INCORPORATION OF BIOSOLIDS IN FIRED CLAY BRICKS

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ABSTRACT

In Australia, thousands of tonnes of biosolids are produced and millions of dollars expended for their management annually. Biosolids are derived from wastewater sludge which is the major solid component collected from the wastewater treatment process. This study investigated the incorporation of biosolids into fired clay bricks. Geotechnical characteristics of three biosolids samples produced from Eastern Wastewater Treatment Plant (ETP) in Melbourne were investigated to assess their suitability as a partial replacement material for the clay in fired-clay bricks. Results of classification tests including liquid limit, plastic limit and sieve analysis indicated that the three biosolids samples are silty clayey sand with low to high plasticity. Linear shrinkage of biosolids samples varied from 10% to 15% and organic content from 6% to 14%. Control clay bricks with 0% biosolids and clay-biosolids bricks with 25% by weight biosolids were made and properties including compressive strength, shrinkage, density, initial rate of absorption (IRA), water absorption, thermal conductivity and other properties were determined. The overall results of this preliminary study are promising. Some of the results of this stage of this investigation are presented and discussed in this paper.

Keywords: Biosolids, Fired-clay bricks, Recycling, Sustainable environmental management

1. INTRODUCTION

Biosolids are primarily the nutrient-rich materials remaining after an intense wastewater sludge treatment process. Sludge refers to sticky liquid, generally contains up to around 8% of dry solids and is collected from the wastewater treatment process which has not undergone further treatment. In contrast, Melbourne Water biosolids contain between 50% and up to 96% of solids and are a product of the wastewater sludge once it has undergone further treatment to significantly reduce disease causing pathogens and volatile organic matter, producing a stabilised product suitable for beneficial uses (ANZBP, 2012) .

The amount of biosolids produced annually in the world has increased dramatically because of a growth of new treatment plants and continuous upgrading of existing facilities (Rulkens, 2007). Australia currently produces roughly 300,000 dry tonnes of biosolids annually from which 55% is applied to agricultural land and 30% is disposed in land fill or stockpiled and the balance 15% is used for composting, forestry and land rehabilitation (AWA, 2012). Furthermore, three million cubic meters of biosolids are presently stock piled at ETP and Western Treatment Plant in Melbourne which are suitable for forestry, farming, producing energy and structural fill (Melb. Water, 2014). It is notable that in Australia alone, approximately A$90 million has been spent for the management of biosolids every year.

At the present, some biosolids are used as an agricultural land application due to its inherent organic matter and nutrient values (Wang et al., 2008). Attempts have been made to recover energy from biosolids, for example, methane production through aqueous anaerobic digestion, electricity production from microbial fuel cells (Rulkens, 2007, GVRD, 2005). Apart from that, multi reuse strategies have been developed worldwide towards biosolids management. For instance, use of biosolids into engineering applications is of great interests and has become innovative approach to biosolids management which undeniably reduce the demand for virgin natural resources (Disfani et al., 2009, Rulkens, 2007, Arulrajah et al., 2011)

Interestingly, biosolids have similar properties to soil such as moisture content, cations exchange capacity, moisture retention and have parallel geotechnical engineering properties to soil (Arulrajah et al., 2011), for instance, plastic behaviour, acceptable shear strength parameters and compaction ability. Furthermore, geotechnical properties of biosolids enhanced remarkably as biosolids were blended or stabilized with binding additives (Lim et al., 2002, Maghoolpilehrood et al., 2013).However little attention has been paid to use biosolids into fired-clay bricks. Incorporating biosolids in fired clay bricks could provide another alternative and sustainable method for the recycling of biosolids.

Brick is one of the oldest and major manufactured building materials which have been used over a long period of time. Dried-clay bricks and fired-clay bricks were used first time as early as 8000 BC and 4500 BC respectively (Zhang, 2013). Due to its strength, reliability, weather resistance, simplicity and durability, brick is led to extensive use and given a leading place in history in conjunction with stone (Beall, 2004). In recent decades, alternative approaches were investigated to assess the suitability of different materials as a replacement material for the clay in fired-clay bricks; for instance, sludge (Weng et al., 2003, Liew et al., 2004), sawdust (Demir, 2008), paper (Sutcu and Akkurt, 2009), cigarette butts (Kadir and Mohajerani, 2011), fly ash (Lin, 2006) and silica fume (Baspinar et al., 2010).

