



The Use of Dredged Sediment from the Watsongpeenong Canal with Paper Mill Residue to Produce Facing Bricks

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Abstract

The potential to use dredged sediment from the Watsongpeenong Canal and paper mill residue as the primary raw materials for producing facing bricks was studied in the laboratory. Dredged sediment and paper mill residue were chemically, mineralogically, and thermally characterized using X-ray fluorescence (XRF) and X-ray diffraction (XRD). To evaluate the effects of the contents of the paper mill residue on pore-forming, large amounts of paper mill residue, ranging from 5 to 7% by mass, were blended with dredged sediments and fired at 700°C. The physical-mechanical properties, including dimensions and tolerances, wryness, deviation of the right angle, water absorption, compressive strength, stain, hole, rails, and cracks, as well as the microstructural properties of the facing bricks, were investigated. In addition, the heavy metals (Mn, Pb, Cd, and Cr) in the facing bricks were identified. The results indicated that the dimensions and tolerance, wryness, deviation from the right angle, water absorption, compressive strength, holes, and rails of the facing bricks with 5% and 7% wt. paper mill residue were compliant with the requirements of the TIS 168-2546 standard. For stains and cracks, no batches of the facing bricks complied with the standard. Facing bricks made from 93% dredged sediment and 7% paper mill residue (93D+7P) obtained the highest compressive strength, with a value of 23.66 MPa. Therefore, dredged sediment and paper mill residue can be considered as suitable for use as primary raw materials in the production of facing bricks.

Keywords: Dredged sediments; Paper mill residues; Facing bricks

Introduction

One of the main goals of sustainable solid waste management is to maximize the ability to recycle and reuse materials. In Thailand, due to rapid population growth and urbanization, the volume of bricks and sediment produced has increased dramatically in recent years, with approximately 100 million tons of dredged sediment generated worldwide every year. River sediment is derived from soil erosion and human activities. These sediments are excavated and placed in designated disposal areas near canals or rivers, leading to visual pollution. Consequently, these sediments need to be disposed in an environmentally safe manner. Preserving natural resources is a matter of sustainable development to ensure sufficient resources for future generations. The reuse of sediment as a partial replacement for other natural resources in construction activities results in reduced demand for extraction of natural raw materials, leading to savings in energy and resources.

Mezencevova et al. [1] found that the average clay particle content in dredged sediment is 47%, which is higher than that found in natural clay soil (40%). The composition and continuous availability of sediment indicates its suitability as a major component in brick production. Many studies have examined the use of river and marine sediment from lakes, dams, and sewage for brick-making [2-8]. In an industrial-scale experiment Hamer and Karius [3] showed that 50-wt% of dredged sediment from Bremen harbour in Germany can be used to produce bricks without a hazardous environmental impact.

Paper mill industrial works produce high amounts of residue, and these firms typically lack a management program to recycle the residue efficiently. Raut et al. [9] found that paper mill residue (which is rich in silicon, with levels of approximately 60.57%) could be used as a raw material in brick production.

These results indicate that paper mill residue-bricks obtained from a mixture of paper mill residue, rice husk ash and cement are light and possess a compressive strength that falls within the requirements of Indian Standards.

Facing bricks are solid masonry units mostly used for indoor and outdoor decoration. Traditionally, facing bricks are made from clay or similar naturally occurring earthy substances and subjected to a heat treatment at elevated temperatures via the sintering process. These components normally contain 48–70% silica by weight, 8–25% alumina by weight, and 4.5–31% fluxing agents (K_2O , Na_2O , and CaO) by weight.

The main objective of this study was to investigate the appropriate mixing proportions using Watsongpeenong Canal-dredged sediment and paper mill residue for production of facing bricks. Physical-mechanical properties and the microstructures of facing bricks produced from Watsongpeenong Canal-dredged sediment and recycled paper mills residue were analyzed to determine optimal mixing proportions.

Materials and methods

1) Characterization of dredged sediment and paper mill residue

Dredged sediment was obtained from the Watsongpeenong Canal, located in the Sam Khok District, Pathum Thani Province, Thailand ($14^\circ 5.278'N$ $100^\circ 32.728'E$). The canal is 1.7 km in length and flows into the Chao Phraya River. Paper mill residue was obtained from the Thai Paper Co., Ltd. As the collected dredged sediment had agglomerated, it was therefore ground using a grinding machine (TBSN-330). A particle-size distribution test was carried out for the dredged sediment and paper mill residue using a sieve size analysis (Retsch, AS 200 digit).

