Effect of Limestone Powders on Compressive Strength and Setting Time of Portland-Limestone Cement Pastes

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Abstract – In this study limestone powders with different particle sizes of 5, 10 and 20 $\mu$m were used to replace a part of Portland cement in different replacement levels to produce Portland-limestone cement pastes. The percentages of limestone replacement are 0, 5, 7.5, 10, 12.5, 15 and 20\% by weight. The effect of fineness and the amount of limestone powders on compressive strength and setting time are investigated. It has been established that limestone replacement causes reduce the compressive strength due to the dilution effect, but it can reduce energy consumption and CO\textsubscript{2} emission in cement manufacturing. The fineness of limestone powder used has influence on the observed compressive strength values. From the standard consistency results, it seems that limestone has no effect on water requirement compared to Portland cement. Moreover, the increase in level of fine particles would require much water. Both initial and final setting times were decreased with an increase in the amount of limestone. Furthermore, at the same level replacement, the cement pastes using 5 $\mu$m of limestone show lower setting time than those using 10 and 20 $\mu$m, respectively.

\textbf{Keyword}: Limestone, Portland cement, Compressive strength, Water requirement, Setting time
1. Introduction

Cement manufacturing produce a large amount of undesirable products, mostly CO$_2$, which result in greenhouse effect that leads to the earth temperature increase. In addition, cement production process is energy intensive as well as raw materials demanding. Technical development to lower the environmental impact of cement production achieved by the reduction of cement demand (blended cement). Therefore, many studies have considerable attention on mineral additions such as slag, natural pozzolana, fly ash and limestone [1, 2] in order to reduce energy consumption and CO$_2$ emission. Nowadays limestone has been widely used to add or replace a part of Portland cement to produce Portland limestone cement and Portland composite cement.

The Limestone is calcareous sedimentary rock mainly consisting of calcium carbonate (CaCO$_3$), commonly called calcite. Limestone is used in cement and concrete for various purposes, namely, as a raw material for clinker production and as coarse or fine aggregate. Limestone powder is produced by finely grinding limestone in quarrying operations and has been suggested for use as an additive in portland cement. Replacing of limestone into Portland cement has been widely studied for several years [3-6]. Limestone is usually considered as an inert filler material that improves the hydration rate of cement compounds and consequently increases the strength at early ages [7]. The incorporation of limestone powder with Portland cement has many advantages on early compressive strength, durability and workability [8]. While some authors claim that limestone acts as an active participant, and that during hydration of Portland cement some calcium carbonate is taken into system and reacts with the alumina phases of cement to form carboaluminates and delays or impedes the ettringite-monosulphate transformation [2]. This leads to the stabilisation of the ettringite and will result in an increase in the total volume of the hydration products, which might result in a decrease in porosity and thus an increase in strength. The effect of this chemical interaction in PC-limestone system is, however, not so pronounced due to limited aluminate content in the clinker.

The aim of this paper is to study the effect of limestone replacement on compressive strength and setting time of Portland-limestone cement pastes. Influence of the amount and limestone particle size will be investigated.

2. Research methodology

The materials used in this studies were ordinary Portland cement (OPC) and limestone (LS). Limestone powders with a different particle size of 5, 10 and 20 µm were used to replace as a part of Portland cement to produce Portland-limestone cement. Cement pastes were formulated varying the replacement of limestone from 0% to 20%. All replacement were made by weight. For each pastes, the water to binder ratio (w/b) was 0.50. The mixture were mixed and cast into 50×50×50 mm moulds. After casting, moulds containing the specimens were covered with a plastic sheet and stored in the laboratory environment for 24 h. Then the paste specimens were demoulded and immersed in saturated lime water at 23±0.5 °C until 1, 7, 14, 28 and 90 days. At the test time, the compressive strength will be investigated.

The physical properties as water requirement and setting time are determined by Vicat probe and Vicat needle apparatus, respectively.

