Utilizing Sawdust and Bottom Ash for Ecological Water Purifying Materials Produced

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Abstract. The expanding of industrial sectors has generated a huge number of wastes and further polluted the environment. Sawdust (SD) is considered as residue generating from the sawing, sanding, and milling process of the furniture industry. Likewise, bottom ash (BA) is the generated waste of palm oil mill production process. It is the residue of empty fruit bunch, palm fibre, and palm shell which is fuelled for boiling water in the palm oil plant. Reutilizing these wastes for developing porous purifying water is the objective of this study. Sediment soil and brown glass have been exploited for facilitating plasticity mixtures and reducing firing temperature. Rectangular specimens are moulded by uniaxial pressing at 70 bars. Firing temperature are set up at 950 and 1050 °C. The water filtrated by tested samples is examined and compared with TIS 257-2549 standard, i.e., pH value, turbidity, total dissolved solids. The results express that combination of 40% sawdust, 10% bottom ash, 50% sediment soil, and 40% brown glass fired at 1050 °C has the potential to be water purifier.

1. Introduction
The large amounts of industrial wastes have been generated year after year as expanding of the manufacturing sector. In addition to leading the burden for disposing to manufacturers, it also pollutes the environment. Attempting to reutilize residues is highly concerned. The objective of the present study is to exploit the wastes from the wooden furniture and palm oil mill plant. Waste of the focused industries will be mentioned below.

1.1. Wooden furniture industry
Sawdust is one of by-products generating from the sawing, sanding, and milling process. Although, this residue has been utilized in many products, i.e., particleboard, clay cat litter, and fuel. Exploiting it to the other valued products is challenge for the researchers. The Center of Fuels and Energy from Biomass \cite{1} reports that 690,000 tons/year of sawdust in Thailand are unutilized. As the review of relevant studies, there are a number of studies applying saw dust in various fields. Bello et al.\cite{2} have tested about sawdust and suggested that saw dust can be used as fuel material for sterilization meat, fish and soup, etc. Chathurangani et al.\cite{3} have utilized sawdust and coconut coir fiber as noise reducing wall surface materials. They can be used as noise control and pleasing environment. Mangi et al.\cite{4} have reviewed about replacement of sawdust ash to cement in concrete which are carried out in Malaysia, Thailand, India, and Nigeria. They concluded that sawdust ash has decreased the test sample’s specimens. Ekpunobi et al.\cite{5} have developed filtering water media by utilizing sawdust, clay and diatomite fired at 850 °C. It can pass WHO limit and be used as water treatment media in the rural area.
1.2. Palm oil mill industry
The abundant of residues; empty fruit brunch, palm fiber, and palm shell, are generated from the palm oil mill process. These residues have been resupplied within the plant as boiler fuel for steaming oil palm in the production process. After burning process, they are transformed to be bottom and fly ash. Reutilizing these wastes are challenge faced by many researchers. Zarina et al. [6] have reviewed the utilization of palm oil fuel ash (POFA). They suggest that POFA has been successfully produced ash geopolymer materials and combined with the rich in alumina (Al) material to produce geopolymer with suitable strength. Munir et al. [7] have tested about POFA in concrete. The results show that the foamed concrete with 20% POFA substitution in Portland cement is applicable for non-bearing wall element based on compressive strength. Gorme et al. [8] have developed filter media for a stormwater treatment facility by exploiting bottom ash from the fired-coal power plant. The experiment found that the bottom ash media can reduce 70% of total suspended solids and more than 50% of iron, zinc, and lead from the synthetic run-off. Utama et al. [9] attempt to utilize palm oil mill fly ash (POMFA) the solid waste of palm oil industry for synthetic carbon zeolite composite. Hamzah et al. [10] are successful for utilizing the palm oil mill boiler (POMB) ashes for POME decolorization.

