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Thermo-Elastic Properties of Artificial Limestone Bricks with Wood Sawdust

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Abstract**—**In this study, artificial limestone brick samples are produced by using wood sawdust wastes (WSW) having different grades of sizes and limestone powder waste (LPW). The thermo-elastic properties of produced brick samples in various WSW amounts are investigated. At 30% WSW replacement with LPW in the brick sample the thermal conductivity value is effectively reduced and the reduction in the thermal conductivity value of brick sample at 30% WSW replacement with LPW is about 38.9% as compared with control sample. The energy conservation in buildings by using LPW and WSW in masonry brick material production having low thermal conductivity reduces energy requirements. A strong relationship is also found among the thermal conductivity, unit weight and ultrasonic pulse velocity values of brick samples produced. 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.

Keywords**—**Limestone dust, masonry brick, thermo-elastic properties, wood sawdust.

I.INTRODUCTION

ENERGY conservation is an important part of any national energy strategy and energy conservation in underdeveloped countries with inadequate resources is even more important [1]. To an increasing extent, energy usage, and more particularly, energy wastage is receiving close examination at present. Using natural waste materials with a low thermal conductivity in building masonry units improves insulation of buildings by providing an energy efficient solution.

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 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 [2].

When Many previous researches [2]-[14] 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. Although these researches provided the encouraging results, the brick mixes having both WSW and LPW combination hitherto was not investigated so much. These utilizable wastes presented in this research are widely available in large amount from the forest and limestone industries. Wood product and furniture manufactures generate sawdust, offcuts and dust. Sawdust is generated from cutting, drilling and milling operations where wood is removed from a finished product. Wood dust is very fine particles and generated during sanding or other machining operations. It is often collected in filter bags or dust collectors. On average, 48 million m^3 of timber is consumed annually in the UK and the wood processing results in 5 to 10% sawdust and dust wastes [15]. The processing limestone which includes crashed limestone production is resulting approximately 20% LPW. The estimated LPW of 21.2 million tons in the UK [16], 18 million tons in Greece is reported [13]. Disposal of LPW causes dust, environmental problem and pollution because of its fine nature.

In the previous work [2], the physico-mechanical properties of WSW-LPW satisfied the standard specifications according to TS 705 [17], ASTM C 140 [18], BS 6073 [19] and ASTM C 129 [20] for load and non-load-bearing concrete masonry units to be used in buildings. The WSW-LPW combinations as an aggregate in its natural form have allowed producing economical, lighter and environmental-friendly new composite brick material. In this study, thermo-elastic properties of WSW-LPW combinations as a brick material are investigated.

II.EXPERIMENTAL PROCEDURE

A.Materials and Fabrication of Samples

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 nearby 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 used in this study are given in [2].

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WSW used in this study is categorized as LWF (fine), LWC (coarse) and LWM (mixed) in terms of their particle sizes. The particle sizes of LWF, LWC and LWM are 0-0.6mm, 0.6-1.18mm, and 0-1.18mm, respectively. The grading properties of the LPW and WSW are given in [2]. Ten different types of mixtures are prepared in the laboratory trials. The details of mixes are given in Table I. The cement and 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 means that the 20% of corresponding LPW volume is replaced by WSW in the LWF-20 samples (see Table I). The percentage weight replacements between WSW and LPW in the mixes are also provided in Table I. The details of mixing, production and curing procedures of samples are given in [2]. All of the samples are tested after 28 days of curing period. A total of 30 brick samples with dimensions of 105×75×225mm^3 are prepared for thermo-elastic properties. After ultrasonic pulse velocity (*UPV*) test is performed on these brick samples, the samples with of dimensions 20×60×100mm^3 are prepared for thermal conductivity test by cutting with diamond saw of these brick samples. The cylindrical samples with dimensions of ϕ50×80 mm for testing elastic properties are also obtained by coring diamond saw of these brick samples.

