Cotton and limestone powder wastes as brick material

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Abstract

Large amounts of cotton and limestone wastes are accumulated from the countries all over the world. The majority of cotton wastes (CW) and limestone powder wastes (LPW) is abandoned, and causes certain serious environmental problems and health hazards. This paper presents a parametric experimental study, which investigates the potential use of CW–LPW combination for producing new low cost and lightweight composite as a building material. The physical and mechanical properties of concrete mixes having high level of CW and LPW are investigated. The obtained compressive strength, flexural strength, ultrasonic pulse velocity (UPV), unit weight and water absorption values satisfy the relevant international standards. The results show that the effect of high level replacement of CW with LPW does not exhibit a sudden brittle fracture even beyond the failure loads, indicates high energy absorption capacity, reduces the unit weight dramatically and introduces another surface compared to the current concrete bricks in the market. The process undertaken can easily be applied in the current brick plants. It results a sturdy lighter weight composite having potential to be used for walls, wooden board substitute, economically alternative to the concrete blocks, ceiling panels, sound barrier panels, etc. Paper presents the results and draws conclusions.

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1. Introduction

Since the large demand has been placed on building material industry especially in the last decade owing to the increasing population, which causes a chronic shortage of building materials the civil engineers have been challenged to convert the industrial wastes to useful building and construction materials. Accumulation of unmanaged wastes especially in developing countries has resulted in an increase environmental concern. Recycling of such wastes as building materials appears to be viable solution not only to such pollution problem but also to the problem of economical design of buildings. The increase in the popularity of using environmental friendly, low cost and 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.

Many previous researches [1–13] undertaken are 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 on the textile waste used in concrete mix are carried out in the past, such as the textile waste cuttings [6], the textile effluent treatment plant sludge [8] and the cotton stalk fibre [13]. Although these researches [6,8,13] using wastes from the textile industry are providing similar and encouraging results, those wastes are dissimilar in behaviour than the cotton wastes (CW) which are widely available in large amount from the ginning industry utilized in this presented research.

The development of new areas for cotton in Brazil, Africa and Turkey is contributing to the rise in world pro-
duction, such as the expansion of irrigation in South East Turkey (GAP region) now accounts for 500,000 tons of production, compared with 164,000 tons in 1995 [14]. Approximately 20.5 million tons of cotton were grown by about 80 countries in 2004 for the fibre production [15].

The residual or secondary wastes of lint in the cotton production have little value and are therefore attractive for the purpose of making lightweight building material. CW used in this research is generated from the mechanical processing of raw cotton in the spinning process. Because of the differences in the manufacturing facilities, it is difficult to determine the quantity of cotton waste generated. According to the experience of the cotton manufacturers in GAP region, approximately 7% of cotton ends up as waste produced in spinning. Therefore, it may be estimated that 1.5 million tons of cotton waste, not including lint content, were generated worldwide by the fibre manufacturers in 2004.

In recent years, the several facilities have been proactively locating markets for this waste material. The alternative use of CW fibres includes soil amendment, mulch, briquetting for direct land application, fuel source, cattle feed or cultivating Volvariella volvacea on CW, etc. [16]. However, these are not officially and widely accepted waste management techniques at the moment. The cotton industry worldwide is expecting to reduce their CW disposal by alternative options for handling this waste as a by-product that has a potential as a multiuse product.

Most of CW used in this research is currently disposed in sanitary landfills or open-dumped into uncontrolled waste pits and open areas. A perennial dilemma for the ginning industry has been the disposal of CW generated. This predicament is not unique to Turkey or the United States. This is a worldwide energy loss and environmental disposal problem. Disposal of this product waste is a major problem for the many small cotton ginning businesses. Assuming an average landfill tipping fee of $20 per ton, more than $30 million is spent on disposal costs alone, and this amount does not account for the cost of handling and shipping or the economic benefits that can be realized from resource recovery. From burning to dumping on fields, CW has been mostly a problem for which hitherto widely acceptable solution with commercial value has not been reached. Additionally, in 2001 the government measures show that 80 cotton producing countries are directly supporting cotton production totaled $5.8 billion worldwide, equivalent to about one-fourth of the value of world cotton production [14]. Adding all the loss through the worldwide cotton production gives very dramatic figure. Therefore, the acceptable solution of this problem with a commercial value is crucial.

A treatment and cleaning method for CW has been developed allowing homogenously mix CW with LPW and cement. LPW is another not effectively used industrial waste that is also excessively available in large amount from limestone processing factories worldwide.