The chemical characterizations of the dredged sediment and paper mill residue were determined by X-ray fluorescence analysis (XRF,

Bruker model, S8 Tiger). Crystalline minerals were identified using X-ray diffraction (XRD, Bruker AXS Model, D8-Discover).

2) Preparation of sediment specimen and sintering operation procedure

In this study, to evaluate the effect of dredged sediment from the canal for production of facing bricks, three different proportions of dredged sediment were added to paper mill residue bodies: 100% dredged sediment and 0% paper mill residue; 95% dredged sediment and 5% paper mill residue; and 93% dredged sediment and 7% paper mill residue (% by weight) on a dry basis using a mixer machine (T.M.C. HYDRAULIC PRESSES No.1009). The sieved sediments and paper mill residues were blended to produce homogenous mixtures using attrition milling, and water content was adjusted to 20% by mass to achieve adequate plasticity. The moist mixtures were molded under 76 Kgf/cm² of pressure using a hydraulic press to produce square-shaped specimens (40 mm x 65 mm x 125 mm). The shaped specimens were dried naturally for 24 hours. Next, using a tunnel kiln, dried bricks were loaded onto a kiln car with dwell at 700°C for 4–5 days, but some variation occurred depending on production schedules.

3) Characterization of fired facing bricks

Dimension and tolerance, general appearance, wryness, deviation from the right angle, stain, hole, rail, and cracks were determined in terms of Thai Industrial Standard 168-2546 and 243-2520 test methods [10-11]. For the water absorption test, the specimens were dried in an oven at 110°C for 24 hours, then allowed to air-cool until they reached constant weight (dry weight, W_d). Then, the specimens were immersed in water for 24 hours at room temperature (wet weight, W_w). Water absorption was calculated using the formula $[(W_w - W_d) / W_d] \times 100$. The compressive strength was

determined using a compression machine (Amsler 20 ton) on test samples of full-brick size (6.5 x 12.5 x 4.0 cm³). The micro-structures of the sintered specimens were examined using scanning electron microscopy (SEM, JSM-6400). The crystalline phases of the facing bricks were also identified via X-ray diffraction (XRD, Bruker D8) analysis.

Results and Discussion

1) Characterization of raw materials

Chemical composition of the raw materials in oxide form is presented in Table 1. SiO₂ is the predominant oxide in the dredged sediment, followed by Al₂O₃, Fe₂O₃, K₂O, P₂O₅, MgO, and CaO. A significant amount of Fe₂O₃ (4.53%) in the clay contributes to the reddish color of the fired bricks. Paper mill residue exhibits a typical composition primarily constituted of CaO, followed by SiO₂, Al₂O₃, Fe₂O₃, K₂O, P₂O₅, and MgO.

The concentration of heavy metals in the dredged sediment and paper mill residue is shown in Table 1. The results indicate that the amounts of heavy metals in the raw materials are below the thresholds prescribed by the Soil Quality Standard of Pollution Control Department [12]. Thus, dredged sediment and paper mill residue can be used as raw materials for producing facing bricks without concern over toxicity.

Figures 1 (a) and (b) present the XRD patterns of dredged sediment and paper mill residue. The results show that quartz (SiO₂) is the main mineral phase of dredged sediment, followed by montmorillonite (Na,Ca)_{0.3}(Al,Mg)₂Si₄O₁₀(OH)₂·nH₂O and greenalite (Fe₃Si₂O₅(OH)₄, respectively. X-ray diffraction analyses were also performed to identify the amorphous or crystalline phase of paper mill residue. As shown in Figure 1 (b), the intense broad peak observed for paper mill residue samples indicates the amorphous nature of the silica content [9].

