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ORIGINAL ARTICLE

Limestone dust and glass powder wastes as new brick material

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Abstract Large amounts of glass and limestone wastes are accumulating all over the world. Disposal of Limestone Powder Waste (LPW) and Waste Glass Powder (WGP) is a rapidly growing problem for some municipalities, so research for alternative utilization of these disposals is needed. In this respect, the objectives of this study are to investigate both physical and mechanical properties of samples containing LPW–WGP combinations for producing as new building brick material. An experimental approach to develop a new brick material including mainly LPW, a small quantity of Portland cement and WGP is presented. The LPW, WGP and cement are mixed, humidified and compacted under high pressure in the moulds. The values of compressive strength, flexural strength, unit weight, water absorption, abrasion resistance, freezing–thawing (F-T) resistance and thermal conductivity satisfy the relevant international standards and introduces smoother surface compared to the current concrete bricks in the market. The process undertaken can easily be applied within the current brick plants. The WGP used in LPW remarkably improves the compressive strength, flexural strength, modulus of elasticity, abrasion resistance, F-T resistance, and thermal conductivity of LPW brick samples produced in this study. The test results indicate that the samples containing LPW–WGP combinations provide better results for a potential of producing economical new brick materials.

Keywords Limestone dust · Glass powder · Waste · Brick · Cement

1 Introduction

Since the increasing demand on building materials in the last decade, the civil engineers have been challenged to convert the industrial wastes into useful building and construction materials. Accumulation of unmanaged wastes especially at the developing countries has resulted in an increase on environmental concern. Recycling of such wastes as building materials appears to be a viable solution not only to solve such pollution problem but also to the problem of economic design of buildings. The increase in the popularity of using environmentally friendly and low-cost 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.

Large amounts of limestone dust come into being in Turkey during quarrying operations. Currently, the blocks of limestone are extracted via chain saw, diamond wire and diamond saws from quarries and

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then the blocks are cut into smaller suitable sizes to be used as building material [1]. The limestone processing which includes crushed limestone production, results in approximately 20% LPW. The estimated LPW of 21.2 million tones in the UK, 18 million tones in Greece and 30 million tones in Turkey is reported [1, 2]. LPW in Sanliurfa region in 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.

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. The combination of limestone powder wastes and wood sawdust wastes was successfully used to produce a lightweight composite as a building material [3, 4].

Another waste material is waste glass that constitutes a problem for solid waste disposal in many municipalities. United Nations estimates the volume of annually disposed glass as 14 million tons [5]. In Turkey, this amount is 120,000 tons annually [5]. In Turkey, most of the non-recyclable 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 this waste glass.

Early basic experimental studies on glass powder provided the following results. Ground glass having a particle size finer than 38 μm exhibited a pozzolanic behavior and compressive strength from lime–glass test exceeded a threshold value of 4.1 MPa [6]. Glass powder in concrete improved some durability properties of concrete [7]. Waste glass considered as coarse aggregate had not a significant effect upon the workability of the concrete and only slightly in the reduction of its strength [5]. 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 [8]. No alkali-silica reaction was detected with particle size up to 100 μm indicating the feasibility of the waste glass reuse as fine aggregate in mortars and concrete [9].

In this study, using LPW–WGP combination as a fine aggregate in its natural form has allowed economical and environmental-friendly new composite material. This paper presents the research work undertaken to study the properties of this new composite material, which contains the various level of LPW and WGP, 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. WGP increases effectively the compressive strength, flexural strength and modulus of elasticity of LPW bricks. In the LPW–WGP combination abrasion and F-T resistance also effectively is improved in the brick material produced. Physical and mechanical properties of brick samples presented in this paper show that they have a great potential as a building material, which may offer significant savings in labor and transportation.

2 Experimental program

2.1 Materials

The LPW and WGP used in the brick samples are obtained from the quarrying operations and the glass beads manufacturer in Sanliurfa, Turkey, respectively. The chemical composition and physical properties of the LPW, WGP and cement used in the test samples are given in Table 1. The grading of the LPW and WGP is shown in Fig. 1.

