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Properties of masonry blocks produced with waste limestone sawdust and glass powder

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Abstract

Large amounts of waste accumulate in every year in all countries which have been running limestone quarries. The majority of waste limestone sawdust (WLS) or dust is abandoned, and causes certain serious problems such as environmental problems and health hazards. This study has been conducted through basic experimental research in order to analyze the usage possibilities of WLS for producing masonry blocks. Two types of masonry blocks are produced for this study. The first type of masonry blocks includes WLS and a small amount of Portland cement. The second type of masonry blocks is composed of WLS with a small amount of Portland cement, and waste glass powder (WGP) at various proportions. The compressive strength and rupture modulus of all masonry blocks are greater than 24.9 MPa and 3.94 MPa, respectively. Compressive strength and rupture modulus' values in the WLS masonry blocks with WGP are higher than those of control masonry block without WGP. Preliminary results show WLS with and without WGP can be used for the production of moulded masonry blocks with acceptable mechanical and physical properties. The data obtained from the first stage of this study show that there is a great potential for the utilization of WLS and WGP in masonry blocks.

Keywords: Limestone; Sawdust; Dust; Glass powder; Masonry block

1. Introduction

Affluent limestone reserves have been one of the most important sources in buildings throughout the construction history of Sanliurfa city in Turkey. In modern times, the small blocks of limestone are extracted via diamond saw from quarries and than these small blocks are cut in factories with suitable sizes that are applicable in the buildings. As a result of these two cutting processes, approximately 80,000 tons of WLS has come into being as a waste annual. This WLS in the Sanliurfa has never been used in anywhere because of its fine nature. Moreover, Municipality of Sanliurfa suffers to store it. Because disposal of this waste is impossible and the storage of it costs too much, with the storms in the summer and spring seasons it contaminates the air of city and causes serious health hazards including specifically asthma. Some countries also have been suffering with the same problems because of not storing WLS properly.

In England a big amount of, 106 million tons, limestone dust has come into being annually [1]. Another example is Greece. Six million tons of WLS disperses in nature as a result of cutting and washing the aggregate in limestone quarries in Greece [2].

There are restricted numbers of studies about the possible utilization strategies of WLS in civil engineering industry.

An experimental approach to develop a new building product consisting mainly of limestone dust, which was considered as waste or by product material of aggregates industry and a small quantity of ordinary Portland cement, was presented by Galetakis and Raka [2]. The specimens with the diameter of 50 mm and height 80 mm were produced and found their compressive strength, modulus of elasticity and density. Their results indicated that all specimens have compressive strength greater than 7 MPa.

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Another waste material is glass that constitutes a problem for solid waste disposal in many municipalities. United Nations estimates the volume of yearly disposed glass as 14 million tons. In Turkey, this amount is 12,000 tons annually [3]. In Turkey most of the nonrecyclable glass is still used in land filling. Since the glass is not biodegradable, using waste glass in landfill does not provide an environment-friendly solution. Consequently, there is a strong need to utilize waste glass.

Early basic experimental studies on glass powder provide the following results.

Ground glass having a particle size finer than 38 μm did exhibit a pozzolanic behavior in concrete and the compressive strength of concrete with ground glass was 4.1 MPa [4]. Glass powder in concrete improved some durability properties of concrete [5]. Waste glass considered as coarse aggregate did not have a significant effect upon the workability of the concrete and only slightly in the reduction of its strength [3]. The rapid mortar bar expansion test results indicated that the replacement of Portland cement with ground glass powder reduced the expansion due to alkali-aggregate reactions [6]. No reaction is detected with particle size up to 100 μm indicating the feasibility of the waste glass reuse as fine aggregate in mortars and concrete [7].

The production of moulded masonry blocks from WLS with and without WGP is possible by using a masonry block manufacturing plant. Moreover, at the laboratory process it is observed that the color of artificial masonry blocks is close to that of natural limestone blocks obtained from limestone quarries.

2. Experimental program

2.1. Materials

WLS used in the masonry blocks is produced during quarrying operations in the area of Akabe (Sanliurfa, Turkey). The results of chemical and physical analysis of WLS are given in Table 1. The grading of the WLS is shown in Table 2.