Table 1 Chemical compositions of dredged sediment and paper mill residue

Properties (%)	Dredged sediments	Paper mill residues	Heavy metals standard (%) (PCD, 2004)*
SiO ₂	43.5	0.038	
Al ₂ O ₃	15.5	0.01	
Fe ₂ O ₃	4.53	>0.01	
P ₂ O ₅	0.10	-	
CaO	0.98	0.12	
K ₂ O	-	-	
TiO ₂	0.65	-	
MnO	0.06	-	0.18
Pb	-	-	0.04
Cd	-	-	>0.01
Cu	-	0.09	-

Note: * Soil quality standards for residential and agricultural use (PCD, 2004)

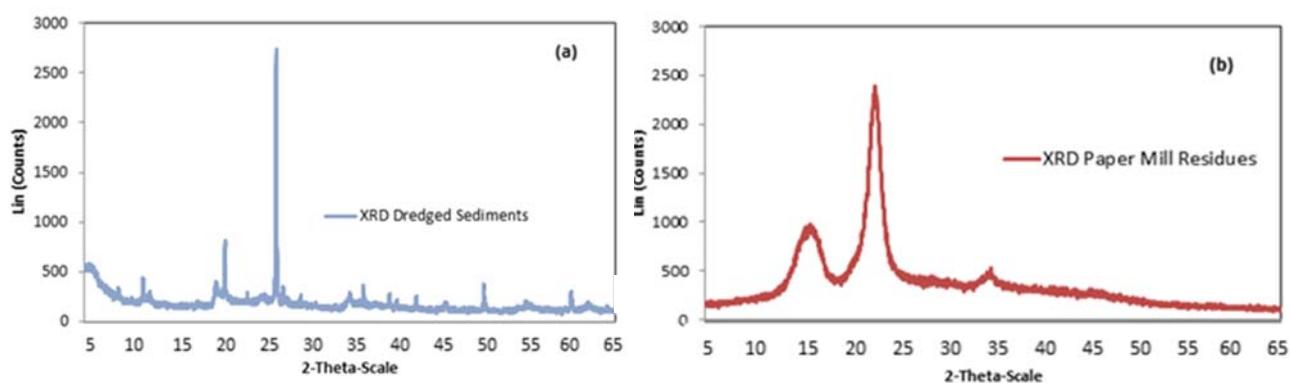


Figure 1 X-ray diffraction patterns of (a) dredged sediment and (b) paper mill residue.

2) Characterization of fired facing bricks

2.1) Physical-mechanical properties

The dimensions and tolerance of fired bricks were analyzed using three approaches. First, the width of the fired bricks, compared with standard bricks, was 125 ± 2.5 mm. Second, the length of the fired bricks, compared with standard bricks, was 65 ± 2.5 mm. Finally, the height of the fired bricks, compared with standard bricks, was 40 ± 2.5 mm. The standards of wryness and deviation from the right angle should be less than 2.5 mm and 3.0 mm, respectively. The results of dimension and tolerance, wryness, and deviation from the angle showed that fired facing bricks made from dredged sediment and paper mill residue satisfied the requirements of TIS168-2546 [10].

The general appearance of the facing bricks is shown in Figure 2. The results indicate that all facing bricks with 0% paper mill residue (100% dredged sediment) were broken, but no cracks or broken pieces were found on facing bricks produced with 5% and 7% paper mill residue.

Staining of the fired bricks was observed in both sample series, as shown in Figure 3. Staining was due to ionic compounds resulting from the neutralization reaction of acids and bases in the bricks when water was present as a solvent. Water-soluble salts led to the formation of a white stain during drying. Stains could become permanently fixed during drying and adversely affect the aesthetic appearance of the bricks [1]; thus, fired facing bricks with 5%

and 7% paper mill residue do not meet the stain requirements for good quality facing bricks. As a result of capillary action in actual conditions, water-soluble salts migrate to the inside of porous mineral materials and then crystallize in the pores during the drying stage [11]. The porosity and structure of the materials play an important role in salt crystallization [11-12]. Reducing the number of small-diameter pores will decrease salt crystallization causing less staining.

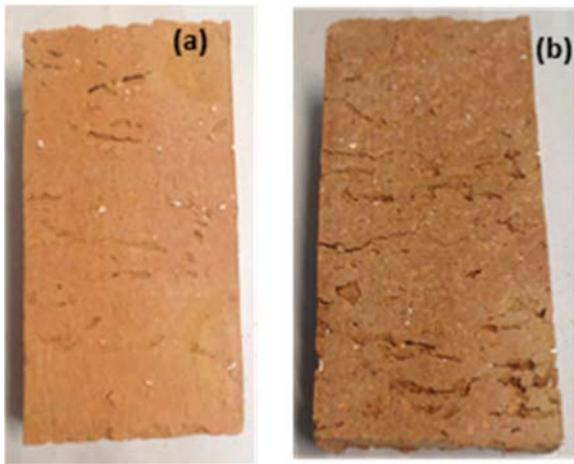


Figure 2 General appearance of facing bricks: (a) facing bricks with 5% paper mill residue and (b) facing bricks with 7% paper mill residue.