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 [17]. The processing limestone which includes crashed limestone production is resulting 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 [17,18]. LPW in GAP region of Turkey is disposed in landfills or open-dumped into uncontrolled waste pits and open areas. It 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 [17,18]. Galetakis and Raka [18] have undertaken some valuable tests on the limited number of cylindrical samples, which are however not on the standard brick sample forms. The flexural strength and water absorption values are not determined in this research [18]. The other engineering properties required by the international standards such as ASTM C 67-03 [19] need to be investigated.

Using CW–LPW combination as a fine aggregate in its natural form has allowed economical, lighter and environmentally friendly new composite material. This paper presents the research work undertaken to study the properties of this new composite material which contains the various levels of CW, LPW, and small amount of cement as binder and water. The process undertaken in the production of this composite can easily be applied into the current brick plants. The better and smoother surface is obtained. The replacement of these wastes as aggregates in the tested samples dramatically reduces the unit weight. This combination provides a unique kind of building material, which exhibits concrete like appearance but it behaves similar to widely used autoclaved aerated concrete (AAC). Its physical and mechanical properties presented in this paper show that it has a great potential as a low cost 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 program

2.1. Materials

CW used in this research is generated from the mechanical processing of raw cotton in the spinning process. The large amount of secondary wastes (contain a mixture of stems, leaves, soils, and lint) from the spinning process of cotton string manufacturers in the GAP region is currently disposed into the uncontrolled open waste pits. The CW used in the sampling is taken from its disposed area nearby the cotton string manufactures in the GAP region.

Several tests have been undertaken to use CW in its original form. However, it is observed that the original CW taken from the waste pits does not homogeneously mix
with LPW, cement and water. It becomes lump and accumulates to the one side of the mixer.

In order to allow homogeneous mix of CW, a treatment process is undertaken that cleans the wastes from oil in present and causes CW diffusing in the mixture. It also removes waxes and oils from fibre to make the fibre more receptive to bleaching. Similar treatment and cleaning process is currently used by the textile industry worldwide [20–22]. In this process 90% NaOH, 7% NaCl and 3% Na2CO3 solution is used. NaOH commonly known as caustic soda, lye, or sodium hydrate, is a caustic compound which attacks organic matter. NaOH is inexpensive and used in many applications in textile industries. It enables greater tensional strength and consistent lustre and provides functions of neutralization of acids, hydrolysis, condensation, replacement of other groups in organic compounds of hydroxyl ions [21]. For 100 kg CW, 4 kg of NaOH, NaCl and Na2CO3 solution is used.

The wastes are processed to clean the cotton fibres and then it submerged in NaOH and water content in 1 h at 90–95 °C heating in first 30 min from 40 to 90 °C. Then, the treated and cleaned CW is rinsed with hot water in 30–40 °C. This process allowed the CW fibres to homogeneously mix with limestone and cement–water mixtures. In this process, the rinsing is carried out thoroughly to minimize the NaCl and Na2CO3 content since the remaining of these salts might cause salt damage in the new brick. This adopted process of cleaning CW is currently used by the textile industries worldwide [20–22] and it is a low cost and environmental friendly process.

Fig. 1 shows the treated CW and LPW used in the presented research. The measured average length of cotton fibres is 100 μm. The pH value of CW is 7.19 prior to the treatment and measured as 8.36 after the treatment.

LPW used in the brick samples is produced during quarrying operations in the region. The results of chemical and physical analysis of LPW, CW, cement and waste glass powder (WGP) which is also used in some of the test samples are given in Table 1. The WGP is obtained from a glass bead manufacturer in the region. The grading of the LPW and WGP is shown in Table 2.

Cement used in this study is Portland cement with calcite, complies with TS EN 197-1-CEM II/A-L 42.5 R [23], produced at the Cement Mill in the region. Tap water is used in the brick samples. The properties of the water in this study are of pH 6.2, 5.6 mg/l sulphate content and hardness of 3.7.

2.2. Mixing and fabrication of bricks

Six different types of mixtures are prepared in the laboratory trials. All types of mixtures are prepared according to the requirements of BS 6073 [24]. The details of mixes are given in Table 3. The cement and water proportions in the mixes are taken as constant to determine the effect of various CW–LPW combinations.

Since the cotton wastes are of higher volume content the replacement ratios between CW and LPW are taken as volumetric. For instance, the 20% replacement of CW means...
that the 20% of corresponding LPW volume is replaced by
CW in the LC-20 samples (see Table 3). The percentage
weight replacements in the mixes between CW and LPW
are also provided in Table 3. The CW replacement in terms
of the cement used can also be defined in this way, such
that LC-10, LC-20, LC-30 and LC-40 mixes contain
8.5%, 17.3%, 25.8% and 34.6% CW of the cement weight,
respectively.

