The Effect of Roughness Concrete Surface and Bonding-Aids on The Bond Strength of Polymer Modified Mortar

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Abstract
The object of this work was to investigate the bond strength between concrete and Polymer Modified (PM) Mortar, when the mortar is applied to the old (existing) concrete, in order to conduct a repairing work. Bond strength will be affected by the roughness of concrete surface conditions and also will be affected by bonding-aids which applied on the concrete surface before applying Polymer Modified (PM) Mortar sheets. As it was reported earlier, the mortar contained Ordinary Portland Cement (OPC), Pulverized Fuel Ash (PFA), micro silica, fine sand, Setcrete S.B.Latex, and Polyvinyl Alcohol (PVA).

The bond surfaces of some Slant Shear Test specimens of 100 x 100 x 300 mm prisms were left smooth whereas the others were either brushed to obtain a rough surface or coated with SB latex to act as a bonding aid just before rolling the mortar sheets on to the surface. The joined specimens were tested in a compressive testing machine at the age of 1, 7, 28, 56 and 84 days.

Bond strength of smooth surface concrete specimens was 27% lower than that of rough surface specimens at the early ages. At 28 – 64 days, this percentage was remain steady i.e. 6.5%. Applying bonding aid on the concrete surface was taught to be a better way of increasing bond strength, however, it was found from the test that the effect of applying SB latex on the concrete surface was useless for bond strength at the age of 7 – 84 days. Applying the latex only benefited bond strength at the very early ages.

Keywords: bond strength, rough surface, polyvinyl alcohol, latex.

Introduction
Mortar can be also rolled onto the existing concrete as a repair material. On going research on high strength polymer modified mortars has proceeded at The University of Birmingham, U.K. for some years \(^{(1,2,3,4)}\). The present paper presents further results for rolled sheets of polymer modified mortar which include modulus of rupture, compressive strength and also bond strength when applied by rolling onto concrete surfaces.

The PFA (Gohsenol) has an excellent adhesive strength to porous and hydrophilic surfaces such as fibres, paper and wood and could also be to the rough concrete surface. The adhesive strength also depends upon the viscosity (degree of polymerisation). An increasing viscosity provides a higher adhesive strength, as well as to produce high bond strength to the concrete. This thought that PM Mortar is especially suitable for enhancing the strength of concrete members in a repair situation. This investigation was
done in order to get more information about the properties of the mortar before applying onto existing (old) concrete surfaces.

The excellent of PM Mortar stickiness is taught to be the reason for investigating the effect of surface condition on the bond strength between the mortar and the concrete surfaces. Two type of mixes with variation of latex contents were prepared into mortar sheets and the two concrete part of slant shear test specimens were jointed by using mortar sheets.

The effect of variation of concrete surface roughness and also the effect of variation of bonding aid used onto the concrete surfaces when applying the mortar sheets onto the concrete surface were investigated in order to get the better way to achieved good bond strength between mortar sheets and the concrete. Therefore, from this work, concrete repairing work using the mortar as a repairing material will be well conducted and good bond between the mortar and the concrete will be excellent.

Preparation of Mortar Sheets

The materials used for producing PM Mortar sheets this investigation included Ordinary Portland Cement (OPC), fine sand, Polyvinyl Alcohol (PVA), Pulverized Fuel Ash (PFA), Micro silica and Styrene Butadiene (SB) latex.

The uncrushed natural sand was supplied from Bodmore Heath, Sutton Coldfield and was composed almost entirely of quarts grains. This as-received sand was then screened to remove the fraction coarser than 1.8 mm.

The PVA used in this investigation was supplied by “Nippon Synthetic Chemical Industry Co.Ltd.-Nippon Gohsei”, Japan, under the trade name of “Gohsenol”. It was a water soluble synthetic resin produced by saponification of polyvinyl acetate. Many grades of Gohsenol, differing in physical properties with various viscosities and percent hydrolysis, are manufactured commercially in order to meet different industrial requirements. One of them called Partially hydrolyzed polyvinyl alcohol, can be used as a cement additive.

The properties of Gohsenol can be described as follows:

**Appearance:**
Gohsenol is a powder or granular material having white to slightly yellowish colour.

**Specific Gravity:**
- Specific Gravity: 1.2 – 1.3
- Bulk Density (kg/m³): 300 – 900

**Heat Stability:**
- Temperature: 130 – 160°C
- Appearance: Slightly coloured

**Solubility:**
- Water solubility of Gohsenol differs according to its type, degree of polymerisation (viscosity level) and degree of saponification. Gohsenol softens or dissolves in acids and alkalis. Gohsenol remains stable in almost all organic solvents such as: animal and plant oil and grease. It will, however, slowly dissolve in the following organic solvents: ethylene glycol, diethylene glycol glycerine, acetamide, dimethylamide, dimethylacetanide, and dimethylsulfuroxide.