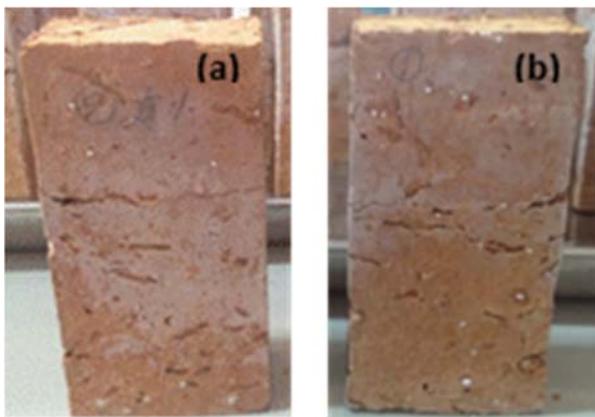


Figure 3 Stain on: (a) facing bricks with 5% paper mill residue and (b) facing bricks with 7% paper mill residue.

Holes, rails, and cracks are crucial identity index elements of facing bricks. As shown in

Figure 4, according to TIS168-2546 [10], for good quality facing bricks, the fired bricks' net cross-section area must be greater than 75% of the gross cross-section area. In the present study, the net cross-section area of fired facing bricks with 5% and 7% paper mill residue were 98.30% and 94.56%, respectively. In addition, the rails and cracks observed in fired facing bricks did not exceed Thai standards. Thus, fired bricks with 5% and 7% paper mill residue meet the hole, rail, and crack requirements for good quality bricks.

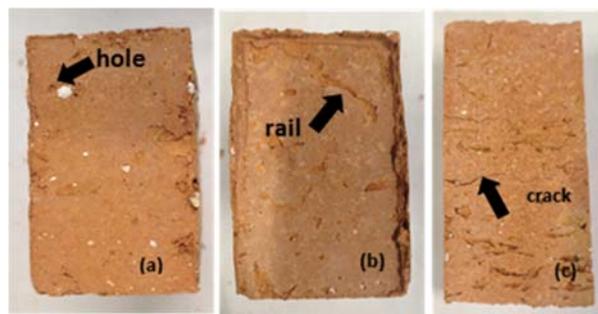


Figure 4 (a) hole (b) rail and (c) crack.

Water absorption is an effective index for evaluating the quality and density of building bricks. Water absorption is based on the amount of open pores in sintered specimens. As the results in Figure 5 show, the water absorption values of fired facing bricks with 5% and 7% paper mill residue were 17.25% and 19.33%, respectively, which is below the maximum 22% stipulated by TIS168-2546 [10]. Thus, both sample series of fired facing bricks satisfy the TIS standard.

Compressive strength is an important factor when using recycled products as construction materials. According to TIS168-2546 [10], the compressive strength of good quality bricks should be higher than 17 MPa. In Figure 6, the compressive strength of fired facing bricks with 5% and 7% paper mill residue was measured at 21.84 MPa and 23.66 MPa, respectively, which indicates compliance with Thailand's standards for facing brick products.

