Effect of Addition of Polypropylene Fibers on The Properties of Gypsum Blocks

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1. Introduction

Wide distribution of gypsum materials and products, that contributes mainly to their high consumer properties and capacity of forming the most comfortable environment requires the increase in their technical parameters, mainly of mechanical and operational ones [1]. Gypsum has been exploited since ancient times in several purposes, mainly in the building industry and for artistic purposes. Later, came the medical, agricultural and chemical applications. Nowadays, besides these fields, it is used in soil stabilization and humidity regulation, cement, neutron shielding, etc. [2].

Gypsum is present as a mineral ore mainly consisting of CaSO$_4$.2H$_2$O. This is dehydrated by heating at about 300 °C to the hemi-hydrate CaSO$_4$.0.5H$_2$O. This product, known as gypsum plaster is the commercial “gypsum”. This sets on water addition to the parent dehydrate CaSO$_4$.2H$_2$O. Although this reaction necessitates a theoretical percentage of 18.6% water, the hydration cannot be completed unless a much higher amount of water is added. Table 1 shows the recommended specifications of gypsum produced by the Ballah Company in the North West of Egypt, which represents the main producer of Gypsum in this country. These are compatible with ASTM C1396 / C1396M – 17 [3].

Table 1 Specifications of gypsum produced by the Ballah Co [3]

<table>
<thead>
<tr>
<th>Type</th>
<th>Minimum purity (%)</th>
<th>Initial setting time (min.)</th>
<th>% retained over sieve 100</th>
<th>MOR (MPa) 1 hour</th>
<th>MOR (MPa) 1 day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal gypsum</td>
<td>68</td>
<td>2 - 3</td>
<td>35%</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>Finishing coat</td>
<td>86</td>
<td>2 - 3</td>
<td>15%</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>Molding plaster</td>
<td>95</td>
<td>1.5 - 2</td>
<td>5%</td>
<td>1.5</td>
<td>3</td>
</tr>
<tr>
<td>Medical gypsum</td>
<td>95</td>
<td>1.5 - 2</td>
<td>5%</td>
<td>1.5</td>
<td>3</td>
</tr>
</tbody>
</table>

Gypsum panels and blocks have first appeared five decades ago and found extensive applications in nonbearing walls and internal partitions. They suffer however, from several drawbacks among which are their high-water permeability, their poor mechanical strength and their poor acoustic properties [4, 5]. Attempts have been made to overcome these disadvantages by such additions as polyvinyl chloride, acrylic emulsions, urea resins etc. [6]. The use of fibers as gypsum boards reinforcement was researched by many authors who employed different types of fibers. Kati et al. [7] used 1% glass fibers as reinforcing material and found out that the compressive strength was increased from 5 MPa to 8.1 MPa. On the other hand, when polyethylene fibers were added they showed a detrimental effect on strength. However, when an adhesive agent was added, the strength values increased over the control fibers free sample [8].

Polypropylene, on the other hand, is a polymer prepared by the polymerization of propylene CH$_3$=CH-CH$_3$. Its molecular weight may reach 40,000 and its density is about 0.91 g.cm$^{-3}$. It softens at 148 °C and melts at 176 °C. It can be processed into fibers by a spinning process. These fibers are then cut into variable lengths (commonly a few centimeters). They have been used as reinforcing fibers in polymer resins and concrete [9]. Polypropylene fibers were also added by Alam and et al. [10] to plaster foamed with polyurethane to produce light boards. They obtained products of low bulk density (1033 to 1416 kgm$^{-3}$) but of low strength. In this present article, it was added to gypsum blocks in a trial to improve their strength and possibly other properties as well.

2. Experimental Methods

2.1 Raw Materials

Commercial gypsum plaster (hemihydrate), purchased from the Ballah Co, stated to have a minimum purity of 95%. This was finely ground in an agate mortar to pass 200 mesh sieve (0.074 mm). Sand, added as a binding material, retained between 80 – 100 mesh sieves, of median particle size = 0.163 mm (D$_{50}$). The fact that the particle size of sand is almost double that of gypsum assists better packing, hence decreasing the porosity. PP fibers of average length 30 – 50 mm purchased locally, produced by Ningyang Bangneg factory (China).