TABLE I
MIXTURE PROPORTIONS

Mix no.	Cement (g)	Water (g)	LPW (g)	WSW (g)	Total (g)
Control	376	188	2936	-	3500
LWF-10	376	188	2706	54	3324
LWF-20	376	188	2405	108	3077
LWF-30	376	188	2117	162	2843
LWC-10	376	188	2706	54	3324
LWC-20	376	188	2405	108	3077
LWC-30	376	188	2117	162	2843
LWM-10	376	188	2706	54	3324
LWM-20	376	188	2405	108	3077
LWM-30	376	188	2117	162	2843

B.Thermo-Elastic Properties and Test Methods

Thermal conductivity (*k*) is the most important thermal property in heat transfer problems. It is necessary to know this property for energy analysis in buildings. Thermal conductivity (*k*) is a measure of the ability of a material to conduct heat. In other words, it is the measurement of the speed at which heat travels through a material through conduction. It depends on the physical structure of matter, atomic and molecular, which is related to the state of the matter. Materials such as copper, aluminum and silver are good heat conductors and therefore have high *k* values. Materials such as rubber, wood and Styrofoam are poor conductors of heat, and therefore have low k values.

A shotherm-QTM unit (Showa Denko) quick thermal conductivity meter based on ASTM C 1113 [21] hot wire method is used in the present study. Measurement range is 0.02-10 Wm^{-1}K^{-1}. Measurement precision is ±5% of reading value per reference plate. Measurement temperature is -100 to 1000^{o}C. Three samples of 20×60×100mm^3 for per mix are used for testing thermal conductivities. Measuring time is standard, 100–120s. This method has wide applications in determining thermal conductivity of refractory materials [22]-[24].

The *UPV* measurements are performed on the brick samples with dimensions of 105×75×225mm^3 by using TIKO make Pundit Plus equipment according to BS 1881 [25]. Three samples for per mix are used to test the *UPV*. The *UPV* through a material is a function of the elastic modulus and density of the material. The *UPV* value of brick sample is determined by placing a pulse transmitter on one face of brick sample, and a receiver on the opposite face. A timing device measures the transit time of the ultrasonic pulse through the brick sample. Then the *UPV* can be calculated from the path length divided by the transit time. The path length is measured through the brick sample length of 225mm.

The samples with diameter of 50mm and height of 80mm are used for the modulus of elasticity and Poisson ratio tests for only LWM samples because mechanical properties of LWF, LWC and LWM are almost similar to each other [2]. The modulus of elasticity and Poisson ratio values are calculated according to ASTM C 469 [26]. The modulus of elasticity and Poisson ratio are calculated as the average of three samples. The end faces of the samples are ground by 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).

III.TEST RESULTS AND DISCUSSION

Table II shows the averaged tests results obtained from the tests. The test results confirm that the thermal conductivity values are inversely proportionate with the percentage WSW replacement with LPW content (see Fig 1). It ranges from 0.601-0.9803Wm^{-1}K^{-1} depending on the WSW level. It is seen that thermal conductivity values of the samples are as small as that of common brick materials used in buildings.

About 19.9% reduction in the thermal conductivity of LWF-10 sample compared to control sample is obtained from the 10% fine WSW replacement. This is an expected result owing to the low thermal conductivity nature of wood. The thermal conductivity value of pine is about 0.11Wm^{-1}K^{-1}. But in the replacement of 10% coarse WSW, there is not a significant reduction of thermal conductivities of LWC-10 and LWM-10 samples as compared with control and LWF-10 samples. The reductions of thermal conductivity values of LWC-10 and LWM-10 are about 4.1 and 0.1% as compared with control sample, respectively (see Fig. 1).

The values of thermal conductivity in the all of samples with WSW are effectively decreased with an increase in the 20% replacement level of WSW as compared with control sample.

