Cement composites with limestone dust and different grades of wood sawdust

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Abstract

This paper presents a parametric experimental study which investigates the potential use of limestone powder wastes (LPW) and wood sawdust wastes (WSW) combination for producing a lightweight composite as a building material. Some of the physical and mechanical properties of brick materials having various levels of LPW and WSW with different particle sizes are investigated. The obtained compressive strength, flexural strength, unit weight, ultrasonic pulse velocity (UPV) and water absorption values satisfy the relevant international standards. The results show the effect of high level replacement of WSW with LPW does not exhibit a sudden brittle fracture even beyond the failure loads, indicates high energy absorption capacity, reduce the unit weight dramatically and introduce a smoother surface compared to the current bricks in the market. It shows a potential to be used for walls, wooden board substitute, alternative to the concrete blocks, ceiling panels, sound barrier panels, absorption materials, etc. Recycling of unmanaged WSW and LPW as new brick material supplements appears to be viable solution not only to the environmental problem but also to the problem of the economic design of buildings.

Keywords: Wood; Limestone; Cement; Waste; Brick; Masonry

1. Introduction

Accumulating of unmanaged wastes especially in developing countries has resulted in an increasing environmental concern. The increase in the popularity of using environmentally friendly, lightweight construction materials in building industry has brought about the need to investigate how this can be achieved by benefiting to the environment as well as maintaining the material requirements affirmed in the standards. Since a large demand has been placed on building material industry especially in the last decade owing to the increasing population that causes a chronic shortage of building materials, the civil engineers have been challenged to convert the industrial wastes to useful building and construction materials.

Many previous researches [1–15] have obtained valuable results to use the industrial wastes in various forms of concrete production. For instance, the use of waste rubber, glass powder and paper waste sludge in concrete mix has received conscribe attention over the past years. Some researches carried out in the past used wood ash wastes as a replacement for cement in concrete mixes [1–2]. Although these researches are providing encouraging results, the brick mixes having both WSW and LPW combination hitherto has not been investigated. These wastes utilized in this research are widely available in large amounts from the forest and limestone industries. This paper presents some of the physical and mechanical properties of brick mixes having various levels of LPW and WSW with different particle sizes.

Most wastes used in this research are currently disposed in sanitary landfills or open dumped into uncontrolled waste pits and open areas. A perennial dilemma for the industries has been the disposal of WSW and LPW generated. This predicament is not unique to Turkey or UK [16,17]. This is a world wide energy loss and environmental disposal problem. Disposal of this product waste is a major problem for the many small businesses. Therefore, the acceptable solution of this problem with a commercial value is crucial.
Wood product and furniture manufacturers generate sawdust, offcuts and dust. Sawdust is generated from cutting, drilling and milling operations where wood is removed from a finished product. Wood dust are very fine particles and generated during sanding or other machining operations, it is often collected in filter bags or dust collectors. The physical and chemical properties of wood dust vary significantly depending on many factors such as geographical location and industrial processes. The condition of wood wastes is often variable in both quantity and quality, and with little or no accurate information documenting wood waste arisings, it is important to develop comprehensive detailed plans for accurate database concerning all aspects of wood waste. In some cases, wood waste contains some degree of contamination reducing the net value of the material and requires further processing in order to meet end market specifications. Each of these factors can generally influence the recyclability of wood waste. On average, 48 million m³ of timber is being consumed annually in the UK and the wood processing results in 5–10% sawdust and dust wastes [16].

Currently, the blocks of limestone are extracted via chain saw, diamond wire and diamond saws from quarries and then the blocks are cut into smaller suitable sizes to be used as building material [6]. The processing limestone that includes crashed limestone production is results in approximately 20% LPW. The estimated LPW of 21.2 million tons in the UK, 18 million tons in Greece and 30 million tons in Turkey is reported [5,6]. Disposal of LPW causes dust, environmental problem and pollution because of its fine nature. It contaminates the air with the storms in the summer and spring seasons and therefore causes serious health hazards including specifically asthma. The industry suffers to store LPW due to the costs of storage.

There are limited numbers of studies about the possible utilization strategies of LPW in civil engineering industry [5,6]. The samples with the diameter of 50 and 80 mm height are produced and their compressive strength, modulus of elasticity and density are determined by Galetakis and Raka [5]. The tests are undertaken on the limited number of cylindrical samples that are not on the standard brick sample forms. The flexural strength and water absorption values are not determined in this research [5]. The other engineering properties required by the international standards such as ASTM C 67-03 [18] need to be investigated.