In this preliminary stage of the study, the effect of the addition of 25%, by weight, of three different biosolids samples from ETP, to the brick-clay on some physical and mechanical properties of bricks was examined.

2. MATERIALS AND METHODS

Three biosolids samples used in this study were collected from existing stock piles at the ETP in Melbourne (Figure 1). All samples, B1,B2 and B3 were collected in airtight containers to maintain their in situ moisture contents.

Biosolids Sample 1 - B1 | Biosolids Sample 2 - B2 | Biosolids Sample 3 - B3

Figure 1 Three biosolids samples used in the study

Geotechnical laboratory tests including liquid limit, plastic limit, particle size distribution, linear shrinkage were conducted for biosolids samples according to Australian Standards whereas loss on ignition test was conducted as per the British Standards. The geotechnical properties of biosolids samples and the brick soil were tested in triplicate and the average values of results are displayed in Table 1.

As can be observed in Table 1 and plasticity chart in Figure 2, liquid limit of biosolids samples ranged between 46% and 67% while the brick soil which was provided by Boral Bricks Pvt Ltd had a liquid limit of 31%. Plastic limit of biosolids samples and the brick soil ranges between 21% and 41%. The plasticity index was found to be in the range of 10% and 33%.

Particle size distributions for all samples were determined according to the Australian Standards (AS 1289.3.6.1, 1995) and showed that the percentage of fine particles (< 75 µm) of biosolids samples noticeably varied from 20.7% to 10.8% whereas the brick soil had the highest percentage (29%) of fine particles (Table 1 and Figure 3). Based on the percentage of soil passing 75 µm sieve and Atterberg Limits results, B1, B2 and B3 can be classified as silty clayey sand with low to high plasticity. B1 tends to be low plasticity material compared with B2 and B3, hence higher adhesiveness and consequently strong bonding ability with the brick soil can be expected (Weng et al., 2003) than other two biosolids samples. The brick soil can be categorized as clayey sand with low plasticity.

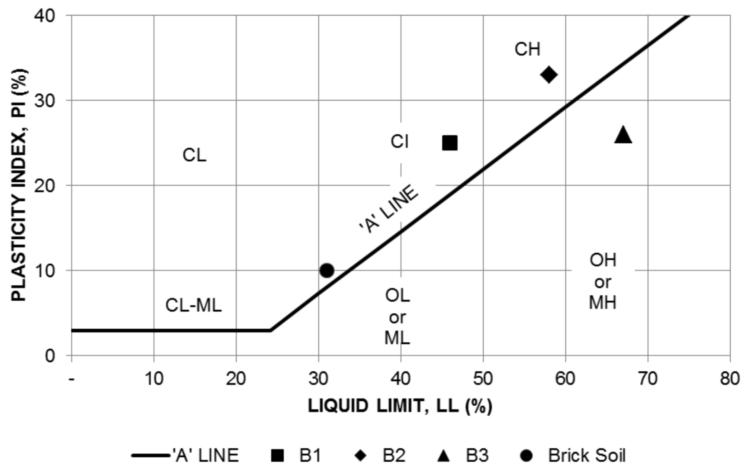

Figure 2 Plasticity chart for biosolids samples and brick soil (AS 1726, 1993)

Initial moisture content of biosolids samples was found to be between 29.1% and 45.5%. Linear shrinkage is an indirect method of estimating the swelling and shrinking capacity of soils; calculated as the percentage reduction in the length of bars of the soil samples prepared at the liquid limit condition, after they have been air dried 24 h and followed by oven drying until no further length reduction is observed. Linear shrinkage of biosolids samples, as shown in Table 1, varied from 10% to 15% whilst the brick soil had a linear shrinkage of 5%. It is important to note that, as shrinkage of the biosolids sample reduces, shrinkage of clay biosolids bricks is expected to be reduced and therefore bricks with higher degree of quality can be expected.

Loss on ignition test measures the organic content and was determined by burning samples in a muffle furnace at 440ºC for 4 h according to British Standards (British Standards, 1990). As presented in Table 1, B3 has a significantly higher loss on ignition of 14.4 % compare with 9.5% and 6.3% for B2 and B1 respectively. The brick soil has appreciably lower organic content which in turn contributes to bricks with lower porosity and subsequently higher density.