Portland cement (PC) used in this study complies with TS EN 197-1-CEM II/A-L 42.5 R [10] and it is produced at the Cement Mill in the region. Mixing water used in the brick samples is provided by tabs. The properties of the mixing 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

For this study, four different mixture types are selected. Mix designs for brick samples are developed by means of trial mixes based on the requirements of

Table 1 The properties of LPW, WGP and cement

Properties	LPW	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 (%)	–	15.69	–
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

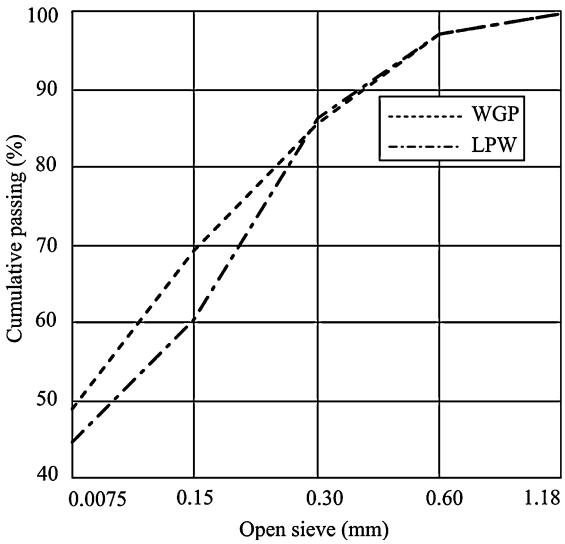

Fig. 1 The grading of the LPW and WGP

BS 6073 [11]. The details of mixes are given in Table 2. Water-to-cement ratio for all mixtures is kept at a constant of 0.30 to determine the effect of various LPW–WGP combinations. Replacement levels of LPW by WGP by mass mix chosen for the sample mixes are 0, 10, 20 and 30%.

In the mixing process of samples, LPW, WGP and cement contents are placed in a pan mixer and mixed for 1 min. In order to obtain more homogeneous mixes and prevent lumping, the water is sprayed by air pump onto the mixes while the mixer is turning. The mixing process is continued for about 4 min. By using the mixture proportions given in Table 2 the steel mould is filled over with the 3,500 g of mix. The initial over thickness of the mould is approximately 150 mm. The pressure (17 MPa) is applied for 1 min to compact the material in the mould (Fig. 2). Subsequently, the formed brick samples are removed from the mould as early as 1 min. No damage is observed on the bricks while demoulding (see Fig. 2). All the brick samples are cured in air at room temperature for 24 h. Then, the samples are stored in the cure tank filled with lime-saturated water at 22°C for 28 days. Then, the brick samples are dried for 24 h in a ventilated oven at 105°C.

Samples having sizes and notations shown in Table 3 are prepared for the compressive strength, the flexural strength, the unit weight, water absorption, abrasion resistance, F-T resistance and thermal conductivity, modulus of elasticity and Poisson ratio tests. A total of 124 samples are tested for this study. The water absorption is obtained from the samples prepared for the unit weight tests. The Ultrasonic Pulse Velocity (UPV) tests are also conducted on the samples made for the flexural strength tests.

2.3 Tests methods

2.3.1 Compressive strength, flexural strength and UPV tests

A series of tests are carried out according to ASTM C 67-03a [12] to determine the water absorption, the unit weight, the compressive strength and flexural strength values 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 the sample having a dimension of 105×90 mm^2. 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 sample according to BS 1881 [13]. The direct path length for the direct UPV is measured through the brick length of 225 mm.

Table 2 Mixture proportions for one brick sample

Mix no.	PC (g)	W (g)	W/C ratio	LPW (g)	WGP (g)	PC/(LPW + WGP) ratio	Plasticer (g)
Control	376	113	0.30	3007	0	0.125	4
LG-10	376	113	0.30	2706	301	0.125	4
LG-20	376	113	0.30	2406	601	0.125	4
LG-30	376	113	0.30	2105	902	0.125	4