Using the WSW–LPW combination as a fine aggregate in its natural form has allowed producing economical, lighter and environmental-friendly new cement composite material. This paper presents the research work undertaken to study the properties of this new composite material, which contains various levels of WSW, LPW, small amounts of cement as binder and water. The replacement of these wastes as aggregate in the tested samples dramatically reduces the unit weight. A better and smoother surface is obtained. This combination provides a unique kind of building material which exhibits concrete brick-like appearance but it behaves similar to the widely used autoclaved aerated concrete (AAC). Its physical and mechanical properties presented in this paper show that it has a great potential as a lightweight building material, which may offer significant savings not only in labour and transportation but also in the amounts of binder and steel reinforcement consumed in the construction.

2. Experimental programme

2.1. Materials

WSW used in this research is generated from the mechanical processing of raw wood in the sawing process. WSW is used in its original form and taken from its disposed area near the timber manufactures in the local region. LPW used in the brick samples is produced during quarrying operations in the region. The results of chemical and physical analysis of LPW, WSW and cement are given in Table 1.

Cement used in this study is Portland cement with calcite, complies with TS EN 197-1-CEM II/A-L 42.5 R [19], produced at the Cement Mill in the region. Tap water is used in the brick samples. The properties of the water used in this study are of pH 6.2, 5.6 mg/l sulphate content and have a hardness of 3.7.

2.2. Mixing and fabrication of bricks

Ten different types of mixtures are prepared according to the requirements of BS 6073 [20] in the laboratory trials. The details of mixes are given in Table 3. The cement and

<table>
<thead>
<tr>
<th>Properties</th>
<th>(Percentage by mass)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>(LPW)</td>
</tr>
<tr>
<td>SiO₂ (%)</td>
<td>0.26</td>
</tr>
<tr>
<td>CaO (%)</td>
<td>56.19</td>
</tr>
<tr>
<td>MgO (%)</td>
<td>0</td>
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<tr>
<td>Al₂O₃ (%)</td>
<td>0.25</td>
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<tr>
<td>Fe₂O₃ (%)</td>
<td>0.30</td>
</tr>
<tr>
<td>SO₃ (%)</td>
<td>0</td>
</tr>
<tr>
<td>Na₂O (%)</td>
<td>0</td>
</tr>
<tr>
<td>K₂O (%)</td>
<td>0</td>
</tr>
<tr>
<td>Cl (%)</td>
<td>0</td>
</tr>
<tr>
<td>Loss on ignition (%)</td>
<td>42.65</td>
</tr>
<tr>
<td>pH</td>
<td>—</td>
</tr>
<tr>
<td>Density</td>
<td>2.67</td>
</tr>
<tr>
<td>Specific surface area (m²/kg)</td>
<td>145</td>
</tr>
<tr>
<td>Compressive strength for 28 days (MPa)</td>
<td>—</td>
</tr>
</tbody>
</table>
water proportions in the mixes are taken as constant to determine the effect of various WSW–LPW combinations.

The replacement ratios between WSW and LPW are taken as volumetric in the mix design. For instance, the 20% replacement of WSW-fine means that 20% of the corresponding LPW volume is replaced by WSW-fine in the LWF-20 samples (see Table 3). The percentage weight replacements between WSW and LPW in the mixes are also provided in Table 3.

In the mixing process of samples, LPW, WSW and cement contents are placed in a concrete mixer and mixed for 1 min. It is observed that WSW is uniformly scattered within the mixes. In order to obtain more homogeneous mixes, the water is sprayed by air pump onto the mixes while the mixer is turning. Another 3 min of mixing is conducted. Afterward, the fresh mixes are fed into the steel moulds. The total number of samples prepared by this procedure is 150. Table 4 shows the sample sizes and the number of samples is prepared for the corresponding compressive strength, the flexural strength and the unit weight tests.

The steel mould is over filled with the mixes using the mixture proportions given in Table 3. The initial depth covering the mould is approximately 150 mm. The pressures are applied for 4 h to compact the material in the mould. The amount of pressures applied to the material is given in Table 3. Subsequently, the formed brick samples are removed from the mould. No damage is observed on the bricks while demoulding. All brick samples are cured in air room temperature for 24 h. Afterwards, the bricks are cured for a period of 28 days in the cure tank filled with lime-saturated water at 22°C. Then, the brick samples are dried for 24 h by a ventilated oven at 105°C. The water absorption is obtained from the samples prepared for the unit weight tests. The UPV tests are also conducted on the samples made for the flexural strength tests. Fig. 2 shows the three typical samples from each WSW categories and their close-up surface texture views.

