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Lightweight bricks manufactured from water treatment sludge and rice husks

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ABSTRACT

Novel lightweight bricks have been produced by sintering mixes of dried water treatment sludge and rice husk. Samples containing up to 20 wt.% rice husk have been fired using a heating schedule that allowed effective organic burn-out. Rice husk addition increased the porosity of sintered samples and higher sintering temperatures increased compressive strengths. Materials containing 15 wt.% rice husk that were sintered at 1100 °C produced low bulk density and relatively high strength materials that were compliant with relevant Taiwan standards for use as lightweight bricks.

1. Introduction

Improving drinking water quality has been a priority in Taiwan for many years. Poor soil conservation and the unique geography of Taiwan has caused drinking water shortages, increased the water supply turbidity and reduced drinking water quality. Water consumption in Taiwan increased from 0.18 to 0.242 m^3/day/person between 1986 and 2008. High doses of coagulants and other chemicals are now used in water treatment to improve the drinking water quality [1]. A typical water treatment plant (WTP) produces about 200,000 m^3 of sludge per day. This amount is expected to increase. Sanitary landfills are normally used for sludge disposal, although the Taiwan Government has a WTP sludge management strategy that aims to reduce landfill disposal by encouraging beneficial reuse. The management of agricultural wastes is also an important environmental issue in Taiwan. Approximately 1.2 million t of rice paddy waste is produced each year, resulting in approximately 0.24 million t of waste rice husks [2]. Most of this material is either burnt or stockpiled. Burning causes air pollution and stockpiling is unsightly, uses valuable space and can cause other environmental problems.

Sintering is becoming an attractive option to allow recycling of certain types of inorganic wastes and residues in Taiwan. Over the last decade many researches have investigated the properties of various materials made from sintered wastes. These materials have included pulverized fuel ash (PFA), bottom ash and air pollution control (APC) residues from municipal solid waste (MSW) incinerators, sewage sludge ash, water treatment sludge, dam sediments, slag from steel production, slag from incinerator residues and various other inorganic wastes. Potential applications include lightweight aggregate, bricks, tiles and other construction products [3–20].

Over the past decade, building brick development has moved toward reducing brick weight and increasing its thermal insulation ability. Considering the modern green building, the amount of inner pores in building bricks is a critical factor. Lightweight bricks were usually manufactured by adding combustible additives as a foaming agent while controlling the appropriate amount of pores, particle size and firing temperature. Plastics have been applied for use as an additive in lightweight brick production. However, the results from previous studies showed that the low apparent density and high water absorption in plasticized lightweight bricks resulted in an excessive amount of the pores and decreased compressive strength [21]. There are many unknowns that must be overcome in the key technologies for improving the compressive strength of lightweight bricks.

Rice husk is a major agricultural waste with a unique residue with high ash silica content. The ash contains above 90% silica with a highly porous, lightweight, specific surface area. Rice hull ash has been applied as an amendment in many materials. This is due to its' high porous insulating property. Many industrial applications include refractory brick manufacturing, concrete and lightweight building materials, and the manufacture of insulation, flame retardants, etc. [22–25]. Although rice husk ash applications in cement and steel manufacturing are well established, silica-enriched ash is usually produced by burning the rice husks. The properties of rice

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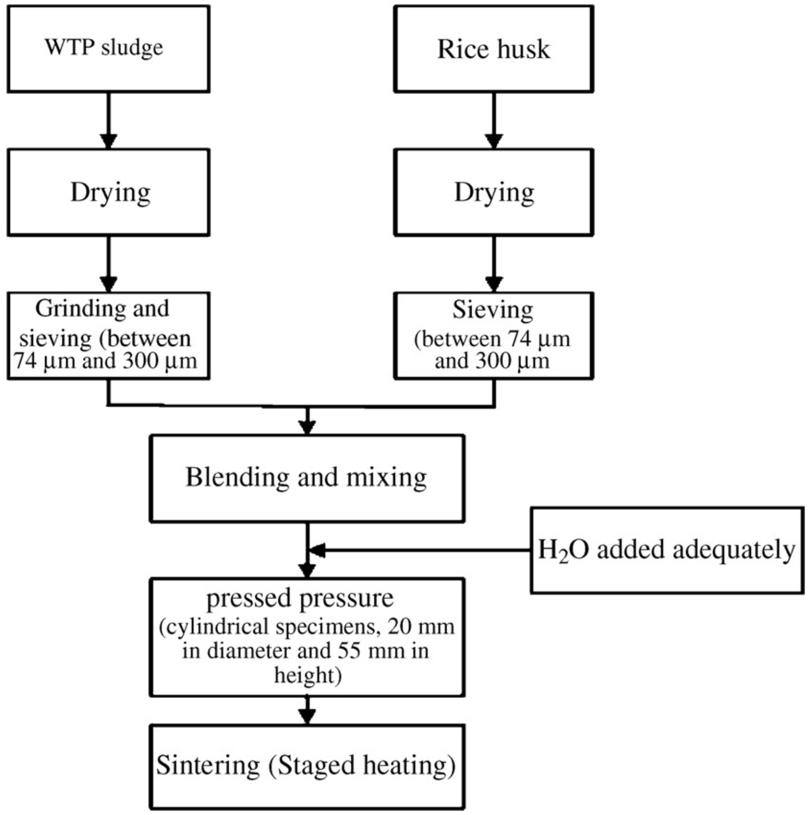

Fig. 1. The process used to prepare sintered specimens.

husk ash silica vary according to the firing temperature and time. It is important to control the firing conditions to produce the appropriate ash for the particular application. In this research, rice husks were added to WTP sludge, homogenised and sintered to produce materials with different porosities. The blending ratio and sintering temperature effects on the properties and micro-structure of the produced materials is reported.