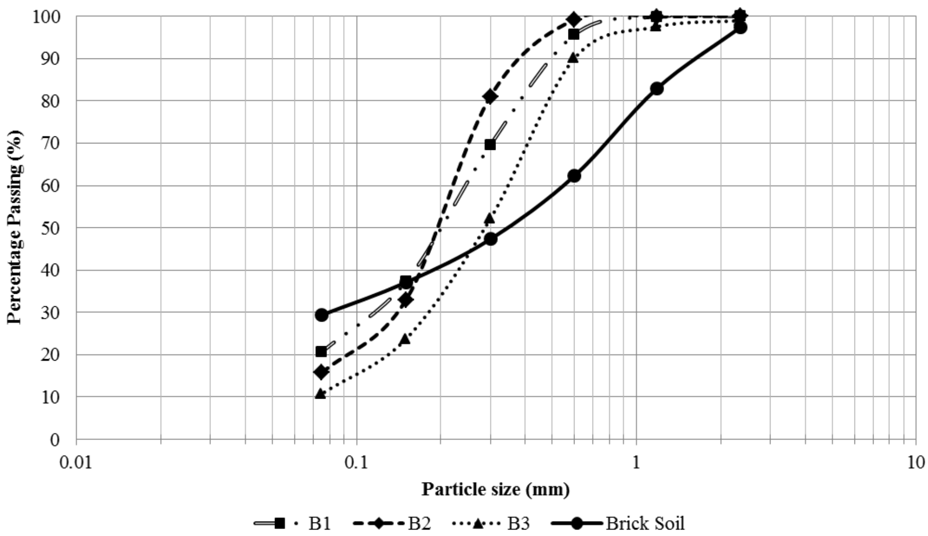

Figure 3 Particle Size Distribution of Biosolids samples and brick soil

Table 1 Some properties of the biosolids samples and the brick soil used in the study

Test / Properties	B1	B2	B3	Brick Soil
Liquid Limit (%)	46	58	67	31
Plastic Limit (%)	21	25	41	21
Plasticity Index (%)	25	33	26	10
Particles < 75 µm (%)	20.7	15.7	10.8	29
Initial Moisture Content	29.1	45.5	41.9	2.7
Linear Shrinkage (%)	10	16	15	5
Loss on ignition (%)	6.3	9.5	14.4	1.4

Control clay bricks with 0% biosolids and clay- biosolids bricks with 25% by weight of biosolids were manufactured. The mixtures were prepared by means of a Hobart Mechanical Mixer with a 10 litre capacity for 5 minutes. Each brick sample was compacted by compaction machine with the same compactive effort, in a mould with the size of 100 mm diameter and 50 mm height. Prepared green bricks were kept for 24 h air for air-drying followed by an oven drying period at 105 ºC for 24h; dried bricks were fired in a muffle furnace at 1100 ºC for 3 h. Fired brick samples were then cooled to room temperature in the furnace itself. Manufactured bricks tested for compressive strength, density, water absorption, IRA, weight loss on ignition, and firing shrinkage. All tests were performed according to the Australian Standards (AS/NZS 4456, 2003).

3. RESULTS AND DISCUSSIONS

Bricks manufactured incorporating 25% by weight of B1, B2 and B3 were labelled as B1-25, B2-25 and B3-25 respectively whereas control bricks were labelled as B-0. The properties of the bricks tested and average values of results are presented in Table 3.

Compressive strength is the utmost important in assuring the engineering quality of bricks because it measures the ability of bricks in withstanding loads. Compressive strength testing was carried out as per the Australian Standards (AS/NZS 4456, 2003). The results in Table 3 and Figure 5 show that B-0 control brick has the highest compressive strength of 36.1 MPa. Interestingly however, biosolids incorporated bricks show considerable amount of compressive strengths, which are much higher than the minimum requirement of Australian Standards for compressive strength which is 3 MPa. The drop in compressive strength is mainly due to different organic contents and percentage of fine particles (<75µm) in the clay and clay- biosolids samples (Table 2). This has been illustrated in Figure 4

Table 2 Percentage of fine particles and organic content of brick Samples before firing

Property	B-0	B1-25	B2-25	B3-25
Fine Particles (< 75µm) of brick samples before firing (%)	29.0	22.8	19.0	15.4
Organic Content of Brick Samples before firing (%)	1.4	2.6	3.4	4.7

The quality of bricks can be further evaluated by studying the shrinkage. Clay brick is prone to crack as the strain increases with the increasing of shrinkage. Therefore, higher shrinkage may induce significant cracking which is undesirable for bricks. As indicated in Table 3 and Figure 6, B1-25 and B2-25 bricks show the lowest volumetric firing shrinkage values of 14.4% and 14.8 % respectively, and interestingly, these values are lower than that of the control bricks which is 16.0%. This could be due to inorganic substances in clay being burnt off during the firing process of brick (Weng et al., 2003).