TABLE II
TEST RESULTS

Mix no.	Unit weight (g/cm^3)	Thermal conduct (Wm^{-1} K^{-1})	Porosity (%)	*UPV* (km/s)	E (GPa)	γ
Control	1.88	0.984	23.3	2.72	15	0.20
LWF-10	1.80	0.788	24.8	2.32	-	-
LWF-20	1.63	0.728	27.4	2.27	-	-
LWF-30	1.47	0.626	27.8	1.98	-	-
LWC-10	1.74	0.944	23.0	2.67	-	-
LWC-20	1.65	0.780	26.4	2.38	-	-
LWC-30	1.50	0.621	30.3	2.03	-	-
LWM-10	1.70	0.983	23.5	2.63	14	0.17
LWM-20	1.66	0.746	25.0	2.38	11	0.19
LWM-30	1.51	0.601	29.0	2.08	8	0.23

The reductions in the thermal conductivity values of LWF-20, LWC-20 and LWM-20 samples at the 20% fine, coarse and mixed WSW replacements are 26, 20.7 and 24.2% as compared with control sample, respectively (see Fig. 1).

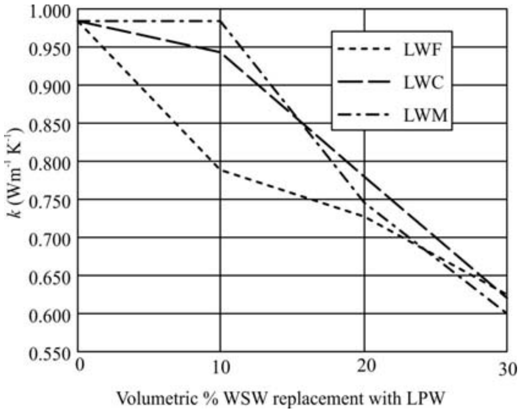

Fig. 1 Relationship between thermal conductivity and WSW amount

The thermal conductivity values of samples with WSW are effectively decreased at 30% WSW replacement. The reductions in the thermal conductivity values at 30% WSW replacement in the LWF-30, LWC-30 and LWM-30 samples are about 36.4, 36.9 and 38.9% as compared with control sample, respectively (see Fig. 1). The effect of fine, coarse and medium particle sizes of WSW at 30% WSW replacement on the thermal conductivity values of all samples with WSW is roughly the similar as seen in test results.

In this study, a correlation between the thermal conductivity and *UPV* values of samples is established. The relationship between the thermal conductivity and *UPV* values of samples is given in Fig. 2. It can be seen from Fig. 2 that there is a strong relationship between the thermal conductivity and *UPV* values of all samples and the *UPV* values are directly proportional to thermal conductivity values of samples. The relation of thermal conductivity against the *UPV* has the best correlation R^2= 0.95. This value is nearest to unity. This means that the thermal conductivity of any samples studied in this work can readily be calculated from laboratory determined *UPV* value. The relationship between the thermal conductivity and *UPV* is found as,

$$k = 0.5484UPV - 0.4829 \tag{1}$$

where, k and *UPV* are the thermal conductivity (W m^{-1} K^{-1}) and ultrasonic pulse velocity (km/h), respectively.

It is also established a correlation among the thermal conductivity, *UPV* and unit weight values of samples produced. In the 95% confidence level, there is also strong relationship among the thermal conductivity, *UPV* and unit weight of samples. The regression equation of thermal conductivity as a function of unit weight and *UPV* is found as,

$$k = -0.459 + 0.530UPV + 0.020\rho \tag{2}$$

where, ρ is unit weight of sample (g/cm^3)

The R^2 value for (2) is 0.95. This means that using the *UPV* and unit weight of samples the thermal conductivity is also calculated more accurately.