2. Materials and methods

2.1. Materials

The Fong-Yuan water treatment plant, located in the central part of Taiwan, produces approximately 700,000 m^3/day drinking water from surface water using a conventional coagulation, flocculation and rapid sand filtration process, using poly-aluminum chloride (PAC) as the coagulant. Drinking water is disinfected with a combination of chlorine gas and chlorine dioxide. The drinking water treatment process produces approximately 6000 t/year of WTP sludge (based on 50 wt.% moisture content). Representative samples of WTP sludge were collected from the drying beds at Fong-Yuan. The collected sludge cake had agglomerated and was therefore shredded and sieved to give particles between 74 and 300 μm. Rice husks were obtained from the Tai-Nan County Farmers' Association in Southern Taiwan. The rice husks were sieved into particles with sizes between 74 and 300 μm for use in subsequent experiments.

2.2. Characterization of WTP sludge and rice husk

The moisture content of WTP sludge and rice husks was determined by heating samples to 105 °C for 48 h. The combustible fraction was determined in triplicate using American Public Health Association (APHA) standard methods [26]. X-ray fluorescence (XRF, SPECTRO, X-Lab 2000) was used to determine the chemical composition of WTP sludge. Crystalline minerals were identified by X-ray diffraction (XRD, MAC Science, MXP3). The pH was determined in triplicate using aqueous extracts from dried samples at a 1:10 ratio of solid: distilled water (w/v).

The Pb, Cd, Cu, Cr, and Zn concentrations were determined using nitric acid (HNO_3)/hydrogen peroxide (H_2O_2) digestion, followed by inductive coupled plasma optima optical emission spectroscopy (ICP-OES, PerkinElmer, Optima 2000DV). The toxicity characteristic leaching procedure (TCLP) test is required by the Environmental Protection Administration of Taiwan (NIEA R201.10T) [27]. This involves the addition of an acetic acid solution (0.57% v/v) to dried samples at a constant ratio of liquid:solid (20:1). After 18 h the leachate is filtered and analyzed using ICP-OES for a range of metals including Pb, Cd, Cu, Cr, and Zn.

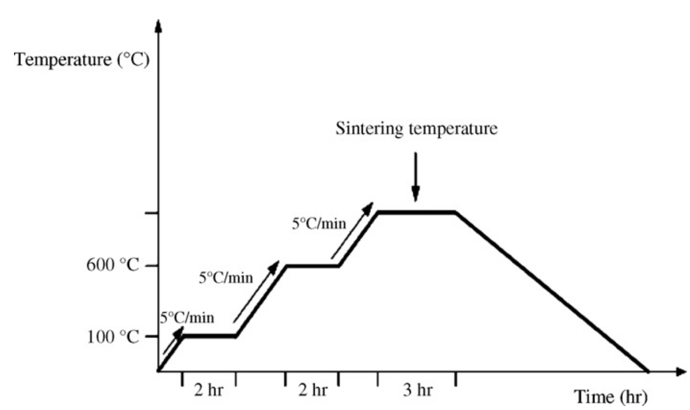

Fig. 2. The temperature profile used to sinter samples.

Table 1
The principal properties and the metal contents of the tested materials.

Properties	WTP sludge	Rice husk
pH (in H_2O)	6.76 ± 0.08*	5.76 ± 0.12
Moisture (%)	35.82 ± 0.20	0.32 ± 0.14
Combustible (%)	2.72 ± 0.10	75.31 ± 0.31
Ash (%)	61.45 ± 0.24	14.37 ± 0.27
Total metal content (mg/kg)		
Zn	75.72 ± 3.93	25.76 ± 2.28
Pb	17.93 ± 1.78	<0.18
Cu	19.13 ± 0.89	6.68 ± 0.47
Cr	15.53 ± 0.94	<0.12
Cd	<0.16	<0.16
TCLP concentration (mg/l)**		
Zn	<0.005	0.02 ± 0.004
Pb	<0.009	<0.009
Cu	<0.005	<0.005
Cr	<0.006	<0.006
Cd	<0.008	<0.008
Chemical composition (dry weight, %)		
SiO_2	53.36	***
Al_2O_3	15.28	–
Fe_2O_3	21.01	–
P_2O_5	0.83	–
CaO	1.20	–
K_2O	5.41	–
TiO_2	1.38	–
MnO	0.73	–

Pb: 5 mg/l, Cd: 1 mg/l, Cr: 5 mg/l, Zn: 25 mg/l.
* 1: data obtained from triplicate.
** TCLP thresholds
*** Not available.