2.3. Tests methods

The series of tests are carried out according to ASTM C 67-03a [18] to determine the water absorption, unit weight, compressive strength and flexural strength values of the brick samples.

After 28 days of curing, the brick samples are tested for water absorption. They are taken out of the curing tank and allowed to drain the surface water by placing them on a metal wire mesh. The visible surface water is removed with a damp cloth and the samples are weighted immediately. After obtaining the saturated weight content, they are placed in an oven at 105°C and dried to a constant mass for 28 h, and then taken out from the oven and weighted at room temperature. The water absorption of wet and dry weight of samples is calculated. The brick samples are cooled at room temperature and each of their unit weights are obtained by dividing the mass of the bricks by their overall volume.

The dry compressive strength of brick samples is determined by using the servo controlled compression test machine with a maximum capacity of 800 kN. The compression load is applied onto the face of the sample having the dimensions of 105×225×75 mm³. The compressive strength is determined by dividing the maximum load with the applied load area of the brick samples. The dry flexural strength of samples is determined by the three-point bending test with a supporting span of 180 mm, a height of 75 mm and a width of 105 mm. The direct UPV measurements are also taken for each brick samples according to BS 1881 [21]. The direct path length for the direct UPV is measured through the brick length of 225 mm.

3. Test results and discussion

Table 5 shows the averaged tests results obtained from the tests. Fifty brick samples with dimensions of 105×225×75 mm³ are used for the flexural strength and UPV tests. Other 50 samples with dimensions of
105 × 90 × 75 mm³ are tested for the compressive strength. The additional 50 block samples of the same dimensions are tested for unit weight and water absorption. All these tests are conducted in accordance with ASTM C 67-03a [18].

The two water absorption terms corresponding to the volume and the mass of samples are calculated. Fig. 3 shows that the water absorption and the percentage WSW values are proportionate. An improvement of 30% in the WSW content almost doubles the initial water absorption value. In the ASTM C 140 [22], the maximum water absorption value is 0.288 g/cm³ for load-bearing and non-load-bearing concrete masonry units. In 30% WSW contents in all mixes, values of water absorption by mass are in relatively acceptable limit compared to the widely used lightweight building materials such as AAC which has an approximate water absorption value of 60% [23] and ASTM C 140 [22].

It is also observed that the WSW–LPW–cement composite even in this compressive strength value can easily be cut with a simple handheld saw.

Fig. 5 shows the results of compressive strength values obtained from the tests. The average compressive strength values are inversely proportional with the percentage WSW replacement (see Fig. 5). The strength dramatically decreases with an increase in the replacement level of WSW. About 70% reduction in the strength of control mix is obtained from the 30% WSW replacement (LWF-30 mix), which attains the average result of 6.1 ± 0.6 MPa complies with BS6073 [21] and Turkish standard code as 5 MPa for burnt clay bricks in load-bearing masonry units [24] (see Table 5). LWF-30, LWC-30 and LWM-30 bricks can be used in the non-load-bearing masonry units because of minimum compressive strength 3.5 MPa in ASTM C 129 [25].

The direct UPV values are measured on the flexural strength samples having a 225 mm direct path length required by BS1881 [21]. Fig. 7 shows the relationship between the UPV results and the WSW replacement values. Since the UPV is lower through the voids, which are produced by the WSW content in the samples, the reduction in the strength values causes the UPV to be decreased. The results suggest that the WSW content, the compressive and flexural strength values may approximately be determined without a destructive testing by using the non-destructive UPV measurements.
Fig. 7 shows that the UPV values for the fine WSW supplements are dramatically reduced within the investigated percentage WSW replacement range, the exception to this occurs only between 10% and 20% WSW replacement content where the UPV values almost attain as constant. This can be confirmed with the compressive and flexural strength values (see Figs. 5 and 6). Whereas the strength values between 10% and 20% WSW replacement content provides better results for the mixed and coarse WSW categories (see Figs. 5–7), the flexural strength values for

![General view of samples: (a) LWF-30, (b) LWC-30, (c) LWM-30.](image)