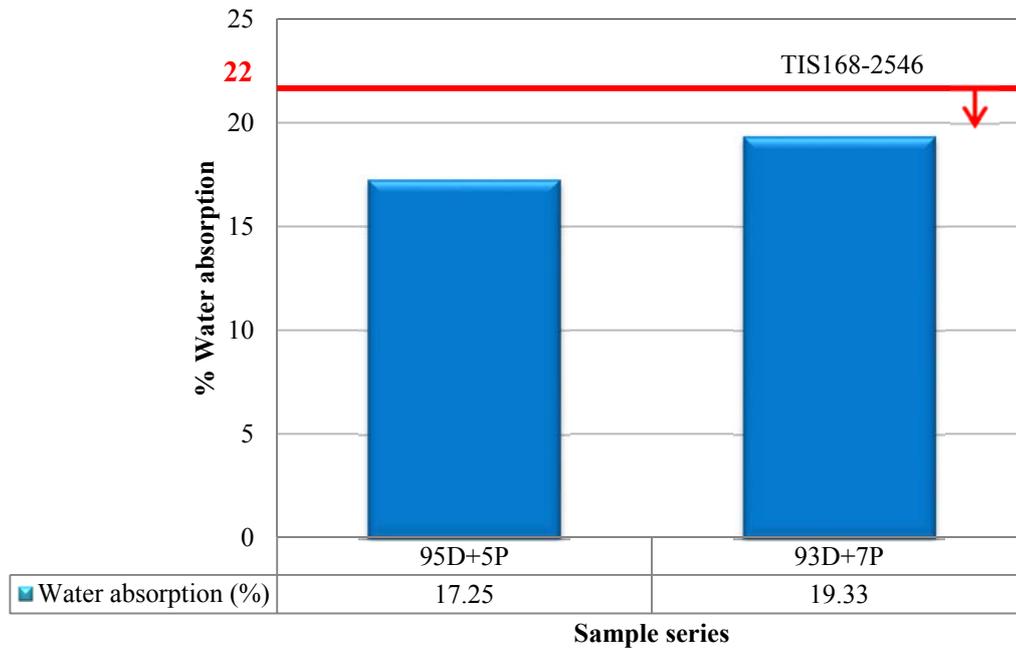


Figure 5 Water absorption of facing bricks with 5% and 7% paper mill residue (D: dredged sediment, P: paper mill residue).

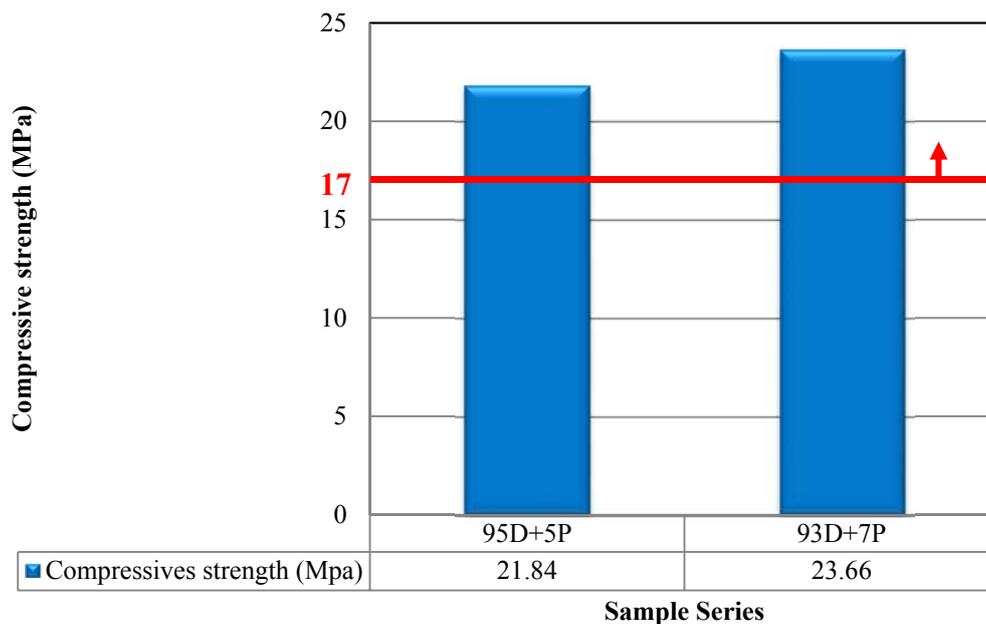


Figure 6 Compressive strength of facing bricks with 5% and 7% paper mill residue (D: dredged sediment, P: paper mill residue).

2.2) Micro-structure and phase analysis

Figures 7 (a), (b), and (c) present the SEM micrographs of facing bricks with 0%, 5%, and 7% paper mill residue, respectively. As shown in Figure 7 (b), macro-pores and smaller particles were observed. Facing bricks with 7% paper mill residue showed the presence of a

fibrous structure. The organic matter content of the bricks decreased with decreasing proportion of dredged sediment. Therefore, as shown in Figure 7 (b), the macro-pores are transformed into an arrangement of smaller particles. In addition, the porosity of facing bricks is related to water absorption and compressive strength.