2.3. Preparation of WTP sludge specimen and sintering operation procedure

Fig. 1 summarizes the sample preparation process. Dried WTP sludge and rice husk samples with particle sizes between 74 and 300 μm were blended to produce homogenous mixes containing rice husk additions of 0, 5, 10, 20, and 25% (by weight) on a dry basis. Compacted samples were prepared by adding 20% water to the dry powder and uni-axially pressing at 60 kgf/cm^2 (800 psi) to form 20 mm diameter cylindrical specimens that were approximately 55 mm high.

The heating profile used in the sintering experiments is shown in Fig. 2. The temperature was increased at 5 °C/min in an electric furnace (DENGYNG, DF-404) with a first dwell at 105 °C for 120 min to evaporate moisture. The dwell at 600 °C for 120 min was used to decompose the organic matter in the rice husk. The temperature was then increased to a sintering temperature between 800 and 1100 °C and held for 180 min.

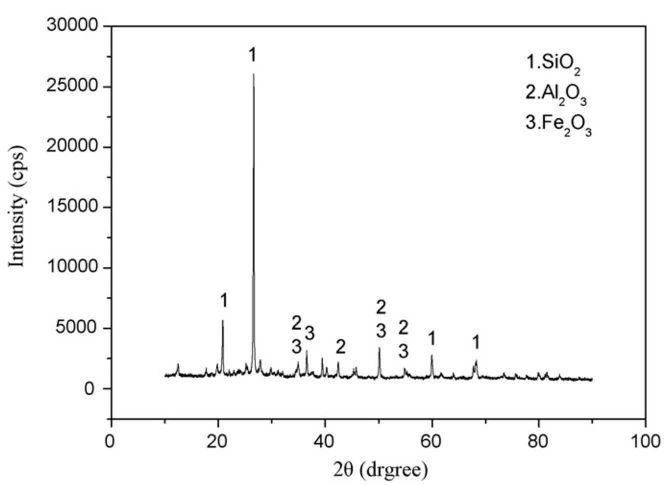

Fig. 3. XRD data for the as-received WTP sludge.

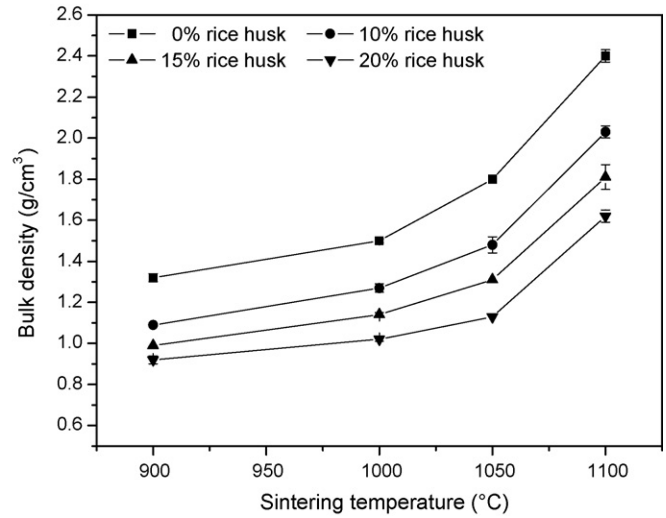

Fig. 4. Sintering temperature effect on the bulk density of specimens.

2.4. Characterization of sintered samples

The bulk density, water absorption, open porosity and dimensional change in the sintered products were determined from their weights and dimensions in term of ASTM C373 and C20-00 standard test methods [28,29]. The bulk density of the sintered products in grams per cubic centimeter is the quotient of its dry weight (W_1) divided by the exterior volume. The exterior volume (V) of the sintered products in cubic centimeters was calculated by subtracting the suspended weight (W_2) from the saturated weight (W_3). The saturated weight of the sintered products was determined while products were immersed in boiling water for 2 h. The specimens remained immersed in water for a minimum of 12 h, surface dried and re-weighed (W_3). The suspended weight (W_2) was determined after boiling while the specimens were suspended in water. The water absorption was calculated from the ratio between W_3–W_1 and W_1. The open porosity expressed as a percentage the relationship between the open pore volume in the sintered products and the exterior vol-

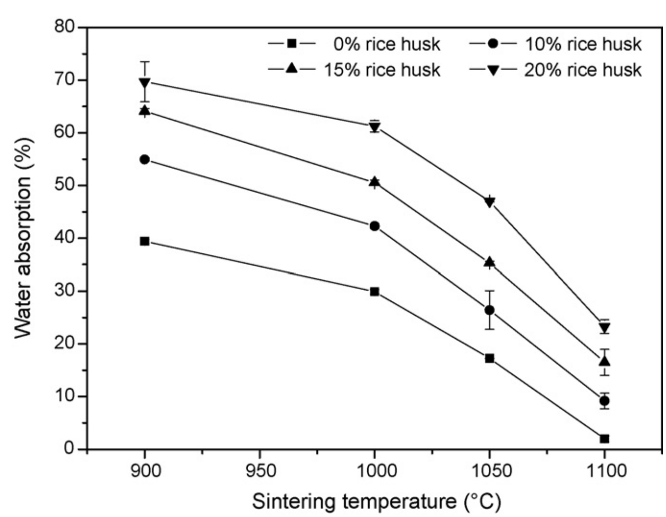

Fig. 5. Sintering temperature effect on the water absorption of specimens.