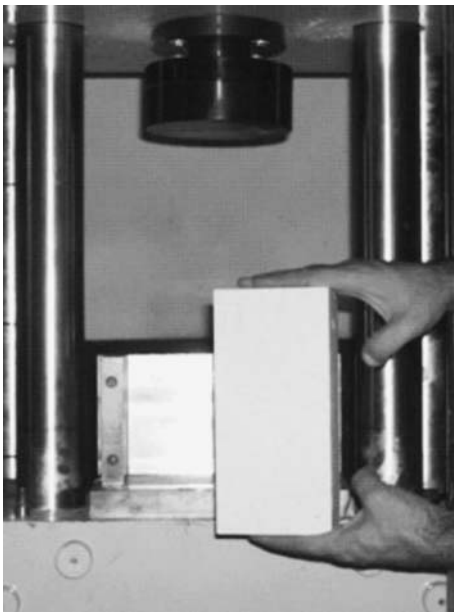

Fig. 2 Fabrication and demoulding of sample

2.3.2 *Water absorption and unit weight tests*

The brick samples are tested for the water absorption and the unit weight according to ASTM C 67-03a [12]. 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, dried to a constant mass for 28 h, and then taken out from the oven and weighted at room temperature. The water absorption of saturated and surface dry weight of samples is calculated. The brick samples are cooled at room temperature and their unit weights are obtained by dividing the mass of the bricks by their overall volume.

2.3.3 *Freezing–thawing (F-T) test*

The F-T test is carried out according to ASTM C 67-03a [12]. In the F-T testing, a freezing chamber and thawing tank are used (see Fig. 3). The temperature in freezing chamber used in this study can be adjusted between 0°C and −50°C. The temperature of the air in the freezing chamber is −9°C in 1 h after introducing the maximum charge of units and initially temperature is 25°C. The container is shallow, metal, having an inside depth of 40 mm. Water temperature in the thawing tank used to submersion of the samples in the container is 25°C. The test samples consist of half brick with plan and parallel ends and five samples are prepared and tested for each mixture. The test procedures for F-T on samples involve the following. The samples are placed in the container with one of their head faces

Table 3 Samples per mix

Tests	Sample sizes (mm)	Sample number	Total number of samples
Unit weight, water absorption	105 × 90 × 75	5	20
Compressive strength	105 × 90 × 75	5	20
Flexural strength, UPV	105 × 75 × 225	5	20
Abrasion resistance	71 × 71 × 71	5	20
F-T	105 × 90 × 75	5	20
Thermal conductivity	20 × 60 × 100	3	12
Modulus of elasticity and Poisson ratio	ϕ50 × 80	3	12

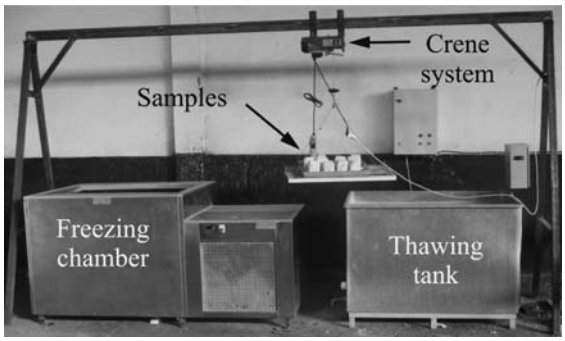

Fig. 3 Freezing chamber and thawing tank

down and submerged in the water of the thawing tank for 4 ± ½ h. The head face is defined as the end surfaces of a whole rectangular brick sample (which have the smallest area). A space of 15 mm is separated the samples as placed in the container. Sufficient water is poured into the container so that each samples stands in 12.5 mm depth of water and then container placed samples is placed in the freezing chamber for 20 h. The container is removed from the freezing chamber after 20 h and it totally immersed in the water of the thawing tank for 4 h.

2.3.4 Abrasion test

The cube samples of 71 mm are used for the determination of abrasion resistance at 28 days according to EN Standard EN13892-3 [14] as an alternative of ASTM C 779 [15]. In compliance with EN13892-3 [14], the abrasion system has a steel disc, which has a diameter of 750 mm and rotating speed of 30 ± 1 cycle/min, a counter and weight made of solid steel, which applies 300 ± 3 N on sample (see Fig. 4). In the test procedure, 20 ± 0.5 g of abrasion dust is spread on the disc, the sample is then placed. The load is applied to the sample and the disc is rotated for a period that is equal to 22 cycles. After that, the surface of the disc and sample are cleaned. The mentioned procedure is repeated for 20 periods (totally 440 cycles) by rotating the sample 90° in each period. The corundum (crystalline AL_2O_3) is used as abrasive dust in this test.