Table 1
The properties of WLS, WGP and cement

Properties	WLS	WGP	Cement
SiO_2(%)	0.26	70.22	19.20
CaO (%)	56.19	11.13	52.00
MgO (%)	–	–	1.00
Al_2O_3(%)	0.25	1.64	3.70
Fe_2O_3(%)	0.30	0.52	0.16
SO_3(%)	–	–	2.80
Na_2O (%)	–	15.29	–
K_2O (%)	–	–	0.27
Cl (%)	–	–	0.006
Loss on ignition (%)	42.65	0.80	8.20
Density	2.67	2.42	3.00
Specific surface area (m^2/kg)	145	133	500
Compressive strength for 28 days (MPa)	–	–	48

Table 2
Sieve analysis of WLP and WGP

BS test sieve	Passing by weight (%)	
	WLP	WGP
1.18 mm	99.76	99.80
600 μm	97.06	96.90
300 μm	86.39	85.60
150 μm	60.27	69.10
75 μm	44.45	48.87

The WGP is obtained from a glass beads manufacturer in Sanliurfa, Turkey. The chemical and physical properties are given in Table 1. The grading of the WPG is given in Table 2.

Cement (c) used in this study is Portland cement with calcite, TS EN 197-1-CEM II/A-L 42.5 R, produced at the Cement Mill in Mersin, Turkey. Analysis of the cement used in this study is given in Table 1.

Tab water (w) is used in the masonry blocks. The properties of the water in this study are pH 6.2, sulfate content 5.6 mg/l, and hardness 3.7.

2.2. Mixing and fabrication of masonry blocks

Five different types of mixtures are prepared in the laboratory trials. All types of mixtures are prepared for producing masonry blocks according to the requirements of BS 6073 [8]. The details of these five types of mixtures are given in Table 3. For investigating the effect of water/cement ratio on strengths L-1 and L-control masonry blocks without WGP are prepared. LG-1, LG-2 and LG-3 masonry blocks contain 25%, 50% and 75% glass powder of used cement weight, respectively. In otherwords, at these three masonry blocks 3.12%, 6.24% and 9.37% limestone is replaced by WGP. The procedures for mixing the L and LG masonry blocks involve the following: For L masonry blocks, WLS and cement are placed in a concrete mixer and mixed for 1 min (Fig. 1). Then, water is sprayed on the mixture by air pump for 3 min while mixer is turning. Afterward, the fresh mixture is fed into the steel mould with internal dimensions of 225 mm in length, 105 mm in width, and 150 mm in depth. The mixed material used is approximately 3.5 kg for each masonry blocks. With these amounts of materials, the steel mould is over filled and the initial depth of materials covering the mould is approximately 150 mm. A compression force of 378 kN (160 MPa) is applied for 1 min to compact the material in the mould (see Fig. 2a). Subsequently, formed masonry blocks are easily removed from the mould. No damage observed on the masonry blocks (see Fig. 2b). All masonry blocks are cured in air room temperature for 24 h. Twenty four hours later, masonry blocks are cured in lime-saturated water at 22 °C in cure tanks for 28 days. Then, the masonry blocks are dried by a ventilated oven at 115 °C for 24 h. WLS masonry blocks with and without WGP after curing are shown in Fig. 3. Similar procedures are followed for LG masonry blocks.

Table 3
Mixture proportions for masonry blocks produced

Mixture notation	Cement (kg/m^3)	Water (kg/m^3)	w/c	WLS (kg/m^3)	WGP (kg/m^3)	WGP/c	Plasticizer (kg/m^3)	Total (kg/m^3)
L-1	212	106	0.5	1657	–	–	–	1975
L-control	212	64	0.3	1697	–	–	2	1975
LG-1	212	64	0.3	1644	53	0.25	2	1975
LG-2	212	64	0.3	1591	106	0.50	2	1975
LG-3	212	64	0.3	1538	159	0.75	2	1975

Fig. 1. Water spraying into mixer.

For each mixtures, 10 masonry blocks are produced. For rupture modulus and direct ultrasonic pulse velocity (UPV) tests five masonry blocks are prepared. Other five masonry blocks are cut into two halves having dimensions of 100 mm in length, 105 mm in width, and 75 mm in depth by a diamond saw and by this process ten half-masonry blocks are obtained. The five half-masonry blocks are allocated for water absorption by total immersion and unit weight tests. On the other five half-masonry blocks the compressive strength tests are performed. In this study, a total 50 masonry blocks are produced for laboratory trials.