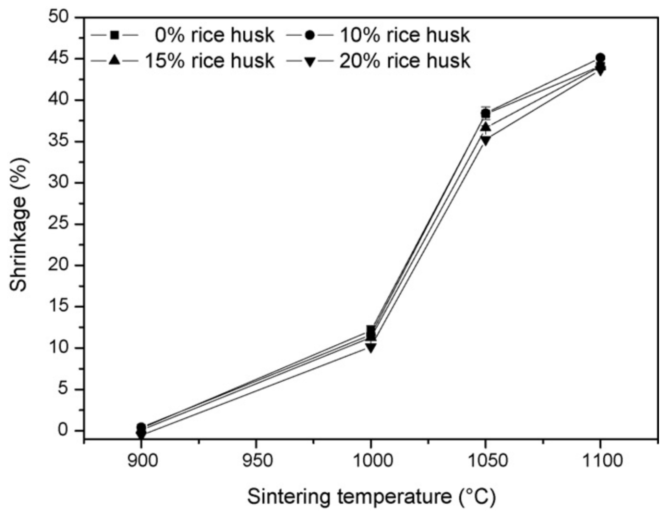

Fig. 6. Sintering temperature effect on the dimensional change of specimens.

ume, calculated from the ratio between W_3–W_1 and W_3–W_2. The change in specimen volume after sintering was also determined.

Unconfined compressive strength was measured using the Taiwan Environmental Protection Administration (EPA) standard method (NIEA R 206.22C) [30]. Strengths were obtained in triplicate using a loading rate of 6 kgf/s. The micro-structures of the sintered specimens were examined using scanning electron microscopy (SEM, Hitachi, S3000). Crystalline phases were identified by XRD (MAC Science, MXP3).

3. Results

3.1. Properties of WTP sludge and rice husk

Table 1 shows the pH, moisture content, combustible fraction, percentage ash and metals content (mg/kg) data for the WTP sludge and rice husk. The water content of the WTP sludge and rice husk was 35.8 ± 0.2% and 0.3 ± 0.1%, respectively. The combustible fractions of the WTP sludge and rice husk were 2.7 ± 0.1% and 75.3 ± 0.3%, respectively. Total metal concentrations in the WTP sludge and rice husk were relatively low. Zn concentrations were typically 25.76 ± 2.28 mg/kg for rice husk and 75.72 ± 3.93 mg/kg for WTP sludge. Other metals were present at less than 20 mg/kg or below detection limits.

TCLP leachate analysis data are given in Table 1. The concentration of Zn leaching from the rice husk was below the Taiwan EPA regulatory limit of 25 mg/l and Pb, Cu, Cd and Cr were below detection limits. Chemical composition data as percentage of major oxides is also shown in Table 1. This indicates that the main components of WTP sludge are SiO_2 (53.36%), Fe_2O_3 (21.01%), Al_2O_3 (15.28%) and CaO (1.20%). XRD data is given in Fig. 3 for the WTP sludge. Silica (SiO_2) is the major crystalline phase present and relatively low intensity peaks corresponding to those for Al_2O_3 and Fe_2O_3 were also detected.

3.2. Properties of sintered specimens

3.2.1. Bulk density

The bulk densities of sintered samples are given in Fig. 4. These were greater than 1.50 g/cm^3 for samples sintered at a range of temperatures containing 0% rice husk. Bulk densities decreased with increasing rice husk addition, from 2.4 to 1.6 g/cm^3 for samples sintered at 1100 °C as the rice husk addition increased from 0% to 20%. The colour of the sintered samples also changed with the sintering temperature and rice husk addition. Dark red samples were produced by sintering at 1100 °C.

3.2.2. Water absorption

The sintering temperature and rice husk addition effects on water absorption are shown in Fig. 5. This decreases from 40% to 2% when the sintering temperature is increased from 900 to 1100 °C for samples containing no rice husks. In the case of 10% rice husk addition, the water absorption of sintered specimens decreased from 55% to 9% when the sintering temperature was increased from 900 to 1100 °C. Water absorption decreased significantly with increasing sintering temperature. The results also indicated that the water absorption increased with increased rice husk addition ratio.

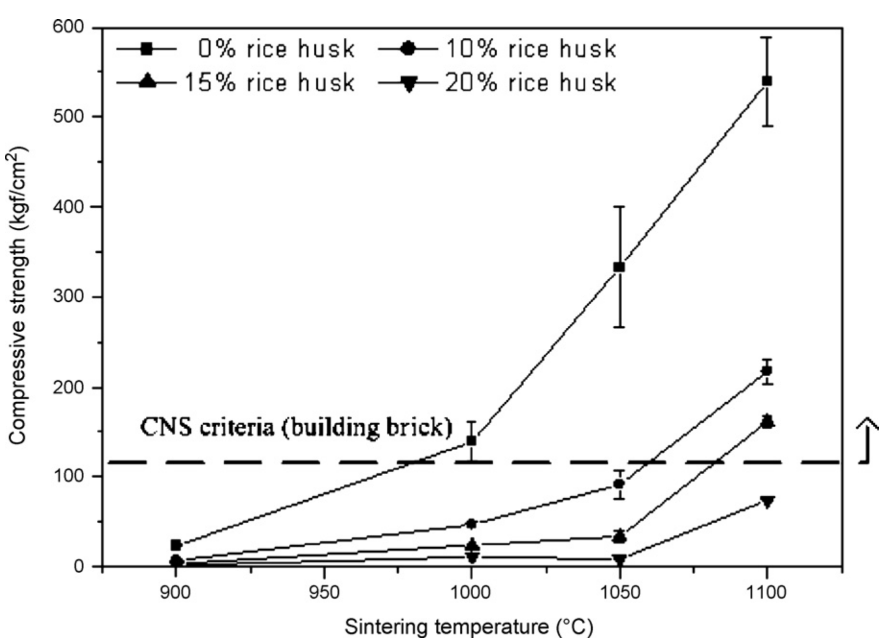

Fig. 7. Sintering temperature effect on the compressive strength of specimens.