2.3.5 Thermal conductivity test

A shotherm-QTM unit (Showa Denko) quick thermal conductivity meter based on ASTM C 1113-90 [16]

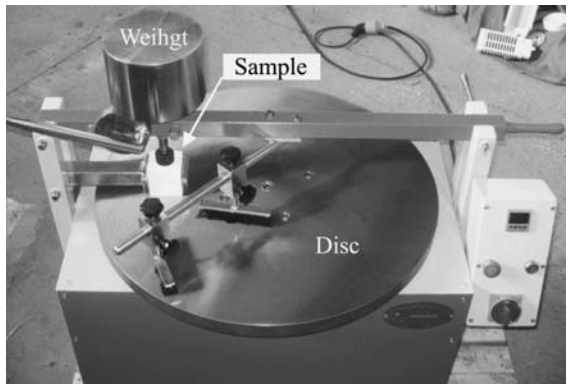

Fig. 4 Abrasion device and sample

hot wire method is used. Measurement range is between 0.02 W m^{-1} K^{-1} and 10 W m^{-1} K^{-1}. Measurement precision is ±5% of reading value per reference plate. Measurement temperature is −100 to 1,000°C. Three samples of $20 \times 60 \times 100$ mm^3 for per mix are used to testing thermal conductivities. Measuring time is standard 100–120 s. This method has wide applications [16–19] in determining thermal conductivity of refractory materials.

2.3.6 Modulus of elasticity and Poisson ratio tests

The samples with diameter of 50 mm and height 80 mm are used for the modulus of elasticity and Poisson ratio tests according to ASTM C 469 [20]. The cylindrical samples are obtained by coring the brick samples with dimensions of $105 \times 75 \times 225$ mm^3. The modulus of elasticity and Poisson ratio are calculated as the average of three samples. The end faces of the samples are ground using an end-face grinder, and then checked for evenness and perpendicularity with respect to the vertical axis. At the mid-height of each sample, two small strain gauges are attached: one along the length (vertical) and one along the circumference (horizontal). The strain gauges are the GFLA-6-50 type (Tokyo Sokki Kenkyujo, Japan).

3 Test results and discussion

The average values of results obtained from the tests are given in Table 4. These tests are conducted in

Table 4 Averaged test results

Tests	Mix no.			
	Control	LG-10	LG-20	LG-30
Compressive strength (MPa)	27.5	28.0	29.5	30.1
Flexural strength (MPa)	4.15	7.69	7.70	7.76
Water absorption as mass (%)	12.5	12.2	12.5	12.4
Water absorption (g/cm^3)	0.237	0.233	0.236	0.234
Unit weight (g/cm^3)	1.90	1.91	1.89	1.89
Volume loss on wear (cm^3/50 cm^2)	8.95	4.59	4.51	4.45
Mass loss after 50 cycles of F-T (%)	16.85	7.13	2.61	1.28
Cycle number of crack seen after F-T	20	40	42	47
Thermal conductivity (W m^{-1} K^{-1})	1.07	1.03	0.99	0.90
Ultrasonic pulse velocity (km/h)	2.80	3.06	3.11	3.15
Modulus of elasticity (MPa)	12110	13500	14875	19296
Poisson ratio	0.18	0.20	0.18	0.20

accordance with ASTM C 67-03a [12] except for abrasion tests based on EN13892-3 [14].

In the ASTM C 140 [21], the allowable maximum water absorption value is 0.288 g/cm^3 for load-bearing and non-load-bearing concrete masonry units. All of the samples tested satisfy allowable water absorption value (see Table 4).

Unit weight obtained from results satisfies the requirements in TS 406 [22] for a building material used in the structural applications and they are lower than 2.20 g/cm^3 and greater than 1.50 g/cm^3.