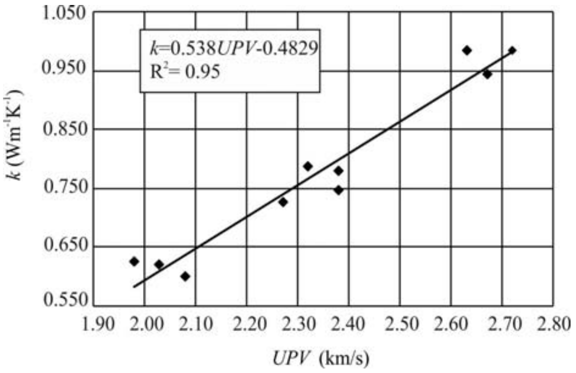

Fig. 2 Relationship between the thermal conductivity and *UPV*

Figs. 3 and 4 show the relationships between thermal conductivity and porosity (*P*), *UPV* and *P*, respectively. It is an interesting result that the correlation coefficients of the thermal conductivity-porosity and *UPV*-porosity are the same as shown in Figs. 3 and 4. In fact, this is expected result for porous materials. This situation can be put following way. The voids of porous materials are filled with air. The thermal conductivity value of air is low because of air is not a good conductor. Thus, the thermal conductivity value of porous materials is lower than that of solid materials. The movement of sound in the porous materials is slower than that of solid materials because of air. The *UPV* values of porous materials are usually low. The test results confirm that the thermal conductivity and *UPV* values are inversely proportionate with porosity. The prediction from *UPV* is cheaper, easier and faster than measuring thermal conductivity on

20×60×100mm^3 plates, which takes longer time. In conductivity tests to reach steady-state conditions takes a longer time. However, the effectiveness in the other porous materials of this relationship should be investigated.

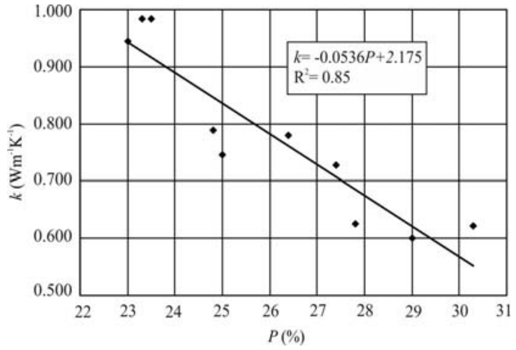

Fig. 3 Relationship between the thermal conductivity and porosity

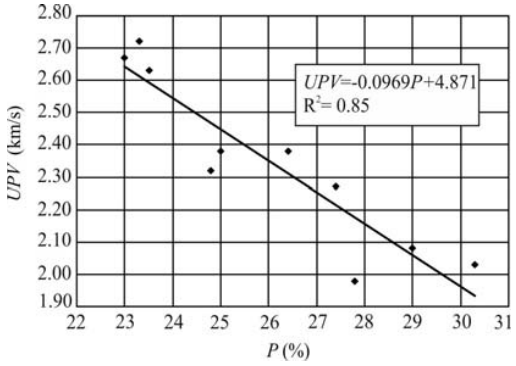

Fig. 4 Relationship between the *UPV* and porosity

The modulus of elasticity (E) and Poisson ratio (γ) values of samples with mixed WSW and control sample are given in Table II. As seen in Table II, the moduli of elasticity values of samples with WSW are decreased as compared with control sample. The decreases in the modulus of elasticity at 10, 20 and 30% WSW replacement are 3.2, 27 and 46.6% as compared with control sample. The Poisson ratios of samples vary between 0.17-0.23. The effect of 10 to 30% WSW replacements in WSW-LPW matrix does not exhibit a sudden brittle fracture even beyond the failure loads and indicated high energy absorption capacity because of low modulus of elasticity of WSW samples.

IV.CONCLUSION

Based on the experimental investigation reported in this paper, the following conclusions were drawn:

1. The WSW with fine size in brick sample at 10% WSW replacement with LPW effectively reduced the thermal conductivity value as compared with WSW of coarse, medium size and control sample.
2. The reduction in the thermal conductivities of brick samples was about 38.9% at 30% WSW replacement with LPW in the medium size of WSW as compared with control sample.
3. There was a strong relationship among the thermal conductivity, ultrasonic pulse velocity and unit weight values of brick samples produced in this study. The effectiveness in the other porous materials of this relationship will stay as a future research.
4. The effect of 10 to 30% WSW replacements in WSW-LPW matrix did not exhibit a sudden brittle fracture even beyond the failure loads and indicated high energy absorption capacity because of low modulus of elasticity of WSW samples.

The test results showed that the WSW-LPW combinations had a potential to be used in the production of a new lighter brick.

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