3.2.3. Dimensional change after sintering

Fig. 6 shows the shrinkage of samples as a result of sintering. Shrinkage increased with sintering temperature and samples sintered at 1000 °C had shrinkage of approximately 10%. Obviously, the shrinkage of sintered specimen increased significantly with the sintering temperature. A maximum of 45% shrinkage occurs at sintering temperature 1100 °C and 20% rice husk addition.

3.2.4. Compressive strength

Fig. 7 shows the compressive strength data for sintered specimens as the function sintering temperature for different rice husk percentage addition. The compressive strength increased with increased sintering temperature and decreased with increased added rice husks. Compressive strength increased from 23 to 540 kgf/cm^2 when the sintering temperature was increased from 900 to 1100 °C for samples containing no rice husks. In the 10% rice husk addition case, the sintered specimen compressive strength increased from 7 to 217 kgf/cm^2 when the sintering temperature was increased from 900 to 1100 °C. The higher compressive strength developed at 1100 °C sintering temperature with the rice husk ratio at 15% and below, ranging from 162 to 540 kgf/cm^2, thereby fulfilling the code requirement (150 kgf/cm^2) with respect to lightweight bricks for construction work.

3.3. Micro-structural analysis of sintered specimens

3.3.1. XRD data

Fig. 8 shows the XRD data for specimens sintered at 1100 °C. Comparison with the XRD data for as-received WTP sludge in Fig. 3 shows that no significant changes in the crystalline phases occurred from sintering. The major mineral phases in the sintered specimens were quartz (SiO_2), alumina (Al_2O_3) and hematite (Fe_2O_3). The added rice husk in this work provided the combustible content to produce the appropriate amount of pores and expected lightweight brick under controlled sintering temperature. Although the rice husk ash contains high silica content derived from co-sintering of rice husk and WTP sludge, the rice husk ash content was approximately 14.37% (as shown in Table 1). The crystalline speciation changes in the sintered products were insignificant due to rice husk sintering. Table 2 gives the intensities of the major peaks for the minerals present. The intensities of the major peak (SiO_2) for sintered specimens decreased significantly with increased added rice husk. This means that the SiO_2 compound in the WTP sludge transformed into some non-crystalline phases.

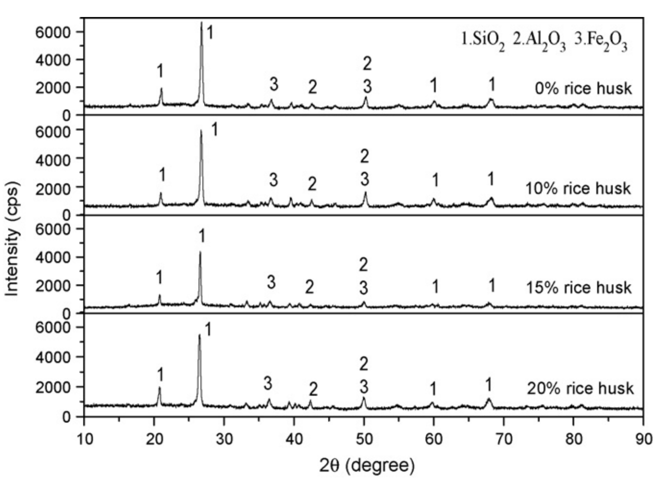

Fig. 8. XRD data for WTP sludge sintered at 1100 °C.

Table 2
The XRD peak intensity of the major peak of crystalline phase identified in WTP sludge and sintered specimens at sintering temperature 1100 °C.

Crystalline species samples	Quartz $2\theta = 26.64°$	Aluminum oxide $2\theta = 35.15°$	Hematite $2\theta = 33.11°$
As-received WTP sludge	26,073	1483	1046
Sintered specimen (0% rice husk)	6,720	620	683
Sintered specimen (10% rice husk)	5,976	720	730
Sintered specimen (15% rice husk)	4,393	730	700
Sintered specimen (20% rice husk)	4,160	793	923

3.3.2. Micro-structural analysis

Fig. 9 shows the micro-structural analysis of sintered specimens sintered at 1100 °C with different amounts of added rice husk. With 0% rice husk, the sintered specimens produced dense matrix material with good surface characteristics. These results are in agreement with the low water absorption, high compressive strength and bulk density of sintered specimens. The microstructure of sintered specimens at 1100 °C with less than 15% added rice husk showed a similar dense matrix material. However, there was evidence of larger pores in the sintered specimens. The sintered products also had relatively low bulk density and high compressive strength. Theses results are also in compliance with the relevant criteria for lightweight brick applications. The micro-structure of sintered specimens at 1100 °C and 20% added rice husk indicated a relatively loose matrix material dominated by the presence of larger open pores in the sintered specimens. The results are in agreement with previous results that the sintered products manufactured from 20% added rice husk had a lower compressive strength than that of sintered products produced from 0% to 15% added rice husk.