Density of manufactured bricks decreased from 2115 kg/m^3 for the control bricks to 2,024, 1,954 and 1,910 kg/m^3 for brick samples B1-25, B2-25 and B3-25 respectively (Table 3 and Figure 7). This is mainly because of the addition of biosolids, with some organic content, which results in fired-bricks with higher porosity and thus lower density. (Figure 4)

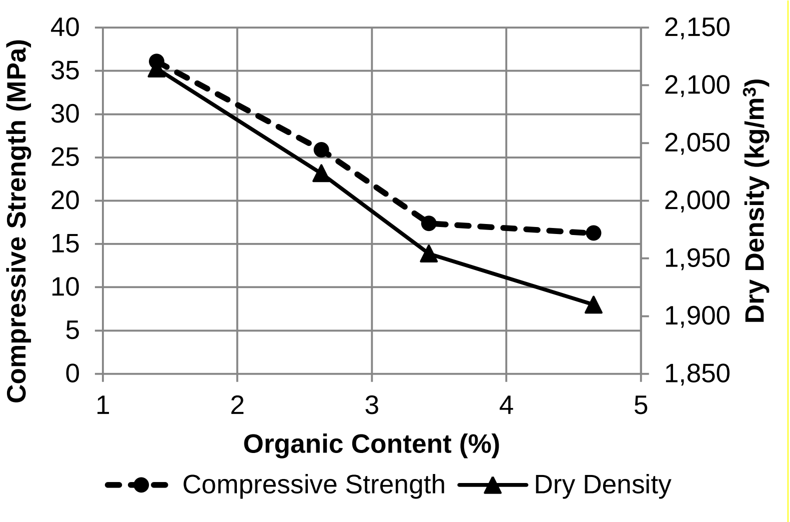

Figure 4 Variation of Compressive Strength and Dry Density of brick samples with Organic Content

IRA refers to the amount of water absorbed in 1 min through the bed surface of the brick. Low water infiltration into bricks contributes to have good durability and consequently higher resistance to natural environment. As detailed in Table 3, B-0 bricks show the minimum IRA of 1.4 kg/m^2 per min while B1-25 has IRA of 2.6 kg/m^2 per min which is the lowest compared with other biosolids amended bricks. This is because growth of pores in number and size is expected to be lower in B1-25 bricks as B1 has the lowest organic content.

Table 3 Summary of test results of Control and biosolids amended bricks

Property		**Unit**	**Brick Sample Name**			
			B-0	**B1-25**	**B2-25**	**B3-25**
Compressive Strength		MPa	36.1	25.9	17.4	16.2
Initial Shrinkage	Height	%	2.5	3.2	2.7	5.0
	Diametric		1.7	2.2	2.4	3.3
	Volumetric		5.8	7.4	7.3	11.1
Firing / Total Shrinkage	Height	%	6.0	5.0	5.0	7.7
	Diametric		5.5	5.0	5.3	7.0
	Volumetric		16.0	14.4	14.8	20.0
Density		kg/m^3	2115	2024	1954	1910
IRA		kg/m^2 per min	1.4	2.6	3.6	4.2
Water Absorption		%	6.9	8.7	9.8	9.7
Weight loss on ignition		%	4.7	5.5	6.5	8.1
Thermal Conductivity		W/m per K	1.08	0.95	0.86	0.81