Greater levels of porosity lead to decreased compressive strength and increased water absorption [9].

The XRD patterns of fired bricks are presented in Figure 8; quartz (SiO_2) is the main component, and traces of anhydrite ($\text{Ca}(\text{SO}_4)$), microcline maximum ($\text{K}(\text{Si}_3\text{Al})\text{O}_8$), and muscovite 2M1 ($\text{KA}_3\text{Si}_3\text{O}_{10}(\text{OH})_2$) are also detected in fired facing bricks. Fired facing bricks with 5% and 7% paper mill residue revealed other peaks of magnetite (Fe_3O_4).

2.3) Environmental impact

Leaching of heavy metals represents the major negative environmental impact of fired bricks containing urban river sediment. Table 2 shows the presence of Mn, Pb, Cd, and Cr in specimens. The results indicate that the concentrations of these heavy metals were below the thresholds prescribed in PCD [13] regulation limits (Mn 1800 ppm, Pb 400 ppm, Cd 37 ppm, and Cr 300 ppm).

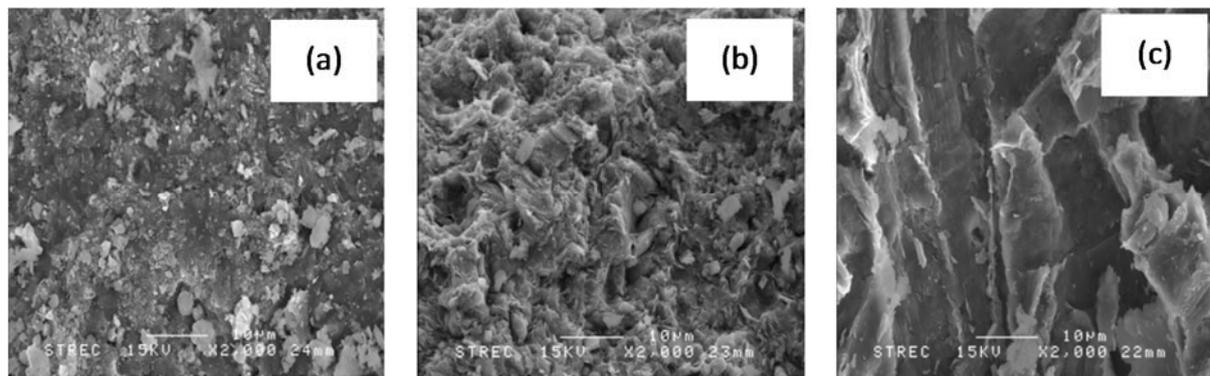


Figure 7 SEM micrographs of the fired bricks: (a) 0% paper mill residue, (b) 5% paper mill residue, and (c) 7% paper mill residue

Table 2 The concentrations of heavy metals (ppm) in fired facing bricks

Properties	Facing bricks without paper mill residue	Facing bricks with 5% paper mill residue	Facing bricks with 7% paper mill residue	Heavy Metals standard (PCD, 2004)*
MnO	913	934	901	Mn 1800
PbO		32.60	32.4	Pb 400
Cd		-	-	Cd 37
Cr_2O_3	128	132	107	Cr 300
CuO	68.30	69.70	69.10	
ZnO	152	157	155	

* Soil quality standards for residential and agricultural use (PCD, 2004).