4. Discussion

Lightweight bricks have become an important trend for green buildings. This is because lightweight bricks reduce the building weight. The numbers of inner pores in lightweight bricks are much greater than in traditional bricks. Lightweight bricks have a relatively low thermal conductivity property that can be applied to reducing the building's energy use. The lightweight bricks in this research were manufactured from WTP sludge and rice husks by controlling the optimum sintering temperature and amendment ratios. The larger the rice husk organic matter content, the greater the porosity and shorter the path among particles for gas diffusion. Therefore, a higher rice husk addition ratio increases the open pore volume and decreases the bulk density of sintered specimens. Fig. 10 shows that the total porosity or open porosity of lightweight specimens increased with rice husk addition and decreased with the sintering temperature. With 1100 °C sintering temperature the specimen open porosity increased from 5% to 38% with an increase in added rice husks from 0% to 20% (as shown in Fig. 10).

Samples sintered at the same firing temperature showed increased bulk density in sintered specimens with decreased rice husk addition ratio. Fig. 4 shows that a maximum bulk density of 2.4 g/cm^3 with specimens sintered at 1100 °C. Increasing the rice husk addition from 0% to 20% decreased the sintered specimen bulk density from 2.4 to 1.6 g/cm^3. In the case of 15% rice husk addition and 1050 °C sintering temperature the sintered specimens revealed a bulk density of 1.31 g/cm^3; lower than that for traditional building brick criteria. These results are in agreement that rice husk addition resulted in low bulk density sintered specimens.

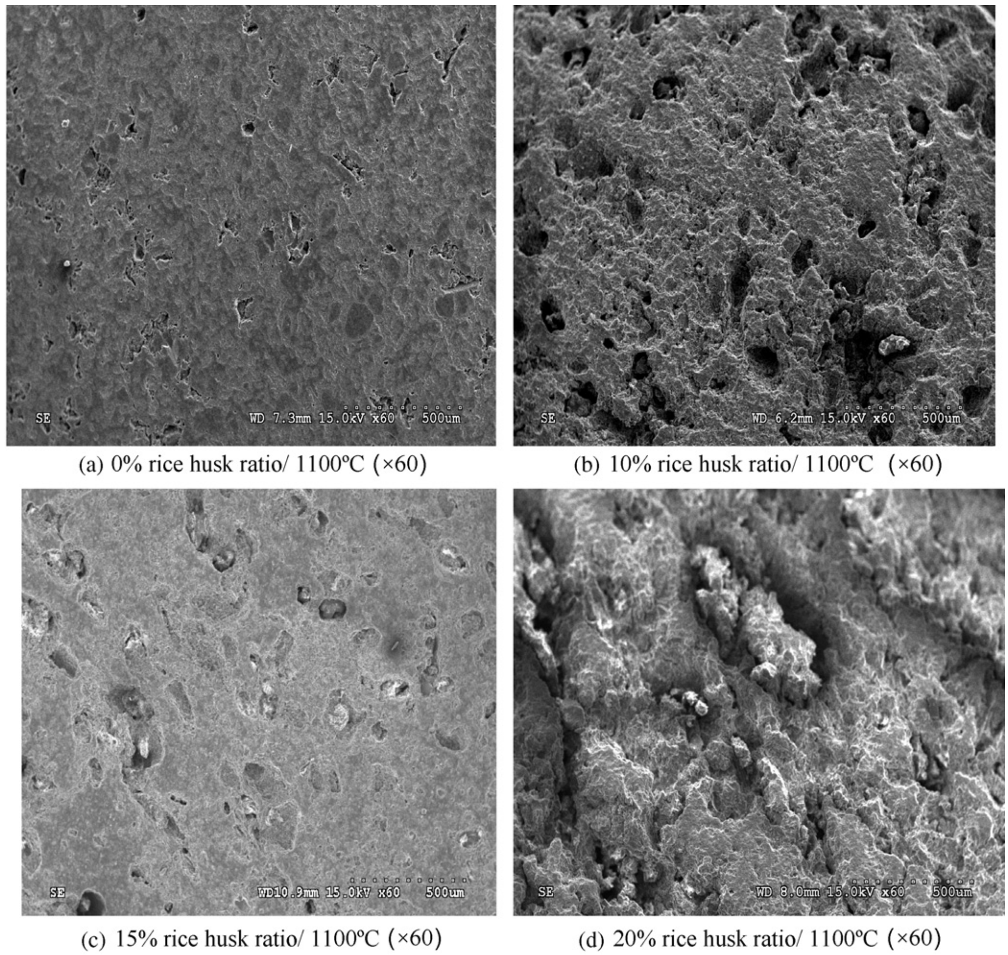

Fig. 9. Scanning electron micrograph images of specimens sintered at 1100 °C: (a) 0% rice husk ratio/1100 °C 60×, (b) 10% rice husk ratio/1100 °C 60×, (c) 15% rice husk ratio/1100 °C 60× and (d) 20% rice husk ratio/1100 °C 60×.