1.3. Water supply treatment plant
The Metropolitan Waterworks Authority (MWA) is one of the important state enterprises providing water supply to people in the metropolitan area [11]. After treatment process of water supply, a large number of sediment soil has been generated. Recycling this waste is highly concerned for the manufacturers and researchers. There are many works studying on reutilizing sediment soil or sewage sludge. Teixeira et al. [12] have studied the effect of water treatment plan sludge of ceramic materials. The results show that up to 20% sludge fired above 1000 °C can be used for manufacturing red brick and roofing tile. Plant sludge is also studied by Martínez-García et al [13]. They conclude that 5% sludge can be applied as raw material for producing bricks fired at 950 °C. Kiznievic et al. [14] have incorporated from water treatment sludge (WTS) varying from 5% to 40% in ceramic mixture with firing from 1000 °C to 1050 °C. The results show that compressive strength of the ceramic bodies is decreased as increasing of WTS. Wangrakdiskul and Neumlut [15] have utilized sediment soil in non-fired wall tiles. They suggest that 10% content of sediment soil can yield 7.51 MPa of 60 days-curing period.

1.4. Glass bottle Industry
Glass bottles have been used as container for filling various products, i.e., liquid substance, medicine, water, etc. When they are no longer useful, it is reaching the end-of-life stage and leading to waste or glass cullet. Currently, 27% of waste glass is still unrecycled [16]. Many works about utilizing waste glass have been conducted. Demir [17] has reported that a mixture up to 10% waste glass additive can be used in building brick production with the suitable firing temperature at 950 °C. Phonphuak et al [18] proposed that utilizing 10 wt.% waste glass and firing at 900 °C can yield bricks with similar strength of normal clay brick fired at 1000 °C. Wangrakdiskul [19] has proposed that the suitable content for producing wall tile fired at 950 °C consists of 30 wt% sediment soil and 60 wt% brown glass cullet. Wangrakdiskul et al. [20] have utilized glass cullet for producing greenish and greyish colored fired clay tile. They summarized that 70% green glass cullet and 30% local white clay fired at 950 °C is the optimal mixture.

The relevant researches as mentioned above, it can be stated that combination of utilizing sawdust, bottom ash, sediment soil, and glass cullet is just not proposed. Therefore, the present study aims at utilizing these residues for developing the porous filtering ceramic material.

2. Materials and method

2.1 Materials
All materials used in this study are the industrial residue in Thailand, i.e., sawdust (SD), bottom ash (BA), sediment soil (SS), and brown glass cullet (BGC). Due to having main content of silica (SiO₂), they can be used as raw materials in ceramic field. The chemical composition of them is illustrated in
table 1. They are characterized by wavelength dispersive X-Ray Fluorescence (XRF) series Bruker S8 Tiger. Note that, containing high carbonaceous matter and ignition loss of SD, it is not analyzed by XRF. Sawdust (SD) and bottom ash (BA) are employed as introducing porous bodies which derived from the furniture plant and palm oil mill industry. Sediment soil (SS) has been incorporated in the mixture for facilitating plasticity of mixture. It is from the water supply treatment process. For lowering the sintering temperature, brown glass cullet (BGC) has been used as additive material, which is derived from the glass manufacturing plant.

| Compound | % Concentration |
|----------|-----------------|
| SiO₂ | 22.36 | 60.95 | 72.1 |
| Al₂O₃ | - | 25.96 | 1.6 |
| Fe₂O₃ | 5.21 | 6.22 | 0.1 |
| K₂O | 20.2 | 1.93 | 0.2 |
| CaO | 45.54 | 0.91 | 10.6 |
| MgO | - | 1.41 | 2.4 |
| TiO₂ | - | 0.85 | 0.05 |
| MnO | - | 0.18 | - |
| P₂O₅ | - | 0.46 | - |
| Na₂O | - | 0.33 | 12.9 |
| SO₃ | - | 0.57 | 0.15 |
| Rb₂O | - | 0.02 | - |
| ZnO | - | 0.02 | - |
| ZrO₂ | - | 0.03 | - |
| Cr₂O₃ | - | 0.02 | - |

Remark: SD is not analyzed;

2.2. Methods

2.2.1. Body preparation

Mixture formulations have been constructed based on the tri-axial diagram. Four groups mixture is carried out which divided into 10 formulas of 15 samples each (n=15), as shown in table 2. The proportion of SD, and BA content is varied from 10-40%. For promoting the mixture plasticity, percentage of SS is determined at >= 50%. In addition, BGC has been employed as additive by 40% adding. All materials are prepared by dried in the oven at 200 °C for 2 h. Then, they are milled by ball mill in the laboratory for 2 h, exception of BGC which is milled for 6 h. After getting the fine particles, materials are sized by sieve no 50 mesh (295 micrometer). The mixture of conducted formulas is mixed up by dried process for 30 minutes. Before molding specimens, 10% water is added to the mixtures. Rectangular specimens with dimension 50x100x7 mm are manufactured by uniaxial pressing at 100 bars. All specimens are dried again in the oven at 200 °C for 2 h. After that, they are fired in the electric kiln by 100 °C/h at 950 and 1050 °C and soaking for 1 h. Fired samples are further investigated the properties.