Table 4 gives the compressive strength results obtained from the tests. The control sample without WGP and with a small amount of cement which is attained 27.5 MPa compressive strength value satisfies the requirements in BS6073 [11], ASTM C 90 [23] and Turkish Code [24] for a building material to be used in the structural applications. BS6073 [11], ASTM C 90 [23] and Turkish Code [24] require the minimum compressive strength values of 7.0 MPa, 11.7 MPa and 5.0 MPa for load-bearing concrete masonry units, respectively. The WGP increases the compressive strength values of samples. The 28-day compressive strength values of LPW–WGP combinations samples at 10, 20 and 30% of levels of replacement of WGP are approximately 1.8, 7.3 and 9.4% higher than compressive strength of control sample, respectively (see Fig. 5).

Table 4 shows the results of the flexural strength values obtained from the tests. The control sample without WGP attained 4.15 MPa flexural strength value satisfies the requirement in BS6073 [11]. The minimum flexural strength value is required as 0.65 MPa in BS 6073 [11]. The flexural strength values of LPW–WGP combinations samples are effectively increased as compared with control sample. The effect of WGP on the flexural strength is higher than the compressive strength. The 28-day flexural strength values of LPW–WGP combinations samples at 10, 20 and 30% of levels of replacement of WGP are approximately 85, 86 and 87% higher than the flexural strength of control sample, respectively (see Fig. 5). Because of the hard structure of the WGP the UPV values also increases in the LPW–WGP combinations samples.

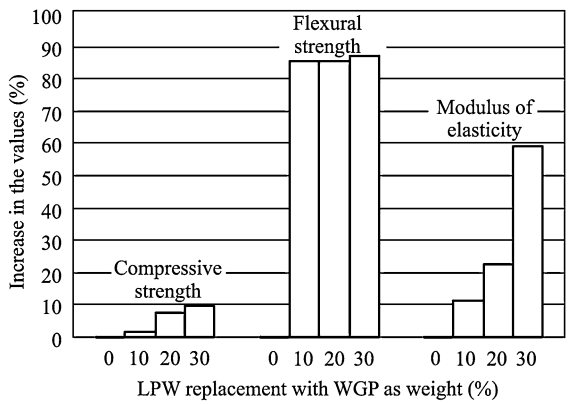

Fig. 5 The improvement in the mechanical properties as used WGP

Table 4 shows the results of the volume loss value on wear is obtained from the tests. The maximum (8.95 cm^3/50 cm^2) volume loss value on wear is obtained in control sample and this value satisfies the requirement (the maximum 10 cm^3/50 cm^2) in ASTM C 568-03 [25]. It can be seen that the abrasion resistance is remarkably improved by using WGP in the mixes. The volume loss values on wear of LPW–WGP combinations samples at 10, 20 and 30% of levels of replacement of WGP are approximately 48.7, 49.6 and 50.2% lower than volume loss value of control sample, respectively (see Fig. 6). The mechanism of WGP improving the abrasion resistance of samples with WPG can be interpreted as follows. Supposed that WGP are uniformly dispersed and each particle is contained in a cube pattern, the distance between WPG particles can be specified. After hydration begins, hydrate products diffuse and envelop WGP particles as kernel. If the content of WGP particles and the distance between them are appropriate, this makes the cement matrix more homogenous and compact. As a consequence, the abrasion resistance and strengths are improved evidently.

The mass loss values of samples as percent after the 50 cycles of F-T are given in Table 4. The F-T resistance of samples is remarkably improved by using WGP in the mixes. The mass loss values as percent on F-T cycles of LPW–WGP combinations samples at 10, 20 and 30% of levels of replacement of WGP are approximately 57.7, 84.5 and 92.4% lower than the mass loss value of control sample, respectively (see Fig. 6). The cycle numbers of first crack formation on the samples are given in the Table 4. Although the first crack formation on control sample is seen in the 20 cycles, in the samples at 10, 20 and 30% of levels of replacement of WGP the first crack formations are seen in the 40, 42, and 47 cycles, respectively (see Table 4). The samples with WGP pass the 50 cycles of F-T test with minor damage (see Fig. 7).