3. Results and Discussion

Compressive strength measurements were carried out at ages of 1, 7, 14, 28 and 90 days. The compressive strength of Portland-limestone cement pastes was calculated from the average of three specimens and plotted as a function of limestone content. Figure 1 shows the compressive strength of Portland-limestone cement pastes using different particle size of limestone powder. The compressive strength is obviously related to the limestone content. It was found that the compressive strength of all Portland-limestone cement pastes was lower than OPC control and decreased with increasing limestone content at the same particle size. However, the replacement of limestone up to 7.5% by weight seems to give similar compressive strength to OPC control at early ages, especially, use of 5 µm limestone. The replacement of Portland cement by limestone powder caused a reduction in the compressive strength that can be explained as a result of cement dilution effect. It is indicated that the filler effect cannot compensate for the dilution effect at all ages. It was also found that all Portland-limestone cement pastes show an increase in compressive strength with increasing curing time.

Figure 2 shows the compressive strength of Portland-limestone cement pastes at 7 and 28 days of curing. At the same limestone content, it was found that the compressive strength of Portland-limestone cement pastes using limestone 5 µm was higher than those using limestone 10 and 20 µm, respectively. This is due to limestone powder at small particle size has a fineness higher than large particle size which results to more reactive. In addition, the small particle size can fill the pore between cement particles in paste that is known as a filling effect. Thus, the fineness of limestone powder used has influence on the observed compressive strength values.
Fig. 1. Compressive strength of Portland-limestone cement pastes with various limestone particle size: (a) 5 μm, (b) 10 μm and (c) 20 μm.

Table 1. Water requirement and setting time of Portland-limestone cement pastes.

<table>
<thead>
<tr>
<th>Mix</th>
<th>Water requirement (g)</th>
<th>Setting time (min)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Initial</td>
<td>Final</td>
</tr>
<tr>
<td>PC</td>
<td>132</td>
<td>142</td>
<td>180</td>
</tr>
<tr>
<td>Limestone 5 μm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10LS</td>
<td>133</td>
<td>108</td>
<td>140</td>
</tr>
<tr>
<td>12.5LS</td>
<td>132</td>
<td>97</td>
<td>125</td>
</tr>
<tr>
<td>15LS</td>
<td>130</td>
<td>89</td>
<td>120</td>
</tr>
<tr>
<td>Limestone 10 μm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10LS</td>
<td>132</td>
<td>117</td>
<td>150</td>
</tr>
<tr>
<td>12.5LS</td>
<td>130</td>
<td>114</td>
<td>140</td>
</tr>
<tr>
<td>15LS</td>
<td>128</td>
<td>109</td>
<td>135</td>
</tr>
<tr>
<td>Limestone 20 μm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10LS</td>
<td>127</td>
<td>129</td>
<td>150</td>
</tr>
<tr>
<td>12.5LS</td>
<td>126</td>
<td>123</td>
<td>150</td>
</tr>
<tr>
<td>15LS</td>
<td>125</td>
<td>121</td>
<td>145</td>
</tr>
</tbody>
</table>

The water requirement and setting time, determined on the fresh paste, are reported in Table 1. It seems that limestone has no effect on water requirement compared to Portland cement. Moreover, increasing the level of fine particles caused higher specific surface area, which requires much water.

From Table 1, it indicates the initial and final setting time of Portland-limestone cement pastes at different amount and fineness of limestone. The obtained values show that both initial and final setting times were decreased with an increase in the amount of limestone. It can be concluded that limestone fills the pores between cement particles due to formation of carboaluminates, which may accelerate the setting of cement pastes. From the examination of setting time behavior, we also see that, at the same level replacement, the cement pastes using 5 μm of limestone show lower setting time than those using 10 and 20 μm, respectively.

4. Conclusions

This study reports the effect of the amount and limestone particle size on the properties of Portland-limestone cement pastes. The following conclusions can be drawn from the obtained experimental data:

- The compressive strength of Portland-limestone cement pastes decreased in all ages with an increasing amount of limestone due to the dilution effect.

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The limestone particle size has influence on the observed compressive strength values. It was confirmed that compressive strength increased with the fineness of limestone.

From the standard consistency results, it seems that limestone has no effect on water requirement compared to Portland cement. Moreover, the increase in level of fine particles caused requires much water.

Both initial and final setting time of Portland-limestone cement pastes were decreased with an increasing of limestone content at the same fineness.

At the same level replacement, the cement pastes using small-sized limestone show lower setting time than those using large-sized limestone.

5. Acknowledgement and References

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