In the mixing process of samples, LPW, CW and
cement contents are placed in a concrete mixer and mixed
for 1 min. It is observed that CW 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 90. 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.

Using the mixture proportions given in Table 3 the steel
mould is over filled with the mixes. The initial depth cover-
ing the mould is approximately 150 mm. The pressures are
applied for 1 min to compact the material in the mould (see
Fig. 2a). 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 observed on
the bricks while demoulding (see Fig. 2b). 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 pre-
pared for the unit weight tests. The UPV tests are con-
ducted on the samples made for the flexural strength tests.

2.3. Tests methods

The series of tests are carried out according to ASTM C
67-03a [19] to determine the water absorption, the unit

<table>
<thead>
<tr>
<th>Mix no.</th>
<th>Cement (g)</th>
<th>Water (g)</th>
<th>LPW (g)</th>
<th>CW (g)</th>
<th>WGP (g)</th>
<th>Total (g)</th>
<th>Pressure (ton)</th>
<th>Volumetric % replacement of CW with LPW</th>
<th>% Weight replacement of CW with LPW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control mix</td>
<td>376</td>
<td>188</td>
<td>2936</td>
<td>–</td>
<td>–</td>
<td>3500</td>
<td>40</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>LC-10</td>
<td>376</td>
<td>188</td>
<td>2706</td>
<td>32</td>
<td>–</td>
<td>3302</td>
<td>20</td>
<td>10</td>
<td>1.18</td>
</tr>
<tr>
<td>LC-20</td>
<td>376</td>
<td>188</td>
<td>2405</td>
<td>65</td>
<td>–</td>
<td>3034</td>
<td>10</td>
<td>20</td>
<td>2.70</td>
</tr>
<tr>
<td>LC-30</td>
<td>376</td>
<td>188</td>
<td>2117</td>
<td>97</td>
<td>–</td>
<td>2778</td>
<td>5</td>
<td>30</td>
<td>4.58</td>
</tr>
<tr>
<td>LC-40</td>
<td>376</td>
<td>188</td>
<td>1804</td>
<td>130</td>
<td>–</td>
<td>2498</td>
<td>2</td>
<td>40</td>
<td>7.21</td>
</tr>
<tr>
<td>LCG-40/20</td>
<td>376</td>
<td>188</td>
<td>1443</td>
<td>130</td>
<td>361</td>
<td>2498</td>
<td>2</td>
<td>32</td>
<td>9.01</td>
</tr>
</tbody>
</table>

Table 4
Sample sizes and the number of samples prepared for testing

<table>
<thead>
<tr>
<th>Mix no.</th>
<th>For the compressive strength test sample size: 105 mm × 90 mm × 75 mm</th>
<th>For the flexural strength test sample size: 105 mm × 225 mm × 75 mm</th>
<th>For the unit weight test sample size: 105 mm × 90 mm × 75 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control mix</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>LC-10</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>LC-20</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>LC-30</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>LC-40</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>LCG-40/20</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Total number of samples</td>
<td>30</td>
<td>30</td>
<td>30</td>
</tr>
</tbody>
</table>

Fig. 2. Fabrication of brick samples. (a) Before compaction and (b) after compaction.
weight, the compressive strength and the flexural strength values of the brick samples.

After 28 days of curing, the brick samples are tested for water content. 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 into an oven at 105°C and dried to a constant mass for 28 h, and then taken out from the oven and weighted at the room temperature. The water content of wet and dry weight of samples is calculated. The brick samples are cooled at room temperature and their each unit weights are obtained by dividing the mass of the bricks by their overall volume. The alternative method [25] providing more precise results for determining material density has not been employed in this research since ASTM C 67-03a [19] is used throughout the testing of brick samples.

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 sample having the dimensions of 105 × 90 mm². 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 taken for each brick samples according to BS 1881 [26]. The direct path length for the direct UPV is measured through the brick length of 225 mm. A portable ultrasonic tester is used to evaluate the direct, indirect and semi direct UPV measurements. This tester measures the time of propagation of ultrasound pulses in the range 0.1–9999.9 μs with a precision of 0.1 μs. The transducers used are of 50 mm in diameter, and having maximum resonant frequencies of 54 kHz.