2.3. Tests methods

A series of tests are conducted to determine the water absorption, unit weight, compressive strength and rupture modulus (flexural strength) of the masonry blocks according to ASTM C 67-03a [9]. After 28 days of curing, masonry blocks are tested for water absorption by total immersion according to ASTM C 67-03a [9]. These masonry blocks are taken out from water curing tank and are allowed to drain water by placing them on a 10 mm wire mesh. Visible surface water is removed with a damp cloth and immediately masonry blocks are weighted. After obtaining the water saturated weight, these masonry blocks are kept in an oven at 105 °C. They are dried to a constant mass and taken out from the oven and are weighted at room temperature. The water absorption value is calculated from the water saturated weight and dry weight of masonry blocks. The masonry blocks are cooled at room temperature and their each unit weights are obtained by dividing the mass of the masonry blocks by their overall volume. The compressive strength of the masonry blocks is determined according to standard methods by using a servo controlling compression testing machine with a maximum capacity of 800 kN. For the masonry blocks, the compression load is applied to the face with an area of 105 × 100 mm. The rupture modulus (flexural strength) of the masonry blocks is determined by a three-point bending test with a supporting span of

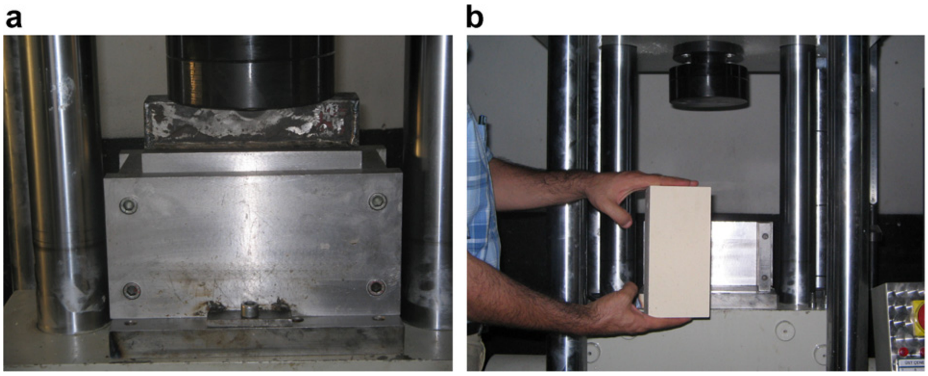

Fig. 2. Fabrication of masonry blocks: (a) before compaction, (b) after compaction.

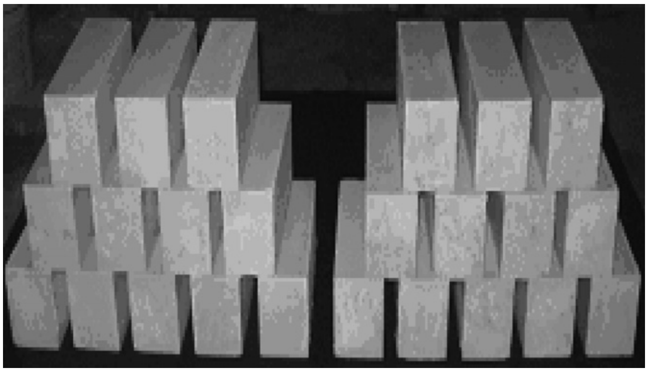

Fig. 3. WLS masonry blocks with and without WGP after curing.

180 mm and a height of 75 mm. Direct UPV measurements are taken for each masonry blocks according to BS 1881 [10]. The UPV through a material is a function of the elastic modulus and density of the material. The pulse velocity can therefore be used to assess the quality and uniformity of the material. The UPV value of masonry block is determined by placing a pulse transmitter on one face of masonry block, and a receiver on the opposite face. A timing device measures the transit time of the ultrasonic pulse through the masonry block. Then the UPV can be calculated from the path length divided by the transit time. The direct path length for the direct UPV is through the masonry block length of 225 mm.

3. Test results and discussion

The averaged tests results and standard deviations obtained from the masonry blocks are given in Table 4.

3.1. Water absorption and unit weight

Table 4 shows the water absorptions and unit weight values of masonry blocks. It is observed that the water absorptions of the masonry blocks slightly decrease with the increase in the glass powder content. The difference between the highest and lowest values of unit weight is 30 kg/m^3. Thus it can be confidently stated that a consistent level of compaction is achieved for all mixtures. As seen in Table 4, the unit weight values of masonry blocks are same, except for L-1 and LG-3 masonry blocks.