2.2 Investigating Properties

The following properties were investigated for plain gypsum plaster, and its blend with sand and PP fibers, according to ASTM C473 – 17 [11]. Workability being not included in the ASTM standard, it was determined according to UNE-EN 13279-2 as described by Serrano et al. [12]. It consists of placing the well mixed gypsum water mix in a truncated cone of standard dimensions then after releasing the paste from the cone, recording the diameter of the slump cone. The rate should range between 150- 210-mm. Final setting time was determined for the wet paste, while water absorption, bulk density, porosity, compressive strength and MOR were determined after drying the molded specimens for one hour at 80 °C. In all cases, three specimens were tested and the average result taken. The molds prepared were made from steel and had different dimensions depending on the test. For water absorption, porosity, density and compressive strength, they were cubes of edge = 50 mm, while for MOR determination by the three-point bending method, they consisted of cuboids of dimensions: 30 mm (b) x 20 mm (w) x 100 (l) mm.
3. Results and Discussion

3.1 Effect of Water Content on the Properties of Plain Gypsum Samples

All samples were tested after 1 day of being de-molded to ensure total setting although final setting of gypsum is normally completed after about one hour [13]. As expected, exceeding the stoichiometric amount of 18.6% water added to plaster had for effect to increase the voids ratio by evaporation of the residual water. Figs. 1 and 2 show that an increase in the amount of water has for effect to increase the porosity and therefore decrease the bulk density of the samples. This was obviously accompanied with an increase in water absorption (Fig. 1).

The workability, on the other hand started increasing on water addition and lied within the recommended range (150 – 220 mm) between 45 – 55% water (Fig. 3). At that water level, the initial setting time was about 17 minutes, which is higher than the recommended value of 10 min [12].

The compressive strength values decreased with an increase in water level, owing to the increase in porosity, as evidenced from Fig. 4. The dependence of MOR on water fraction is illustrated in Fig. 5. The values attained at a 50% water level are compatible with the minimum recommended value of 1.5 MPa for MOR and 10 MPa for compressive strength [3, 12]. It was possible to correlate both the MOR and the compressive strength to fractional porosity by the following semi-logarithmic relation as suggested by Barsoum [13] (Fig. 6).

\[
\text{MOR} = 10.91e^{-4.97p} \\
\sigma_{\text{comp}} = 27.97e^{-2.78p}
\]

Following these results, it was decided to use a water addition of 50% in all subsequent work.

3.2 Effect of the Addition of Sand and PP

Fig. 7 shows that when PP fibers were added, the initial setting time rapidly decreased owing to the nucleating effect of the added fibers. The further addition of sand accentuated this effect. Adding sand at a percentage higher than 10% caused no further reduction in setting time. The recommended value of 10 minutes (600 s.) was reached with 500 g/m³ PP addition without any sand addition. The addition of 10% sand slightly decreased this value to 8 min.

Fig. 8 shows the effect of adding PP fibers and sand on the porosity of the samples. It is clear that the addition of sand at levels ranging from 5 to 10% decreases the porosity from about 30% to 20%. The effect of PP in decreasing the porosity is only pronounced in the absence of sand.
The variation of compressive strength on adding sand and PP fibers is shown in Fig. 10. It appears from this set of curves that the addition of PP alone doesn’t affect strength to the same extent observed on adding sand. In absence of PP, the addition of sand slightly increases the strength values from 10.2 MPa to 11.2 MPa from 0 to 10% level. The combined effect of PP and sand produces a maximum value exceeding 14 MPa at 10% sand and 500 g/m² PP addition. Increasing the percent sand and/or PP above these values reduces the strength to lower levels owing to the inert nature of sand which interferes with the hydration of the hemihydrate. The decrease in strength observed even in sand free samples, was also reported by Daood et al [14] who used vegetable fibers as reinforcing material. Their results show a maximum strength of 9 MPa at 1% fibers addition (by weight) followed by a decrease at higher doses of addition.

The effect of adding PP fibers on MOR was more pronounced than that of sand, presumably because of the reinforcing effect of fibers which contributes to better mechanical resistance to bending. The effect of adding sand is not very pronounced as can be followed from Fig. 11.

4. Conclusion

The conclusion could be reached regarding the effect of the addition of PP fibers to plaster at different levels together with sand. The optimum water level for maximum workability of the used plaster was 50%. The addition of PP fibers decreased the setting time, an effect further accentuated by the presence of sand. The recommended value of 10 min. was reached using 500 g/m² PP addition. At that PP level, an addition of 10% sand, however, decreased the setting time to about 8 min, which is slightly below the minimum recommended time of 10 min. It was possible to reduce the porosity by adding PP fibers and sand. Adding 500 g/m² PP and 10% sand reduced the porosity from 22% to 17.3%. An addition of 500 g/m² PP and 10% sand produced a spectacular increase in MOR that did not depend appreciably on the level of sand content. The values of compressive strength obtained were higher than the recommended value of 10 MPa. This means that it could be possible to produce hollow sections of reasonable strength, thus economizing the cost of gypsum used per unit surface area of panel.

References


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