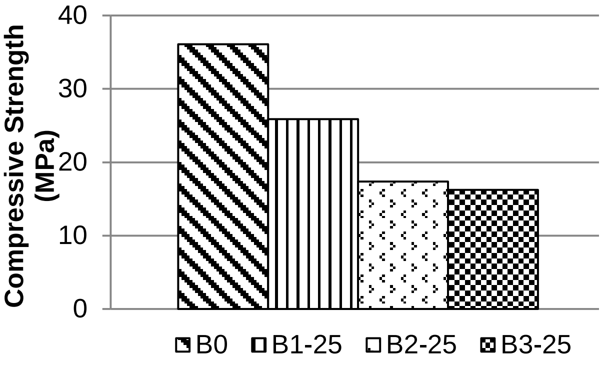

Figure 5 Compressive Strength of Brick Samples

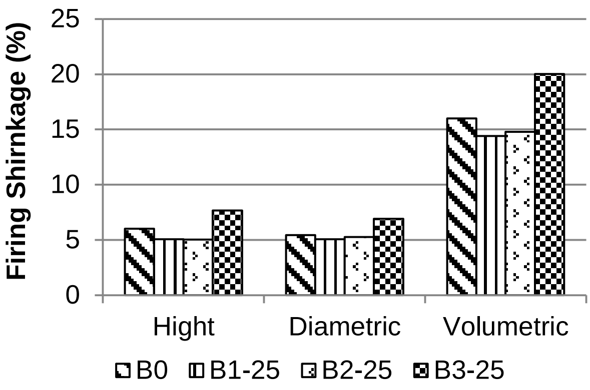

Figure 6 Firing shrinkage of Brick Samples

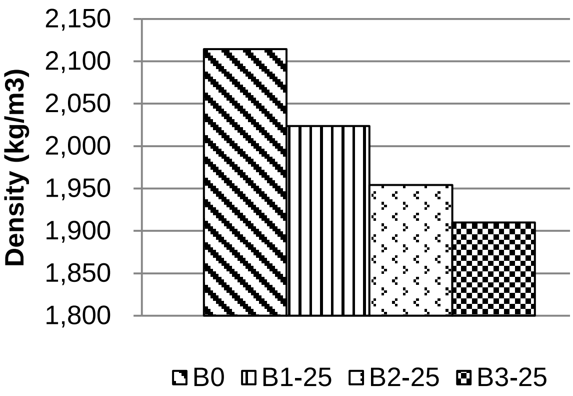

Figure 7 Density of Brick Samples

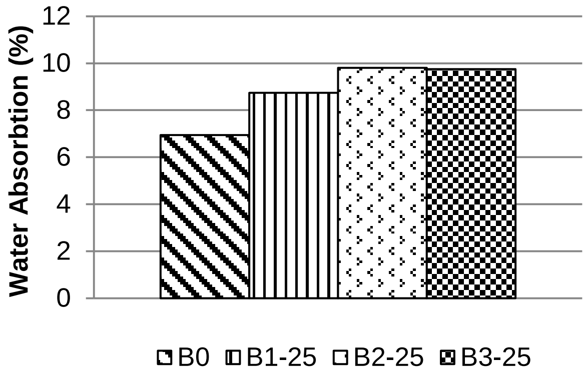

Figure 8 Water Absorption of Brick Samples

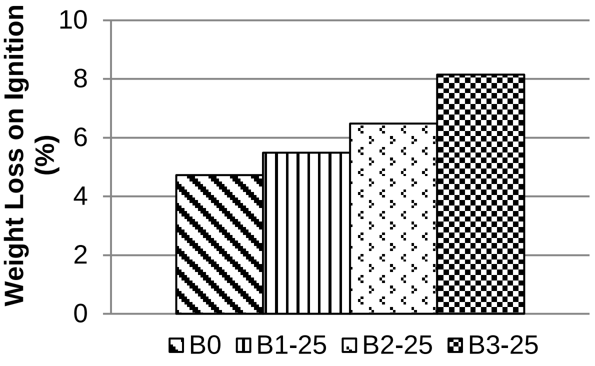

Figure 9 Weight Loss on Ignition of Brick Samples

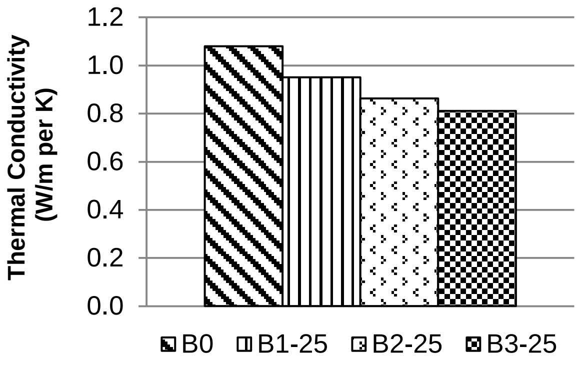

Figure 10 Thermal Conductivity of Brick Samples

Water absorption is of paramount importance in assessing the durability and thus measuring the quality of manufactured bricks. Test results of water absorption on brick samples (Table 3 and Figure 8) indicated that water absorption is increased as biosolids incorporated into bricks. It is apparent that B-0 bricks showed the minimum water absorption of 6.9% since it has the highest density and the lowest porosity. It is noteworthy that B1-25 again showed the minimum water absorption value (8.7%) among the other clay-biosolids bricks. However, this is about 26% higher compared to B-0 bricks. It is known from the literature that higher values of water absorption and IRA can give rise to several kind of damage, such as frost damage, inadequate bond strength between brick units, salt crystallisation, changes in volume of bricks that subsequently cause the appearance of cracks which eventually could result in structural damage to buildings (Kadir and Mohajerani, 2011, Pel et al., 1995, Marotta, 2005). This will further investigated for bricks incorporated with biosolids