3.2. Compressive strength

The compressive strength values of the masonry blocks with and without WGP are shown in Fig. 4. Five masonry blocks are tested per mixture for the compressive strength tests. For masonry blocks produced with WLS, the least compressive strength is 24.9 MPa and this satisfies the requirements of BS 6073 [8] for compressive strength ($\geqslant$7 MPa).

The reduction in the w/c ratio of WLS mixture effectively increases the compressive strength of masonry blocks. As seen in Fig. 4, the compressive strength increases approximately 10.5% in the control masonry blocks as w/c ratio is decreased from 0.5 to 0.3 in the WLS mixture.

Fig. 4 shows the test results of compressive strength depending on changes in the mixing rate of WPG. It is observed that as the content of WPG increases in masonry blocks, the compressive strength of them increases too. The compressive strengths of the masonry blocks containing 25%, 50% and 75% WGP of cement weight are 6.2%, 11.6% and 21.1% higher than that of the control masonry block, respectively.

3.3. Rupture modulus (flexural strength)

The rupture modulus (flexural strength) values of the masonry blocks with and without WGP are shown in Fig. 5. For masonry blocks produced with WLS, the least flexural strength is 3.94 MPa and this satisfies the requirements of BS 6073 [8] for flexural strength ($\geqslant$0.65 MPa).

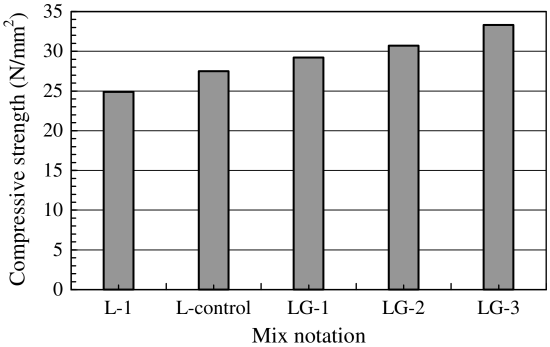

Fig. 4. Compressive strength of masonry blocks.

Table 4
Test results

Mixture notation	Compressive strength (N/mm^2)	Rupture modulus (N/mm^2)	Unit weight (kg/m^3)	Water absorption (%)	Direct UPV (m/sn)
L-1	24.9 ± 2.1	3.94 ± 0.3	1880 ± 0.01	12.4 ± 0.5	2718 ± 31.0
L-control	27.5 ± 1.4	4.15 ± 0.4	1900 ± 0.01	12.5 ± 0.4	2804 ± 30.0
LG-1	29.2 ± 1.8	4.92 ± 0.5	1900 ± 0.01	12.4 ± 0.3	2848 ± 18.0
LG-2	30.7 ± 2.5	5.86 ± 0.7	1900 ± 0.01	12.2 ± 0.1	2950 ± 8.0
LG-3	33.3 ± 0.8	7.36 ± 0.8	1910 ± 0.01	11.7 ± 0.2	3063 ± 29.0

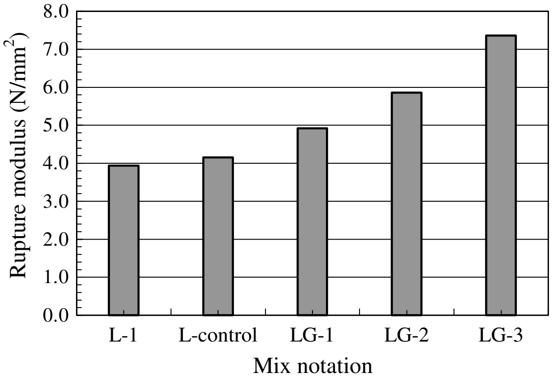

Fig. 5. Rupture modulus (flexural strength) of masonry blocks.

The reduction in the w/c ratio of WLS mixture effectively increases the flexural strength of masonry blocks. As seen in Fig. 5, the flexural strength increases about 5% in the control masonry block as w/c ratio is decreased from 0.5 to 0.3 in the WLS mixture.

Fig. 5 shows the test results of flexural strength depending on changes in the mixing rate of WGP. It is observed that as WPG content increases in masonry blocks, the flexural strength of them increase effectively. Flexural strengths of the masonry blocks containing 25%, 50% and 75% WGP of cement weight are 18.6%, 41.2% and 77.3% higher than that of the control masonry block, respectively.

The increase ratios in the flexural strength are higher than those of the compressive strength in the masonry blocks with WGP.

Fig. 6 shows the relationship between the compressive strength and the rupture modulus of the mixtures. The rupture modulus rates about 1/6.6–1/4.5 of the compressive strength.