With respect to recycling and reusing sintered specimens, controlling shrinkage or swelling is a critical concern. In general, higher shrinkage rate represented greater densification in sintered specimens. That is, significant densification occurred, resulting in a total shrinkage in volume. The shrinkage rate of the sintered products increased dramatically at 1050 °C sintering temperature, as shown in Fig. 6. It can be concluded that sintered specimen densification occurred at 1050 °C sintering temperature.

The water absorption and compressive strength of the sintered specimens are also key factors in considering their application as construction bricks. Increasing the number of open pores in the sintered specimen implies an increase in water absorption

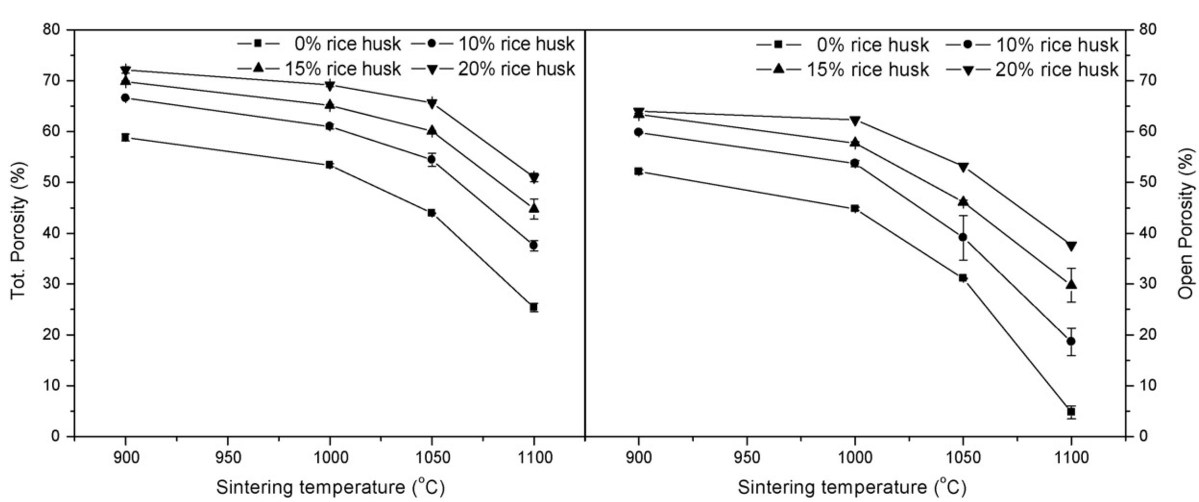

Fig. 10. Sintering temperature effect on the total and open porosity of specimens.

and decrease in bulk density. Fig. 5 shows that water absorption increases with the increase in rice husk addition ratio. At 1100 °C sintering temperature, water absorption increases from 2% to 23% as the rice husk addition ratio is increased from 0% to 20%. In samples sintered at 1100 °C with 15% rice husk addition, the water absorption of the sintered specimens was approximately 15% in compliance with the current Taiwan traditional building brick criteria. Lightweight bricks have been applied widely in the inner walls of green buildings, although they have relatively high water absorption. That is, the water absorption of lightweight bricks is an insignificant factor in considering their application. This is because the large number of open pores in sintered specimens provides good thermal insulation properties for green building applications. A contrary trend occurred between water absorption and compressive strength occurs in the sintered specimens. The compressive strength increases with decreasing water absorption. The compressive strength of the proposed sintered products complies with Taiwan's lightweight brick criteria when sintered at 1100 °C with 15% or less added rice husks. The low bulk density and relatively high compressive strength of lightweight brick were successfully manufactured from WTP sludge and rice husks.

5. Conclusions

This study examined the characteristics of sintered WTP sludge mixed with varying amounts of rice husks. These following conclusions are presented:

1. The bulk density of the proposed sintered product decreased significantly with increasing rice husk addition and decreasing sintering temperature. In the 1100 °C sintering temperature with 15% rice husk addition, the sintered specimens obtained a bulk density of less than 1.8 g/cm^3. Increasing rice husk addition definitely decreased the bulk density of sintered products due to the increased amount of open pores in the sintered products.
2. The higher compressive strength of lightweight brick sintered at 1100 °C and below 15% rice husk addition ratio complies with the relevant building brick code requirement (100 kgf/cm^2). In the case of 1000 °C, the compressive strength of the sintered products gradually decreased with increasing rice husk addition. To simultaneously enhance the bulk density and compressive strength of the proposed sintered products, further research would be necessary to study the optimum rice husk addition amount, initial pressing pressure and firing temperature profile.
3. The amount of open pores in the sintered products manufactured from WTP sludge and rice husk addition increased gradually compared to bricks made from WTP sludge alone. Due to the large amounts of open pores, sintered products have good thermal insulation properties for future green building applications.