2.2.2. Testing properties

Properties of fired samples are investigated consisting of physical properties, microstructure, and capability of filtering water.

- For physical properties, bending strength, water absorption, linear firing shrinkage, wt. loss and bulk density have been examined.
- For analyzing microstructure, Scanning Electron Microscope (SEM) has been employed for characterizing the specimen’s microstructure.
- For investigation the filtering water’s capabilities, the filtered water is determined pH value, turbidity, total dissolved solids, preparing with Thai Industrial Standard; TIS 257-2549.
Table 2 Mixture formulations of the experiment

| Group | Mixture | Adding | % wt SD | % wt BA | % wt SS | % wt BGC |
|-------|---------|--------|---------|---------|---------|----------|
| 1     | 1       |        | 10      | 10      | 80      | 40       |
| 2     | 2       |        | 10      | 20      | 70      | 40       |
| 3     | 3       |        | 10      | 30      | 60      | 40       |
| 4     | 4       |        | 10      | 40      | 50      | 40       |
| 5     | 5       |        | 20      | 10      | 60      | 40       |
| 6     | 6       |        | 30      | 10      | 60      | 40       |
| 7     | 7       |        | 10      | 40      | 50      | 40       |
| 8     | 8       |        | 20      | 30      | 50      | 40       |
| 9     | 9       |        | 30      | 20      | 50      | 40       |
| 10    | 10      |        | 40      | 10      | 50      | 40       |

The results of this experiment will be described in the next section.

3. Results and discussion

The results of test samples fired at 950 and 1050 °C are described the technological properties as shown in table 3.

3.1. The physical properties

3.1.1. Bending strength (BS)

Three points bending has been employed to examine the strength of fired specimens. The bending strength of samples fired at 950 °C has led to zero as increasing of SD >= 30 wt. % content or the mixture of SD and BA is 50 wt. %. Meanwhile, the samples fired at 1050 °C have decreased the bending strength as the increasing of SD or BA content. This phenomenon is the effect of carbon matter in SD and BA has been burnt during the firing process. It leads to the porous structure and lowering strength of specimens. However, firing temperature at 1050 °C has the higher bending strength than that of 950 °C. This is the result of BGC effect which induce high melting condition in ceramic bodies.

3.1.2. Water absorption (WA)

Samples have been tested water absorbed under specified conditions. They have been dried in the oven at 200 °C for 2 h and then weighing. After that, they are placed in boiling water for 4 h and left under boiled water for 24 h and weighed again. It has the converse result comparing with BS. Due to having high porous structure, absorbing water of specimens are increased.

3.1.3. Linear firing shrinkage (Sh)

It is to evaluate dimension changed in length of fired specimens. The vernier callipers with a resolution of 0.05 mm is used. The results show that % Sh has decreased as decreasing of SS and increasing of SD and BA. It has the high porous structure and leads to high water absorption. Due to higher sintering condition of firing temperature 1050 oC, it shows the higher % Sh than that of 950 oC.

3.1.4. Weight loss (WL)

During firing process, carbonaceous matter has been burnt and led to lowering weight of specimens. Firing at 950 and 1050 °C has the similar result, % WL has increased as the increasing of SD and BA. However, the higher firing temperature (1050 °C) can also induce higher WL.