3.4. Direct UPV and strength relationships

The direct UPV technique is used as a means of quality control of produced masonry blocks which are supposed to be made of similar mixture. Both of lack of compaction and a change in the WGP ratio would be easily detected. Thus, there is a reduction in the labour consumption of testing.

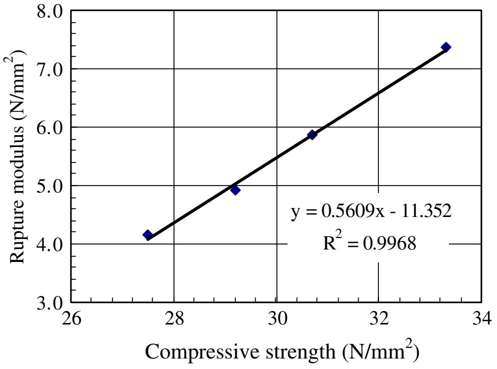

Fig. 6. Relationship between rupture modulus and compressive strength.

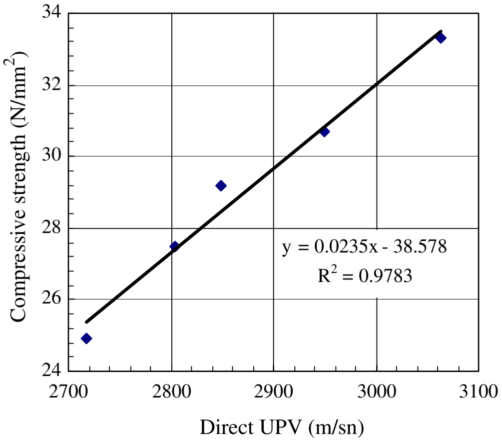

Fig. 7. Relationship between compressive strength and UPV.

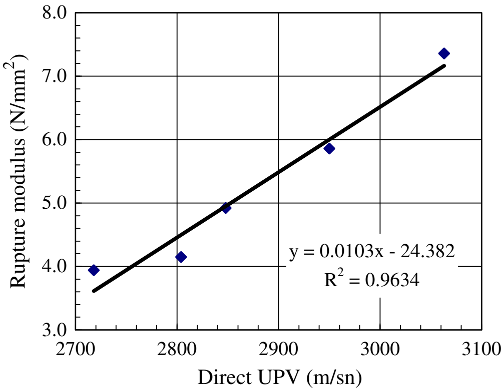

Fig. 8. Relationship between rupture modulus and UPV.

Figs. 7 and 8 show the relationships between the compressive strength and direct UPV, rupture modulus and direct UPV in the produced masonry blocks, respectively. There is an increase in the direct UPV of masonry blocks as the compressive strength and rupture modulus increase. Because of the hard structure of WGP the direct UPV increases as the WGP content in the masonry blocks increases. For the compressive strength and rupture modulus the R^2 values are 0.9783 and 0.9634, respectively. There are strong relationships between the direct UPV and compressive strength as well as direct UPV and flexural strength.

4. Conclusions

The aim of this study is to evaluate the usage possibilities of WLS and WGP in standard masonry blocks production as a first step. This basic experimental study on the physical and mechanical properties of produced masonry blocks provides the following results. The results are surprising because of certain aspects. The WLS masonry blocks with and without WGP require no skilled labour and can also be moulded in to any shape and size depending on the requirements. In the masonry blocks it has been obtained a good compaction level.

1. The reduction in the w/c ratio of WLS mixture effectively increases the compressive and flexural strength of masonry blocks.
2. The least compressive and flexural strength in the masonry block are 24.9 MPa and 3.94 MPa, respectively. This satisfies the requirements of BS 6073.
3. Compressive strengths of the masonry blocks containing 25%, 50% and 75% WGP of cement weight are 6.2%, 11.6% and 21.1% higher than that of the control masonry block, respectively.
4. Flexural strengths of the masonry blocks containing 25%, 50% and 75% WGP of cement weight are 18.6%, 41.2% and 77.3% higher than that of the control masonry block, respectively.
5. The rupture modulus rate is approximately 1/6.6–1/4.5 of the compressive strength.

The results obtained from the first stage of this study argue for a widening of the comprehensive utilization of WLS and WGP in the standard masonry blocks production. The masonry block/mortar system behavior, from the physical and mechanical point of view, water absorption coefficient, pore size distribution, bond wrench tests and mechanical tests on the masonry block/mortar combination will stay as a future research.

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