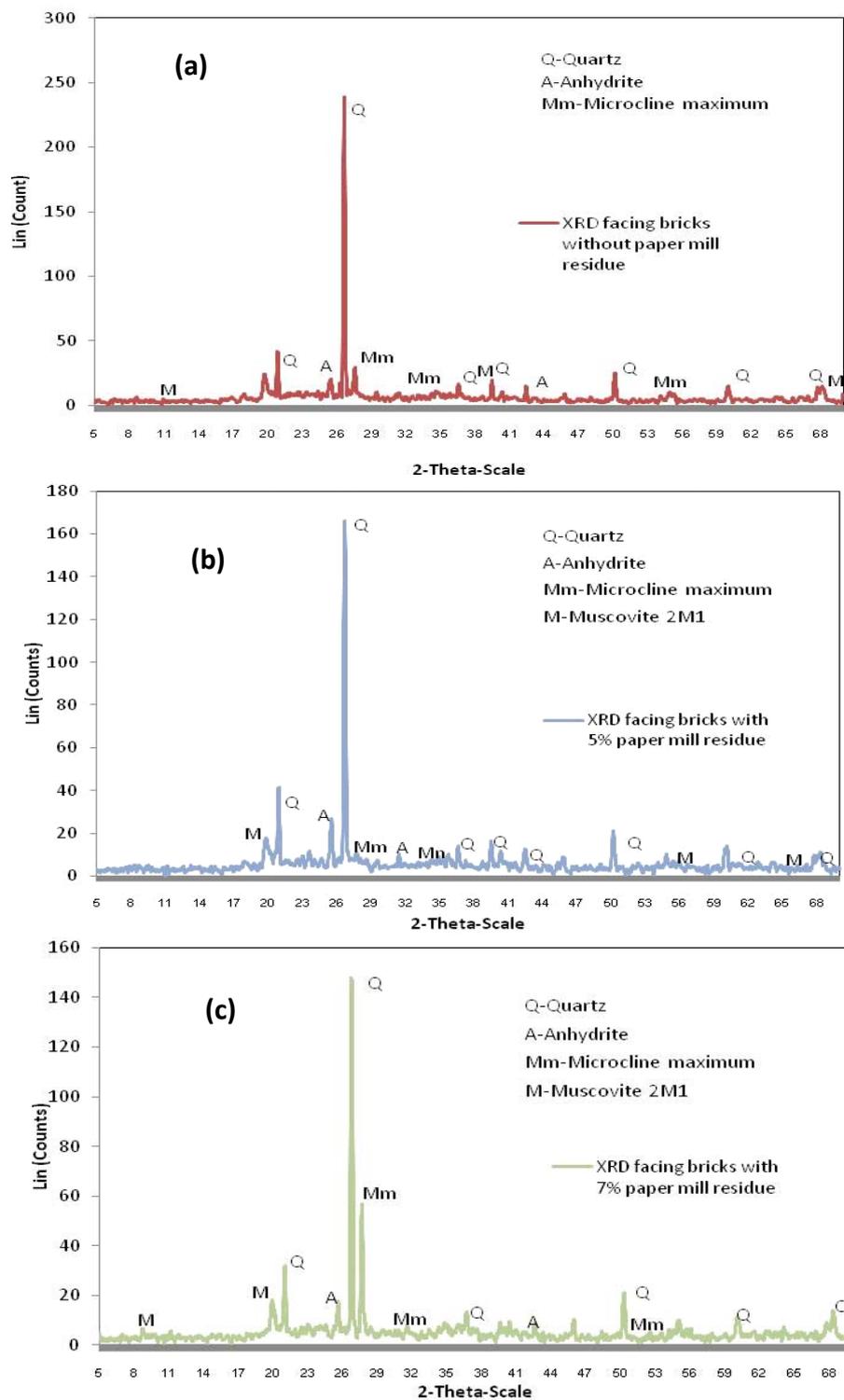


Figure 8 X-ray diffraction patterns of: (a) facing bricks without paper mill residue, (b) facing bricks with 5% paper mill residue, (c) facing bricks with 7% paper mill residue.

Conclusions

This study investigated the properties of dredged sediment and paper mill residue used for production of facing bricks. The results indicate that dredged sediment from the Watsongpeenong Canal and paper mill residue can be used as raw materials to produce facing bricks that comply with the requirements of TIS168-2546. The following conclusions can be drawn:

1) Dredged sediment and paper mill residue can be used as raw materials for facing brick production. Adding 5% and 7% wt. paper mill residue will increase the compressive strength of the bricks to higher than 17 MPa, which is the TIS 168-2546 standard.

2) The results showed that the dimensions and tolerance, wryness, deviation from the right angle, water absorption, compressive strength, holes, and rails of the facing bricks with 5% and 7% wt. paper mill residue were compliant with the requirements of the TIS 168-2546 standard. However, for stains and cracks, no batches of the facing bricks were compliant with the standard.

3) Facing brick made from 93% dredged sediment and 7% paper mill residue (93D+7P) obtained the highest compressive strength, with a value of 23.66 MPa.

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