3.1.5. Bulk density (Den)

Archimedes technique is employed for evaluation bulk density (Den) of test samples. Both of firing temperature, 950 and 1050 °C, show the similar result. Bulk density of each mixture is slightly different which varying from 2.11-2.29 g/ cc.
Table 3 Comparison the bending strength, water absorption, linear shrinkage, weight loss, bulk density of fired specimens fired at 950 and 1050 °C

| Group | Mixture | SD  | BA  | SS  | BGC | 950 °C | 1050 °C | 950 °C | 1050 °C | 950 °C | 1050 °C | 950 °C | 1050 °C |
|-------|---------|-----|-----|-----|-----|--------|---------|--------|---------|--------|---------|--------|---------|
|       |         |     |     |     |     | % wt   | % Adding | BS (Mpa) | % WA      | % Sh      | % WL      | Den (g/cc) |
| 1     | 1       | 10  | 10  | 80  | 40  | 4.21   | 9.05    | 35.43   | 26.99  | 7.02    | 9.29    | 17.83   | 17.81   | 2.20    | 2.29    |
|       | 2       | 20  | 10  | 70  | 40  | 1.95   | 4.75    | 48.86   | 37.13  | 7.18    | 9.53    | 20.67   | 20.34   | 2.00    | 2.25    |
| 2     | 3       | 10  | 30  | 60  | 40  | 1.39   | 2.97    | 52.62   | 46.66  | 6.93    | 8.52    | 20.77   | 22.88   | 2.26    | 2.24    |
|       | 4       | 20  | 20  | 60  | 40  | 1.16   | 3.03    | 56.34   | 51.63  | 6.95    | 7.07    | 20.01   | 21.66   | 2.22    | 2.21    |
|       | 5       | 30  | 10  | 60  | 40  | 0.00   | 3.34    | 55.49   | 54.99  | 7.06    | 8.03    | 20.31   | 21.52   | 2.38    | 2.24    |
| 4     | 6       | 10  | 40  | 50  | 40  | 0.00   | 2.63    | 56.46   | 54.93  | 7.13    | 7.64    | 23.56   | 23.84   | 2.16    | 2.22    |
|       | 7       | 20  | 30  | 50  | 40  | 0.00   | 2.57    | 55.59   | 55.86  | 6.75    | 7.04    | 24.25   | 24.52   | 2.18    | 2.24    |
|       | 8       | 30  | 20  | 50  | 40  | 0.00   | 1.86    | 56.72   | 55.69  | 6.57    | 9.38    | 24.34   | 27.34   | 2.12    | 2.21    |
|       | 9       | 40  | 10  | 50  | 40  | 0.00   | 2.05    | 60.86   | 60.78  | 6.98    | 9.77    | 28.05   | 30.24   | 2.11    | 2.18    |

Remark: BS= Bending strength, WA= Water absorption, Sh= Linear shrinkage, WL= Weight loss, Den= Bulk density

Fig. 1 SEM micrograph of specimens (a) mixture no.1 at 1000x (b) mixture no.1 at 5000x (c) mixture no.10 at 1000x (d) mixture no.10 at 5000x

3.2. Microstructure characterisation

Scanning Electron Microscope (SEM) series Hitachi SU3500 at an acceleration voltage of 10 kV with 1000x and 5000x magnification has been employed for analysing microstructure of fired specimens. Mixture no. 1 of group 1 fired at 950 °C and no.10 of group 4 fired at 1050 °C have been selected to be analysed. This is the reason of the highest bending strength fired at 950 and the lowest bending strength
fired at 1050 °C. Figure 1 has illustrated the micrograph of SEM of mixture no. 1 (950 °C) and no. 10 (1050 °C) by the magnification of 1000x and 5000x. It is obvious illustrated that microstructure of mixture no.1, see Figure 1(a) and (b), occurred various pores in the structure. However, mixture no. 10, see Figure 1(c) and (d), is also found higher various pores than that of mixture no. 1. This is the confirmation for lower bending strength of mixture no. 10 (2.05 MPa).

3.3. Capabilities for filtering water
Testing abilities of test samples for purifying water are important for this study. The procedure for testing has been classified as the following steps.

3.3.1. Water flow rate
The remained specimens after bending strength have been selected for testing. They have been cut into dimension 35x35x7 mm and assembled with acrylic pad (100x100x3 mm). The glass box in dimension 80x80x100 mm is constructed for used as the frame of the experiment. Test water has been collected from the Chaopraya river in Thailand, 500 cc water is poured in the box for each mixture specimen. The time used for filtering water is recorded. The results are shown in table 4. The best mixture has the high flow rate is no. 10 fired at 1050 °C, which is better than the capability of mixture fired at 950 °C. It means that mixture no. 10 has the high porous structure consistent with high water absorption (60.78%). Note that, the highest flow rate is 170.6 cc/h filtered by specimen with surface area of 8,576 mm$^3$ or 8.6 cm$^3$. If the user requires to increase the flow rate, increasing specimens’ surface area can be done. The amount of 19.8 liter/h can be attained with increasing surface area of specimen to 1000 cm$^3$.