Figure 9 and Table 3 shows the weight loss on ignition of manufactured bricks after firing process. Control brick samples showed the lowest loss on ignition (4.7%) but B3-25 bricks had the highest weight loss on Ignition (8.1%). As shown in Figure 9 upon the addition of biosolids in the mixture, weight loss on ignition during the firing increased gradually which may be due to the contribution of organic matter in biosolids as well as inorganic matter in both brick soil and biosolids (Liew et al., 2004, Lin and Weng, 2001, Weng et al., 2003).

Thermal insulating properties of fired-clay bricks are indeed very important in view of energy savings, and also some engineering applications greatly depend on the thermal insulation performance. Previous studies point out that the thermal conductivity of bricks mainly related to their density (Jungk et al., 1996, Schmidt-Reinholtz, 1990). In this stage of the study, an equation shown below which was developed in a previous study has been used to evaluate the thermal conductivity of manufactured brick samples (Kadir and Mohajerani, 2011).

$$T = 0.0559e^{(0.0014\,D_d)} \quad (1)$$

where T is the thermal conductivity (W/m per K) and D_d is the dry density (kg/m^3). Figure 10 and Table 3 illustrate the calculated results of thermal conductivity of brick samples, and it can be observed that as the dry density of brick samples changes, thermal conductivity of bricks varies accordingly. With respect to the control brick samples, thermal conductivity values of B1-25, B2-25 and B3-25 samples were reduced by approximately 12%, 20% and 25% respectively, which are significant amounts in terms of energy saving. Furthermore, adding biosolids to the soil for manufacturing clay bricks assists firing due to its organic content. This will be investigated in the next stage of the study.

Oxidation of organic compounds during firing stage of bricks contributes to the heating process which subsequently saves the amount of energy required (Domone and Illston, 2010, Kadir and Mohajerani, 2011). It has been found that 5%-6% by weight of dispersed organic matter in Lower Oxford Clay provides about two-thirds of the energy required during the firing (Jackson and Dhir, 1996).

4. CONCLUSION

Worldwide, recycling and reusing of leftover and unused materials are now of greater concern in context of the sustainable environment. This study investigated the possible incorporation of biosolids into fired-clay bricks.

Three biosolids samples (B1, B2 and B3), from ETP in Melbourne, were underwent series of laboratory tests and found that the samples were low to high plasticity according to Australian Standards. Particle size analysis of biosolids samples showed that percentage of finer particles (<75 µm) ranged from 10.8% to 20.7%. Linear shrinkage of biosolids samples was found to be varied between 10% and 15%. In addition, loss on ignition results indicated that organic content of biosolids samples used in this study varied between 6.3% and 14.4%.

Bricks were manufactured by incorporating 25% of biosolids (B1-25, B2-25 and B3-25), and control bricks with 0% biosoilds (B-0) by weight. Compressive strength values of brick samples decreased from 36.1 MPa (B-0) to 25.9, 17.4 and 16.2 MPa for B1-25, B2-25 and B3-25 correspondingly. Moreover, dry density of brick samples was reduced by 4.3% to 9.7% after modifying bricks with biosolids. Most notably, B1-25 showed the lowest values for IRA, water absorption and weight loss on ignition. In addition, corresponding values for thermal conductivity of B1-25, B2-25 and B3-25 were 0.95, 0.86 and 0.81 Wm^{-1}K^{-1} respectively. Organic materials in biosolids being burnt off during the firing process could lead to have biosolids amended bricks with lower density and thus lower thermal conductivity compared with control bricks (B-0). The reduction of thermal conductivities of biosolids amended bricks is significant in terms of energy savings.

The promising results obtained in this preliminary study indicate that biosolids can be regarded as a possible beneficial addition to raw materials used in the manufacturing of fired-clay bricks. In the next stage of this research, a comprehensive study will be carried out to find the effects of different percentages of biosolids on short-term and long-term physical and mechanical properties of bricks, and, to investigate the environmental impacts related to the incorporation of biosolids in bricks.

5. ACKNOWLEDGEMENT

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