Sulphur sand mixes as building material

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Following an extensive research programme lasting more than 4 years, it has been possible to prepare sulphur sand mixtures which are suitable as building material. As compared to normal concrete, sulphur sand mixes exhibit greater compressive and flexural strengths, have equivalent modulus of elasticity, have a lower and much more rapid shrinkage, creep is less under compression and these mixes also retain strength when temperature varies from -30 to 70°C. Durability as measured by 45 temperature cycles (0°C, 70°C) is good. One of the most difficult problem for overcoming the damaging effect of water on sulphur mixes was also studied. Addition of silicon oil 0.5% by weight of sand with or without fillers gave satisfactory and economical solution to this problem. We also found that up to 10% sulphate content in sand the mechanical behaviour of sulphur mixes was not adversely affected. This would permit many quarries of sand with high sulphates to be utilized for such mixes. Glass fibre reinforcement was also tried which gave large increase in tensile strength and improved durability under 100% relative humidity.

1. INTRODUCTION

At present, aggregate/portland cement composites serve as the backbone of building construction in the world. Other types of binders may provide equally or more acceptable materials when portland cement is not easily available. Thus, there is a very definite need for low cost/high performance binder materials. Sulphurbound systems appear to be a very promising answer to the need. The sulphur mix reaches full strength in hours, which has practical and economic advantage particularly for precast industry.

Sulphur mixes possess many useful characteristics exhibited by portland cement concrete as well as some unique properties which make them suitable for many speciality applications. Sulphur-sand mixes promise excellent structural and mechanical properties at low relative cost. However, heat susceptibility and effect of water and temperature cycling still need to be examined very carefully to overcome the problem of long term durability.

For these reasons sulphur sand mixes have been thoroughly investigated to determine the mix design, the best method for preparation of mixture and the behaviour particularly when subjected to temperature variation, thermal cycling and the effect of water.

In this paper a summary of the results of this research is presented.

2. MIX DESIGN

Excess sulphur binder will separate out while insufficient binder will result in an unworkably stiff mix. The optimum binder level required for maximum strength for a particular sand gradation will depend on the voids in sand. For strength the binder should fill all voids in sand; therefore careful grading of sand to minimize the voids content can permit the use of minimum sulphur levels while still maintaining good strength properties. In practice a compromise has to be made between strength, sulphur content and sand.
gration on the basis of end use for the product and the economics of alternatives.

2.1. Sand gradation

Three different gradations of sand were used in this study.

I. Uniformly graded standard sand with fineness modulus of 2.68.

II. Gap-graded sand with fineness modulus of 2.63.

III. Natural sand with fineness modulus of 2.25.

Figure 1 shows particle-size distribution curves of these three sands mentioned above.

2.2. Sulphur content

Average taken from over 18 samples prepared with each type of sand gave the following maximum sulphur content to completely fill the voids in each of the three gradations of sand.

<table>
<thead>
<tr>
<th>Type</th>
<th>Percent sand</th>
<th>Percent sulphur</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Standard sand...</td>
<td>69</td>
<td>31</td>
</tr>
<tr>
<td>II. Gap graded sand.</td>
<td>73</td>
<td>27</td>
</tr>
<tr>
<td>III. Natural sand</td>
<td>69</td>
<td>31</td>
</tr>
</tbody>
</table>

These ratios are the maximum and any excess sulphur used will separate out as a layer of surface on the surface of the samples. It is therefore important that maximum sulphur content determined by the voids content of the aggregate for a fixed aggregate gradation is not exceeded as not only does it increase the cost of the mixture but also the presence of pure sulphur crystals on the mixture affects the appearance and also gives material with different shrinkage characteristics than that of the mixture. Due to these reasons, in all subsequent work, ratio of sulphur was not increased beyond these maximum limits. However, many other lower ratios were tested as given below:

- sand I and sulphur ratio of 31, 27 and 25%;
- sand II and sulphur ratio of 27, 25, 22 and 17%;
- sand III and sulphur ratio of 33, 30, 27 and 25%.

In one of the mixtures with sand III, sulphur ratio greater than the maximum ratio was used (33 instead of 31) to examine if excess sulphur has any effect on the strength of the mixture.

3. PREPARATION OF SAMPLES

A systematic study of different parameters affecting the preparation of samples was made. In particular, the parameters studied were the following:

- sulphur sand mix temperature;
- mould temperature during casting of the mixture;
- effect of vibration of the mixture after casting;
- sample time/temperature history (slow cooling or sudden cooling).

As a result of this study a suitable method for the preparation of test specimens was obtained which consists in the following steps:

- putting the sand on a heating mixer;
- heating the sand and mixing it until homogenous temperature of 140°C is attained;
- adding the desired quantity of sulphur and mixing it until the molten sulphur and sand is blended to ensure thorough mixing to give homogeneous mix.
- casting the mixture into hot metallic moulds (140°C);
- vibrating the moulds for 20 seconds. Vibration when sulphur has minimal viscosity is effective in compacting and densifying the material to minimize voids;
- turning out the samples from the moulds as soon it is possible;
- leaving the samples to cool until normal temperature is reached.
- keeping the samples under conditions of 50% of relative humidity and 20°C till the samples are tested.

4. STRENGTH

Flexural strength tests were carried out on 6 samples (size 4 x 4 x 16 cm) for each selected composition and mean value was taken. Compressive strength was determined by using portions of beam broken in flexure for the test specimens and mean value was taken. Strengths were measured after 9 hours, 1, 3, 7, 14, 90, 180 days, 1 and 2 years. Figures 2 and 3 demonstrate the development of compressive and flexural strengths respectively of various studied sulphur-sand mixtures with age.

These test results indicate that sand II i.e. gap-graded sand which has a sulphur-sand ratio of 27% gave the best compressive strength. The sulphur ratio of 22% with the same sand showed little difference in compressive strength. The curve for the mixture with this sand with a sulphur ratio of 25% shows an irregular