**Adhesive Strength:**
Gohsenol has an excellent adhesive strength to porous and hydrophilic surfaces such as fibres, paper and wood. The adhesive strength also depends upon the viscosity (degree of polymerisation). An increasing viscosity provides a higher adhesive strength.

**Mechanical Properties:**
Gohsenol shows exceptionally high tensile strength, elongation, peeling strength and abrasion resistance. The level of each property, however, differs with type of Gohsenol. The high viscosity type is generally superior to the low viscosity type.
Chemical Properties:
Gohsenol reacts with halogens, oxidisers etc. and also exhibit typical polyhydric alcohol reactions:
- Acetal reaction as the result of the reaction of polyvinyl alcohol with aldehydes or ketones.
- Esterfild reaction as the result of the reaction of the alcohol with acid or anhydrides.

Hygroscopic Properties:
Mechanical, physical and chemical properties vary according to storage conditions, i.e. moisture content of ambient air. The hygroscopic properties of Gohsenol, however, are slow to change even when exposed to high humidity compared with those of other water soluble resins.

Optical Properties:
Gohsenol film is completely stable in both natural and artificial lighting.

Electrical Properties:
Basically, Gohsenol has a dielectric constant and power faktor of an insulator, although the properties change due to the moisture absorption.

Gas Impermeability:
Gohsenol film shows high degree of impermeability to oxygen, hydrogen sulphide, nitrogen and many other gases when it is alone or applied on the surface of paper etc. However, it allows almost unobstructed passage of steam and ammonia.

Surface Active Properties:
Gohsenol functions as a protective colloid. Its surface tension varies according to its type, i.e. hydrolysis. The surface tension of partially hydrolysed type solution is generally lower than that of fully hydrolysed solutions.

Hygienic Properties:
Pure polyvinyl alcohol is considered as a non-toxic material and is certified for use in cosmetics (special grade of Goshen are available for use in cosmetics). Although it is not approved for use as a food additive, the Food and Drug Administration (FDA) of the United States allows its use as an adhesive and as a coating resin in food packing. Wearing gloves during the preparation of the matrix containing PVA is recommended, although there is no special attention to be paid during the work dealing with PVA. There is one type of Gohsenol used in this work, it was K-17 S.

The cement used in the investigation was Ordinary Portland Cement (OPC) confirmed with BS 12, 1989 and it was supplied by “Blue Circle” Cement. The PFA used was supplied by Pozzament Ltd. and it complied with BS 3892: Part 1: 1982 in relation to its physical properties and chemical compositions.

The micro silica used was micro silica slurry in order to facilitate handling and dosing, therefore the micro silica powder is blended with water to produce stabilised slurry. It was supplied by Elkem Chemical Ltd. One type of Styrene Butadiene (SB) Latex namely Setcrete SB was used in this study. It is a milky white emulsion styrene butadiene, with an added stabiliser and foam agent, supplied by Don Construction Chemicals Ltd.

Two types of mixes (varying latex content) were prepared for mortar sheets as follows:
- Mix A, containing OPC : sand : PVA : PFA : micro silica : SB latex : water = 1.0 : 2.0 : 5.0% : 25% : 10.0% : 2.23% : 34.7%.
- Mix B, the proportions of latex/cement ratio was 4.45 % while the other proportions were the same as that of mix A.

The material used must be in a dry condition to avoid an early reaction of polymer with water. The suitable dry ingredients which were mixed were 2 to 5 kg batches for a 10 dm³ bench mounted mixer. Firstly each batch was dry-mixed for 3 – 4 minutes to allow the polymer to be fully dispersed in the other materials. Water was then added gradually to the mixer in order to avoid a rapid and unevenly distributed reaction with the polymer. The mixer was
run at a medium speed at the beginning of mixing with water, but the speed was lowered in between when forming the plasticene-like material. This material needed more power to be mixed due to the extreme cohesion and adhesion (stickiness) of the plasticene-like material. The total time for mixing was 6 – 10 minutes when the material was ready for compaction. It was found during the experiments that higher PVA or OPC contents resulted in a more cohesive (i.e. sticky) material, and was thus more difficult to mix and to compact. On the other hand more water, or PFA, or sand, lead to easier mixing and compaction.

Compaction of the PM mortar was most conveniently achieved by rolling. The plasticene-like material was first rolled into a sheet of uniform thickness. A suitable thickness for each layer for the large mechanical twin-roller was 5 mm.