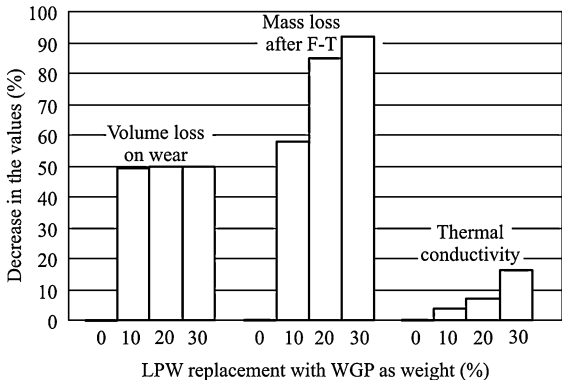

Fig. 6 The improvement in the physical properties as used WGP

Figure 6 shows the variation in the thermal conductivity with WGP replacement. The effect of WGP replaced LPW at 10, 20, and 30% by weight on the thermal conductivity is approximately 3.7, 7.5, and 15.9% lower than the thermal conductivity of control sample, respectively. The thermal conductivity of samples is improved in LPW–WGP combinations.

Figure 5 shows the variation in the modulus of elasticity with WGP replacement. The effect of WGP replaced LPW at 10, 20, and 30% by weight on the modulus of elasticity is approximately 11.5, 22.8, and 59.3% higher than the modulus of elasticity of control sample, respectively. The modulus of elasticity of samples is effectively improved in LPW–WGP combinations. The Poisson ratio values of the samples are varied between 0.18 and 0.20.

4 Conclusions

The physical and mechanical properties of brick samples with LPW and LPW–WGP combinations are investigated. The test results show that the LPW–WGP combination provides results, which are of potential for this combination to be used in the production of economical new brick material. The compressive strength, flexural strength, water absorption, unit weight, volume loss values on wear, the mass loss values as percent after F-T cycles satisfy the requirements for a building material to be used in the structural applications. The detailed results obtained in this study lead to the following primary conclusions:

(1) The compressive strengths of LPW–WGP combinations samples at 10, 20 and 30% of levels of replacement of WGP were approximately 1.8, 7.3 and 9.4% higher than the compressive strength of control sample, respectively.
(2) The flexural strengths of samples with LPW–WGP combinations at 10, 20 and 30% of levels of replacement of WGP were approximately 85, 86 and 87% higher than the flexural strength of control sample, respectively.