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References

[1] Taiwan Agriculture and Food Agency (2009) http://www.afa.gov.tw/.
[2] Taiwan Water Corporation (2009) http://www.water.gov.tw/.
[3] J. Camilleri, M. Sammut, F.E. Moutesin, Utilization of pulverized fuel ash in Malta, Waste Manage. 26 (2006) 853–860.
[4] M. Campos, F. Velasco, M.A. Martinez, J.M. Torralba, Recovered slate waste as raw material for manufacturing sintered structural tiles, J. Eur. Ceram. Soc. 24 (2004) 811–819.
[5] C.R. Cheeseman, S.M. Rocha, C. Sollars, S. Bethanis, A.R. Boccaccini, Ceramic processing of incinerator bottom ash, Waste Manage. 23 (2003) 907–916.
[6] C.R. Cheeseman, G.S. Virdi, Properties and microstructure of lightweight aggregate produced from sintered sewage sludge ash, Resour. Conserv. Recycl. 45 (2005) 18–30.
[7] G.R. Xu, J.L. Zou, G.B. Li, Effect of sintering temperature on the characteristics of sludge ceramsite, J. Hazard. Mater. 150 (2008) 394–400.
[8] K.Y. Chiang, K.L. Chien, S.J. Hwang, Study on the characteristics of building bricks produced from reservoir sediment, J. Hazard. Mater. 159 (2008) 499–504.
[9] C.P. Huang, J.R. Pan, K.D. Sun, C.T. Liaw, Reuse of water treatment plant sludge and dam sediment in brick-making, Water Sci. Technol. 44 (2001) 273–277.
[10] J. Jonger, J.H. Potgieter, An evaluation of selected waste resources for utilization in ceramic materials application, J. Eur. Ceram. Soc. 25 (2005) 3145–3149.
[11] C.F. Lin, C.H. Wu, H.M. Ho, Recovery of municipal waste incineration bottom ash and water treatment sludge to water permeable pavement materials, Waste Manage. 26 (2006) 970–978.
[12] S.C. Huang, F.C. Chang, S.L. Lo, M.Y. Lee, C.F. Wang, J.D. Lin, Production of lightweight aggregates from mining residues, heavy metal sludge, and incinerator fly ash, J. Hazard. Mater. 144 (2007) 52–58.
[13] T. Mangialardi, Sintering of MSW fly ash for reuse as a concrete aggregate, J. Hazard. Mater. 87 (2001) 225–239.
[14] J.H. Tay, S.Y. Hong, K.Y. Show, C.Y. Chien, D.J. Lee, Manufacturing artificial aggregates from industrial sludge and marine clay with addition of sodium salt, Water Sci. Technol. 47 (2002) 173–178.
[15] K.S. Wang, K.Y. Chiang, J.K. Perng, C.J. Sun, The characteristics study on sintering of municipal solid waste incinerator ashes, J. Hazard. Mater. 59 (1998) 201–210.
[16] K.S. Wang, K.Y. Chiang, C.C. Tsai, K.L. Lin, The recycling of MSW incinerator bottom ash by sintering, Waste Manage. Res. 21 (2003) 318–329.
[17] H. Zhang, Y. Zhao, J. Qi, Study on use of MSWI fly ash in ceramic tile, J. Hazard. Mater. 141 (2007) 106–114.
[18] T. Basegio, F. Berutti, A. Bernardes, C.P. Bergmann, Environmental and technical aspects of the utilization of tannery sludge as a raw material for clay products, J. Eur. Ceram. Soc. 22 (2002) 2251–2259.
[19] S. Bethanis, C.R. Cheeseman, C.J. Sollars, Properties and microstructure of sintered incinerator bottom ash, Ceram. Int. 28 (2002) 881–886.
[20] K.L. Lin, K.Y. Chiang, D.F. Lin, Effect of heating temperature on the sintering characteristics of sewage sludge ash, J. Hazard. Mater. B128 (2006) 175–181.
[21] S. Veiseh, A.A. Yousefi, The use of polystyrene in lightweight brick production, Iranian Polym. J. 12 (4) (2003) 323–329.
[22] A.A. Boateng, D.A. Skeete, Incineration of rice hull for use as a cementitious material: the Guyana experience, Cement Concrete Res. 20 (1990) 795–802.
[23] D.S. Chaudhary, M.C. Jollands, Characterization of rice hull ash, J. Appl. Polym. Sci. 93 (2004) 1–8.
[24] N.W. Choi, I. Mori, Y. Ohama, Development of rice husks-plastics composites for building materials, Waste Manage. 26 (2006) 189–194.
[25] Rice Husk Ash website (2008) http://www.ricehuskash.com/.
[26] Standard Methods for the Examination of Water and Wastewater, 20th edition, American Public Health Association (APHA), Washington, DC, 1998.
[27] Taiwan Environmental Protection Administration Standard Method (NIEA R201.10T), Test method for Toxicity Characteristic Leaching Procedure (TCLP), Taiwan, 2003.
[28] Taiwan Environmental Protection Administration Standard Method (NIEA R 206.22C), Compressive strength of cylindrical concrete specimens, Taiwan, 2005.
[29] American Standard Testing and Materials (ASTM) Standard C 373-72, Standard Test Methods for Water Absorption, Bulk Density, Apparent Porosity and Apparent Specific Gravity of Fired Whiteware Products, ASTM, Philadelphia, PA, USA, 1972.
[30] American Standard Testing and Materials (ASTM) Standard C 20-00, Standard Test Methods for Apparent Porosity, Water Absorption, Apparent Specific Gravity, and Bulk Density of Burned Refractory Brick and Shapes by Boiling Water, ASTM, West Conshohocken, PA, USA, 2005.