Preparation of Specimens

The concrete specimens for a slant shear test were basically based on the “Arizona Slant Shear Test”\(^{(5)}\). It was also found that the most sensitive and least variable method of testing for bond strength and flexibility was slant shear test\(^{(8)}\). The concrete prisms were cast in two parts with separation plane at an angle of 30° in special prism moulds and they were demoulded after 24 hours.(see Fig.1).

The split prisms were stored in water and then dry cured for 24 hours before joining. The PM mortar strip was rolled on to each inclined surface and the two parts were pressed together under a standard pressure of 1.96 kN/m\(^2\) (normal to the inclined surface) for 24 hours\(^{(3&6)}\). 100x100x300 mm prisms were used throughout the experiment. The surface of some specimens in series 2 were left smooth whereas others were either brushed to obtain a rough surface or painted with SB latex to act as a bonding aid just before rolling on the PM Mortar.

Bond strength between PM Mortar and hardened concrete were determined by compressing the jointed prisms (Fig.2). Three specimens for each group were tested at the rate of 150 kN/minute. These values were based on the load which should be applied on the cube, i.e. at a constant rate of stress equal to 15 MPa/minute (BS 188: Part 4: 1970 and ASTM Standards C39-72).
FIGURE 2: Concrete prism after joined using PM Mortar strips.

Results and Discussion

The experimental results are shown in Table 1, Figs.1, 2, 3 and 4.

TABLE 1: Bond Strength from Slant Shear Test for mixes A and B with varying concrete surface conditions and varying bonding aids.

<table>
<thead>
<tr>
<th>Conc.</th>
<th>Bond aid</th>
<th>Mix</th>
<th>Bond Strength (MPa) at (days)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>A</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>None</td>
<td>1</td>
<td>9.2</td>
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<td></td>
<td>None</td>
<td>5</td>
<td>9.2</td>
</tr>
<tr>
<td></td>
<td>Latex</td>
<td>6</td>
<td>3.</td>
</tr>
<tr>
<td></td>
<td>Latex</td>
<td>6</td>
<td>3.</td>
</tr>
<tr>
<td>Rough</td>
<td>None</td>
<td>A</td>
<td>3.</td>
</tr>
<tr>
<td></td>
<td>None</td>
<td>5</td>
<td>9.</td>
</tr>
<tr>
<td></td>
<td>None</td>
<td>0</td>
<td>9.</td>
</tr>
<tr>
<td>Rough</td>
<td>Latex</td>
<td>A</td>
<td>4.</td>
</tr>
<tr>
<td></td>
<td>Latex</td>
<td>B</td>
<td>4.</td>
</tr>
<tr>
<td></td>
<td>Latex</td>
<td>0</td>
<td>4.</td>
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</table>

FIGURE 3: Bond Strength vs. Age at Test for mixes A and B with different concrete surface.

FIGURE 4: Relation between Bond Strength with smooth concrete surface vs. Bond Strength with rough concrete surface for mixes A and B.

The results have shown that the bond strength of smooth surface concrete specimens was lower than that of rough surface at the early ages of joining. Rough concrete surface provided much better bond strength between concrete and the PM Mortar strip. At the age of 7 days bond strength of rough surface specimens was 27 % higher than that of smooth specimens. At the age of 28 to 84 days, the ratios of bond strength of the rough surface specimens to the smooth specimens were very similar (about 6.5 %). More latex content in the mix increased bond strength for both surface conditions.

FIGURE 5: Bond Strength vs. Age at Test for mixes A and B with different bonding aid applied on the concrete surface.
Previously, applying bonding aid on the concrete surface before rolling the mortar sheets was thought to be a better way of increasing the bond strength. However, the effect of applying SB latex onto smooth concrete surface specimens was negligible (see Fig. 3). Even at the early age of one day, it gave little in bond strength for mix A (less SB latex content in the mix).

Conclusions

The conclusions which may be reached from the laboratory investigations concerning the variation of concrete surface condition (roughness) and variation of bonding aid on the surface, are as follows:

1. A rough concrete surface provided better bond strength between concrete concrete and PM Mortar strip than that of smooth surface.

2. The inclusion of SB latex in the mix was also increased bond strength especially at later ages. Bond strength was thought to be increased by the application of the bonding aid onto smooth concrete surface specimens before rolling on the PM Mortar strip, however, the effect of this latex application was negligible, even at the early age of one day, it gave a little improvement in bond strength.

3. It can be concluded that preparing rough concrete surface is much better than applying bonding aid on that surface before rolling on the mortar strip. This conclusion will give an idea, how the concrete surface will be treated before applying/rolling on the mortar strip in the real repairing work.

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