coarse Sand Specimens

Standard specimens made from coarse sand taken from desert river belt recorded maximum strength of 415 and 436 kg/cm^2 with resin content 10 and 15 per cent respectively (Table 2) after 4 h of curing. With 2 h curing time, almost the same strength (391 and 428 kg/cm^2) is obtained with 10 and 15 per cent resin systems, showing that almost complete curing of specimens takes place after 2 h (Fig. 3). It is also noticed that the required strength of the order of 275 kg/cm^2 for chemically stabilised sand surfaces is obtained after 30 min of curing of standard specimens made from coarse sand with 10 per cent resin system.

3.3 Gravel Specimens

It is observed from Table 2 that standard specimens made from 10 and 15 per cent resin systems with gravel recorded maximum strength of 226 and 305 kg/cm^2 respectively after 4 and 24 h of curing. It may, therefore, be concluded that gravel specimens requiring 15 per cent resin content and after 4 h of curing have recorded a UCS of 305 kg/cm^2, which is adequate for the preparation of runways and tracks.

3.4 Compaction Studies

Standard specimens made by manual compaction using Jodhpur mini compactor recorded a maximum average bulk density of 2.02 g/cm^3 in dune sand specimens, 2.11 g/cm^3 in coarse sand specimens and 1.85 g/cm^3 in gravel specimens. Specimens with higher densities were found to record higher strength. The relationship between UCS and average bulk density for dune sand specimens is shown in Fig. 4.

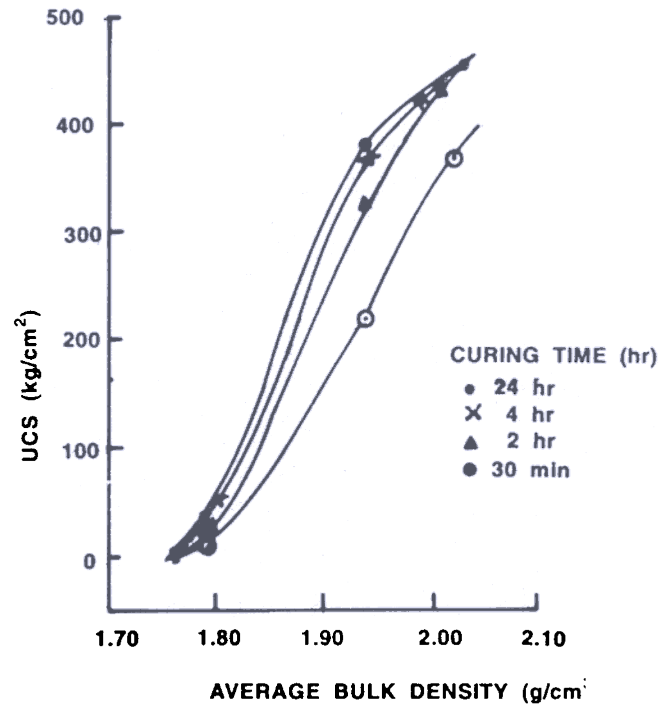

Figure 4. Variation of UCS with bulk density.

3.5 Mathematical Model

The following mathematical model has been obtained for predicting the UCS values of composite material specimens at varying percentages of resin (10-25 per cent) with constant initiator (4 per cent) and accelerator (2 per cent) used for dune sand.

$$Y \quad 161.05X \quad 3.93X^2 \quad 1207.75$$

where X is the quantity of resin used (%), and Y, is UCS (kg/cm^2) of composite material with fine sand cured at 50 °C for 2 h.

Alternatively, this model can also be used to find the resin quantity (%) needed for obtaining composite material of requisite strength for rapid repair of runways and tracks. For example, the needed strength for runways (275 kg/cm^2) will be obtained by using 14 per cent of resin, as calculated using the above model.

Theoretical values of UCS at different percentages of resin and fixed quantities of initiator (4 per cent) and accelerator (2 per cent) have been calculated using the above model. Both calculated and experimental UCS data are given in Fig. 5. It is seen that the experimental and theoretical values are in close agreement.

The first differential coefficient of the model when equated to zero yields the optimum resin quantity as 20.5 per cent. Using this quantity of resin, the maximum UCS value obtained would be 442 kg/cm^2, which is in good agreement with the experimental value.

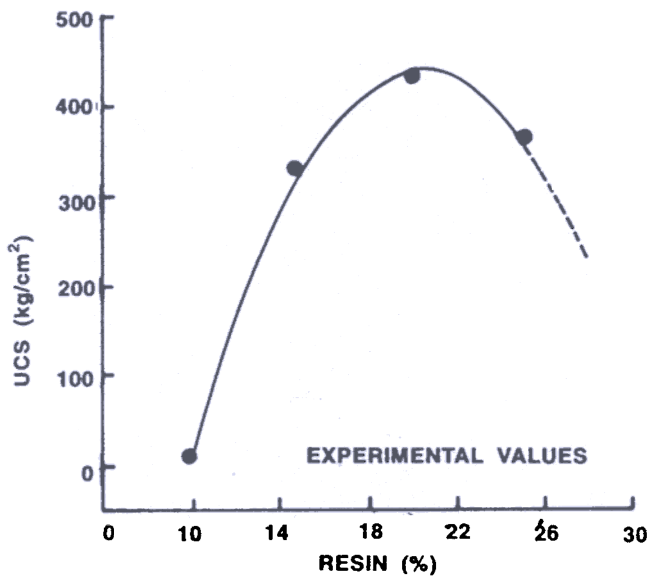

Figure 5. Experimental and predicted values of UCS at varying resin percentage with constant initiator (4%) and accelerator (2%) contents.

4. CONCLUSIONS

(a) Chemical stabilisation of dune sand can be achieved in 2 h with 15 per cent orthophthalate-type unsaturated polyester resin system.

(b) Using coarse sand, stabilisation can be achieved in 30 min with 10 per cent resin system.

(c) The chemically stabilised gravel surfaces (UCS 109 kg/cm^2 with 10 per cent resin) hold promise for use in rapid repair of roads.

(d) Both types of desert sand (fine and coarse) can be rapidly stabilised with this resin system giving the high strength required for trafficability of vehicles and operation of helicopters/aircrafts in sandy areas. This technique can prove an effective tool for rapid repair of roads, helipads, runways, etc., during exigencies.

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