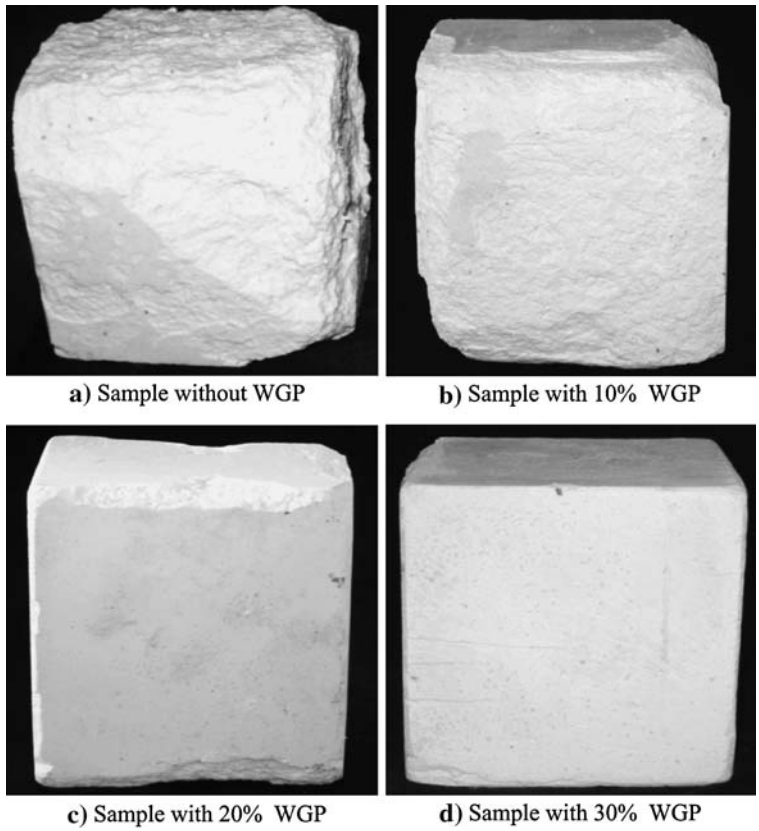

Fig. 7 Appearance of samples after 50 cycles of F-T test

(3) The volume loss values on wear of samples with LPW–WGP combinations at 10, 20 and 30% of levels of replacement of WGP were about 48.7, 49.6 and 50.2% lower than the volume loss value on wear of control sample, respectively.
(4) The mass loss values as percent after F-T cycles of samples with LPW–WGP combinations at 10, 20 and 30% of levels of replacement of WGP were approximately 57.7, 84.5 and 92.4% lower than the mass loss value of control sample, respectively.
(5) The thermal conductivities of LPW–WGP combinations samples at 10, 20 and 30% of levels of replacement of WGP were about 3.7, 7.5 and 15.9% lower than the thermal conductivity of control sample, respectively.
(6) The effect of WGP replaced LPW at 10, 20 and 30% by weight on the modulus of elasticity were approximately 11.5, 22.8 and 59.3% higher than the modulus of elasticity of control sample, respectively.

References

1. Manning D (2004) Exploitation and use of quarry fines. Report No.087/DACM/01
2. Galetakis M, Raka S (2004) Utilization of limestone dust for artificial stone production: an experimental approach. Miner Eng 17:355–357
3. Turgut P, Algin HM (2006) Limestone dust and wood sawdust as brick material. Build Environ, DOI: 10.1016/j.buildenv.2006.08.012
4. Turgut P (2007) Cement composites with limestone dust and different grades of wood sawdust. Build Environ, DOI: 10.1016/j.buildenv.2006.11.008
5. Topcu IB, Canbaz M (2004) Properties of concrete containing waste glass. Cem Concr Res 34:267–274
6. Shao Y, Lefort T, Moras S, Rodriguez D (2000) Studies on concrete containing ground waste glass. Cem Concr Res 30:91–100
7. Shayan A (2004) Value-added utilization of waste glass in concrete. Cem Concr Res 34:81–89
8. Shi C, Wu Y, Riefler C, Wang H (2005) Characteristic and puzzolanic reactivity of glass powders. Cem Concr Res 35:987–993
9. Corinaldesi V, Gnappi G, Moriconi G, Montenero A (2005) Reuse of ground waste glass as aggregate for mortars. Waste Manage 25:197–201

10. TS EN 197-1-CEM II/A-L 42.5 R (2004) Part 1: Cement compositions and conformity criteria for common cements. Turkish Standards
11. BS 6073 (1981) Part 1: Precast concrete masonry units, Part 1. Specification for precast concrete masonry units. British Standards Institution
12. ASTM C 67-03a (2003) Standard test methods for sampling and testing brick and structural clay tile. American Society for Testing and Materials, Philadelphia, PA
13. BS 1881 (1997) Recommendations for measurement of pulse velocity through concrete. British Standards Institute, Part 203, London
14. EN13892-3 (2004) Methods of test for screed materials. Determination of wear resistance-Bohme
15. ASTM C 779 (2005) Standard test method for abrasion resistance of horizontal concrete surfaces. American Society for Testing and Materials, Philadelphia, PA
16. ASTM C 1113-90 (1990) Test method for thermal conductivity of refractories by hot wire
17. Daire WR, Downs A (1980) The hot wire test—a critical review and comparison with B 1902 panel test. Trans Br Ceram Soc 79:44
18. Willshee JC (1980) Comparison of thermal conductivity methods. Proc Br Cerm Soc 29:153–174
19. Sengupta K, Das R, Banerjee G (1992) Measurement of thermal conductivity of refractory bricks by the nonsteady state hot-wire method using differential platinum resistance thermometry. J Test Eval, JTEVA 29(6):455–459
20. ASTM C 469 (2002) Standard test method for static modulus of elasticity and Poisson's ratio of concrete in compression, American Society for Testing and Materials, Philadelphia, PA
21. ASTM C 140 (2006) Methods of sampling and testing concrete masonry units. American Society for Testing and Materials, Philadelphia, PA
22. TS 406 (1988) Concrete blocks and bricks for wall. Turkish Standards
23. ASTM C 90 (2006) Standard specification for load-bearing concrete masonry units. American Society for Testing and Materials, Philadelphia, PA
24. TS 705 (1985) Solid brick and vertically perforated bricks. Turkish Standard Institution
25. ASTM C 568-03 (2003) Standard specification for limestone dimension stone