**Table 5**

<table>
<thead>
<tr>
<th>Mix no.</th>
<th>Compressive strength (MPa)</th>
<th>Flexural strength (MPa)</th>
<th>Unit weight, (g/cm³)</th>
<th>Absorption (mass) (%)</th>
<th>Absorption (volume) (%)</th>
<th>UPV (m/sn)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control mix</td>
<td>24.9±2.1</td>
<td>3.94±0.34</td>
<td>1.88±0.01</td>
<td>12.4±0.0</td>
<td>23.3±1.0</td>
<td>2718±31</td>
</tr>
<tr>
<td>LWF-10</td>
<td>10.0±0.6</td>
<td>3.01±0.26</td>
<td>1.80±0.01</td>
<td>13.9±1.0</td>
<td>23.5±1.5</td>
<td>2323±55</td>
</tr>
<tr>
<td>LWF-20</td>
<td>9.9±1.0</td>
<td>2.88±0.16</td>
<td>1.63±0.02</td>
<td>16.8±0.8</td>
<td>25.0±1.2</td>
<td>2270±52</td>
</tr>
<tr>
<td>LWF-30</td>
<td>6.1±0.6</td>
<td>2.42±0.09</td>
<td>1.47±0.03</td>
<td>19.0±1.2</td>
<td>27.8±1.1</td>
<td>1980±66</td>
</tr>
<tr>
<td>LWC-10</td>
<td>16.1±1.0</td>
<td>3.80±0.10</td>
<td>1.74±0.06</td>
<td>13.2±0.7</td>
<td>23.0±0.6</td>
<td>2667±75</td>
</tr>
<tr>
<td>LWC-20</td>
<td>10.4±0.6</td>
<td>3.30±0.29</td>
<td>1.65±0.01</td>
<td>16.0±0.4</td>
<td>26.4±0.6</td>
<td>2380±50</td>
</tr>
<tr>
<td>LWC-30</td>
<td>6.2±1.2</td>
<td>2.34±0.40</td>
<td>1.50±0.02</td>
<td>20.2±0.9</td>
<td>30.3±1.0</td>
<td>2027±79</td>
</tr>
<tr>
<td>LWM-10</td>
<td>16.6±0.9</td>
<td>3.65±0.17</td>
<td>1.70±0.06</td>
<td>13.9±1.2</td>
<td>23.5±1.5</td>
<td>2627±69</td>
</tr>
<tr>
<td>LWM-20</td>
<td>11.0±0.2</td>
<td>3.50±0.54</td>
<td>1.66±0.02</td>
<td>15.1±0.9</td>
<td>25.0±1.2</td>
<td>2383±67</td>
</tr>
<tr>
<td>LWM-30</td>
<td>7.2±0.9</td>
<td>3.08±0.13</td>
<td>1.51±0.02</td>
<td>19.2±0.5</td>
<td>29.0±0.4</td>
<td>2083±90</td>
</tr>
</tbody>
</table>

![The relationship between the percentage WSW replacement and the water absorption values in terms of the WSW categories.](image)

![The influence of percentage WSW replacement on the unit weight results.](image)
the coarse WSW are dramatically reduced in the 30% WSW replacement content. Figs. 5–7 suggest that the mixed WSW category provides better strength values within the investigated percentage WSW replacement range.

4. Conclusions

The feasibility of producing artificial limestone brick with wood sawdust was showed technically in this study. Based on the experimental investigation reported in this paper, the following conclusions were drawn:

(1) The physical and mechanical properties of brick samples with WSW and LPW were determined. The test results showed that the WSW–LPW combinations have a potential to be used in the production of a new lighter brick.

(2) The effect of 10–30% WSW replacements in the WSW–LPW matrix did not exhibit a sudden brittle fracture even beyond the failure loads and indicated high-energy absorption capacity.

(3) The WSW, having particle size less than 1.18 mm and higher than zero, provided better results.

(4) In 30% WSW contents for all bricks, the values of water absorption by mass were in acceptable limit in accordance with the ASTM C 140 [22].

(5) This composition produced a comparatively lighter brick which was about 65% lighter than the conventional concrete brick.

(6) All bricks with 30% replacement level of WSW satisfied the minimum compressive strength and flexural strength requirements in BS6073 [20] and TS 705 [24] for load-bearing concrete masonry unit materials to be used in the structural applications. These bricks with 30% replacement level of WSW can be used in non-load-bearing masonry units according to ASTM C 129 [25].

It would be valuable to investigate the thermal properties of these composite brick materials in future works.

References