### Table 4 Water filtering flow rate, and properties of filtered water (PH, Turbidity, and TDS)

| Group | Mixture | Flow rate (cc/h) | PH  | Turbidity (NTU) | TDS (PPM) |
|-------|---------|-----------------|-----|-----------------|-----------|
|       |         | 950 °C          | 1050 °C | 950 °C | 1050 °C | 950 °C | 1050 °C |
| 1     | 1       | 62              | 58.5 | 7    | 7    | 4    | 4    | 236  | 246  |
| 2     | 2       | 64              | 60.6 | 7    | 7    | 4    | 4    | 196  | 206  |
| 3     | 3       | 67              | 61.3 | 7    | 7    | 4    | 4    | 174  | 193  |
| 4     | 4       | 70              | 67.8 | 7    | 7    | 4    | 4    | 167  | 191  |
|       | 5       | 72              | 70   | 7    | 7    | 4    | 4    | 147  | 168  |
|       | 6       | -               | 87.7 | 7    | 7    | 4    | 4    | 159  |       |
| 7     | 7       | -               | 119.6 | -    | 7    | 4    | 4    | 150  |       |
| 8     | 8       | -               | 151.5 | -    | 7    | 4    | 4    | 141  |       |
| 9     | 9       | -               | 166.7 | -    | 7    | 4    | 4    | 138  |       |
| 10    | 10      | -               | 170.6 | -    | 7    | 4    | 4    | 135  |       |

Remark: Mixture no. 6-10 is unable to be tested as low BS and soft structure.

3.3.2. Potential of Hydrogen ion (PH)
It is the indicator for measuring the condition of acidic/basic water which ranged from 0 – 14. In this study, litmus paper is used to measure the filtered water and compare the color of paper with the PH scale. All mixture formulas show the value of PH= 7. It means that filtered water is neutral.

3.3.3. Turbidity
Measuring the turbidity of water is intended to determine the amount of suspended material in the liquid by detecting the degree of a transparent liquid scatters light. As shown in table 3, all filtered water has the same value of turbidity= 4 NTU (Nephelometric Turbidity Units).
3.3.4. Total Dissolved Solids (TDS)

It is to measure the total dissolved solids which represented in the inorganic and organic substances in test liquid in molecular, ionized, or colloidal sol suspended form. In this study, TDS of filtered water from mixture no.1 fired at 950 °C has the highest concentrations of 263 parts per million (ppm). The lowest TDS of the filtered water is 135 ppm from mixture no. 10 (1050 °C).

3.4. Comparison filtered water properties with TIS 257-2549

TIS 257-2549 is the standard of Thailand setting up for drinking water regulation. It is shown in table 5. When comparing with the result of all mixture in table 4, it is found that all formulas can pass the requirement of TIS 257-2549. However, due to the high porous structure of formula no.10 (1050 °C), it has the highest flow rate of water (170.6 mm/h). Therefore, it is proposed for developing the filtering water material.

| PH     | Turbidity (NTU) | TDS (ppm) |
|--------|-----------------|-----------|
| TIS 257-2549 | 6.5-8.5 | 5 | < 500 |

4. Conclusion

As the results reported in the previous section, it can be summarized that utilizing industrial residues; sawdust (SD), bottom ash (BA), sediment soil (SS) and brown glass cullet (BGC) for developing filtering water media is possible. The optimal percentage consists of 40% sawdust, 10% bottom ash, 50% sediment soil, and adding 40% brown glass fired at 1050°C. Although all mixture fired at both temperatures can achieve the criteria of TIS 257-2549, mixture 10 (1050 °C) is suggested with the reason of its high flow rate of filtering water. For increasing the flow rate, increased surface area of specimens should be further investigated. Finally, in addition to developing the eco-friendly water filtering media, the benefit of this study can also alleviate the burden of the manufacturers for disposing their residues.

5. References

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Acknowledgments

The authors would like to thank anonymous persons for supporting this work and the studied company for cooperating of the experiment. This research was funded by the Faculty of Engineering, King Mongkut’s University of Technology North Bangkok. Contract no. ENG-63-69.