3. Test results and discussion

Table 5 shows the average test results obtained from the tests. Thirty brick samples with dimensions of 105 × 225 × 75 mm³ are used for the flexural strength and UPV tests. Other 30 samples with dimensions of 105 × 90 × 75 mm³ are tested for the compressive strength. The additional 30 block samples of the same dimensions are tested for the unit weight and water absorption. All of these tests are conducted in accordance with ASTM C 67-03a [19]. The obtained test results show that the minimum compressive and flexural strength requirements in BS6073 [24] are obtained (see Table 5).

3.1. Water absorption and unit weight

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 CW content values are proportionate. An improvement of 40% in the CW content doubles the initial water absorption values. In this CW content, 27.2% of water absorption by mass is in relatively acceptable limit compared to the widely used lightweight building materials such as autoclaved aerated concrete (AAC) which has an approximate water absorption value of 60% [27].

![Graphical representation of some of the results in Table 5.](image)
The test results confirm that the unit weight values are inversely proportionate with the volumetric percentage CW replacement with LPW (see Fig. 3). A 29% reduction in the unit weight of control mix is obtained from the 40% CW replacement and this replacement value doubles the initial water absorption value for these samples. This is an expected result owing to the water absorption nature of CW. By assuming the average unit weight of ordinary concrete brick as 2.3 g/cm³ the mixture having 40% of CW content provides a 58% lighter concrete. A 29% reduction in the unit weight of control mix is a useful result, which exhibits the potential of this composite to be used in the lightweight building material applications.

3.2. Compressive strength

Table 5 shows the results of the compressive strength values obtained from the tests. The average compressive strength values are inversely proportionate with the percentage CW replacement (see Fig. 3). The strength dramatically decreases with an increase in the replacement level of CW. A 71% reduction in the strength of control mix is obtained from the 30% CW replacement (LC-30 mix), which attains the average result of 7 ± 0.3 MPa complies with BS6073 [24]. It is also observed that the CW–LPW–cement composite even in this compressive strength value can easily be cut with simple handheld saw (see Fig. 4). Therefore, the LC-30 mix may be used for the structural applications such as masonry units whereas the LC-40 and LC-40/20 mixes may be used for the non-structural applications. It is observed the addition of WGP content in CW–LPW combination increases the compressive strength as 8.5% in the tested LCG-40/20 samples, which are having the replacement of WGP with LPW (see Table 3).

3.3. Flexural strength

Fig. 5 shows the relationship between the average flexural strength and the compressive strength values that are inversely proportionate with the CW content in the test samples. BS 6073 [24] requires 0.65 MPa as a minimum flexural strength for the building materials to be used in structural applications. All of the samples tested for the flexural strength satisfy this requirement (see Table 5 and Fig. 5). It is observed that the addition of WGP content in CW–LPW combination increases the flexural strength as 24.5% in the tested LCG-40/20 samples (see Table 5).

3.4. Direct UPV measurement

The direct UPV values are measured on the flexural strength samples having 225 mm direct path length required by BS 1881 [26]. Fig. 5 shows the comparative relationships of the UPV, the compressive and flexural strength values. Since the UPV is lower through the voids which are produced by the CW content in the samples, the reduction in the strength values causes the UPV to be decreased. The results suggest that the CW content, the compressive and flexural strength values may approximately be determined without a destructive testing by using the non-destructive UPV measurements.

4. Conclusions

The physical and mechanical properties of brick samples with CW, LPW, and glass powder wastes are investigated. The test results show that the CW–LPW combination provides results, which are of potential for this combination to be used in the production of lighter and economical new brick material. The observations during the tests show that the effect of 10–40% CW replacements in CW–LPW matrix does not exhibit a sudden brittle fracture even beyond the failure loads and indicates high energy absorption capacity by allowing lower labouring cost. This CW–LPW composition produces a sturdy lighter composite, which is about 60% lighter than the conventional concrete bricks. Concrete with 30% replacement level of CW which is attained 7 MPa compressive and 2.19 MPa flexural strength values satisfies the requirements in BS6073 for a building material to be used in the structural applications.

The performed tests presented in this paper constitute only a first step research on CW–LPW combination to be used as brick materials and the further tests are pos-
sibly needed prior to use the new bricks as construction materials. The possible behaviour of the bricks assembled in masonry also needs to be investigated to assess the physical and mechanical behaviour of the brick/mortar system. The further tests may be required such as the water absorption coefficient, the pore size distribution and the bond wrench tests as well as the mechanical tests on brick/mortar combination. The variation in the mechanical strength of these bricks containing the high percentage replacement of cotton when they are saturated with water is another research area need to be investigated. This further information on the new bricks would allow proposing this composite as new building material.

References