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Utilization of Bagasse Ash in Interlocking Block Production

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Abstract

In the present work, the interlocking blocks was modified by partial substitution of lateritic soil (LS) with bagasse ash (BA). The effect of ordinary Portland cement (OPC) to LS ratio of 1:3 1:5 1:7, 1:9 and 10, 15 and 20 wt.% of BA content on the engineering properties of interlocking blocks was investigated. The chemical and physical properties of LS and BA were determined by X-ray fluorescence spectrometer, sieve analyzer, and scanning electron microscope. The engineering properties of modified interlocking blocks were compared with interlocking blocks without replacement of BA. The results show that BA was a porous material with high water adsorption. The adding BA to interlocking blocks decreased compressive strength, dry density values and lead to high void within interlocking blocks structure. The interlocking blocks at OPC:LS ratio of 1:5 with 15 wt.% of BA were perfectly suitable for inside and outside building construction.

Keywords: Lateritic soil, Bagasse ash, Interlocking blocks, compressive strength

1. Introduction

Sugarcane, as raw material for sugar production, is an important agricultural economics in Thailand. It is particularly in Kanchanaburi and Ratchaburi provinces having approximately 8-10 factories with each factory producing sugar more than 10,000 tons per year. Alarge amount of sugarcane waste known as bagasse is mostly used as fuel for steam generator (boiler) in the sugar industry, resulting in a lot of bagasse ash (BA). At present, BA is dumped in landfill, or agriculturist may bring BA to adjustment of agricultural land. BA dust has an air pollution and human health in factory and surrounding communities. Nevertheless, the chemical compositions of BA consist of 60-70 wt.% of SiO_2+Al_2O_3+Fe_2O_3, leading to using BA as partial substitution for ordinary portland cement (OPC) in concrete manufacturing (Loh, *et.al.*, 2013).

Interlocking blocks are an interesting cementitious and construction materials. They are continuously developed thanks to easy production process, production cost reduction and use of local raw materials, for example, fine lateritic soil, crushed dust and sand. Interlocking blocks were use to build wall, water tank and decorate garden, in addition it easy produce and using nature materials. The OPC, lateritic soil (LS) and small gravel were main composition materials for producing interlocking blocks.

The LS occur weathering of laterite rock that is as fine aggregate in interlocking block (Ali, *et.al.*, 2012 and Carlesso, *et. al.*, 2012).

The lateritic soil (LS) is major composition in interlocking blocks production. Interlocking blocks can be generally varied OPC:LS ratio from 1:1 to 1:12 in order to reduce OPC content and production cost. In this work, we have focused on utilization of BA for producing interlocking blocks. The effects of OPC:LS ratio and BA content on interlocking blocks properties were studied. The compressive strength, dry density and water adsorption of modified interlocking blocks were compared to original ones.

2. Material and Methods

2.1 Raw materials

Portland cement type I (OPC) was purchased from Elephant brand of SCG Cement – Building Materials Company Limited. LS was provided from Ratchaburi Block Din Cement Factory, Ratchaburi province, Thailand. BA, as sugarcane waste from sugar manufacturing process, was gained from Ratchaburi Sugar Company Limited, Ratchaburi province, Thailand. LS and BA were sun-dried and ground by Los Angeles abrasion machine until the particle size was less than 0.85 mm (Sieve No. 40). LS and BA were analyzed with a X-ray fluorescence spectrometer (XRF). The particle size distribution was determined by sieve analyzer according to ASTM C136M-14 (ASTM C136/C136M, 2014).

2.2 Production of interlocking blocks

OPC and LS were thorough mixed in several proportions of 1:3, 1:5, 1:7, and 1:9 and then slowly added water. The optimal water content was estimated by standard compaction test following ASTM 1557-12 (ASTM 1557, 2012). After that, the mixtures were formed by compression molding machine. The obtained interlocking blocks with 10 cm height, 25 cm length and 12.5 cm wide were represented as the original interlocking blocks. These interlocking blocks were covered on wet curing for 7 days and further wrapped with plastic film for 14 and 28 days. The interlocking blocks could be modified by partial substituting BA for LS. BA was added in the interlocking blocks at 10, 15 and 20 wt.% based on the LS weight. Preparation and production of the modified interlocking blocks were performed as the original ones. All proportion of interlocking blocks shown in Table 1

Table 1. Proportion of original and modified interlocking blocks

Sample	Mix proportion (wt.% for 1000g)		
	OPC	**LS**	**BA**
1:3	250	750	-
1:3 + 10 wt.% BA	250	675	75
1:3 + 15 wt.% BA	250	638	113
1:3 + 20 wt.% BA	250	600	150
1:5	167	833	-
1:5 + 10 wt.% BA	167	750	83
1:5 + 15 wt.% BA	167	708	125
1:5 + 20 wt.% BA	167	666	167
1:7	125	875	-
1:7 + 10 wt.% BA	125	787	88
1:7 + 15 wt.% BA	125	744	131
1:7 + 20wt.% BA	125	700	175
1:9	100	900	-
1:9 + 10 wt.% BA	100	810	90
1:9 + 15 wt.% BA	100	765	135
1:9 + 20 wt.% BA	100	720	180

Table 2. Chemical compositions of LS and BA

Compound	Chemical compositions (wt.%)	
	LS	BA
SiO_2	90.49	68.60
Na_2O	0.03	1.07
K_2O	0.44	3.92
Al_2O_3	6.22	3.97
CaO	0.11	7.85
Fe_2O_3	1.25	3.16
Cl	-	0.95
P_2O_5	0.03	1.71
MgO	0.20	1.69
TiO_2	-	0.27
MnO	-	0.14
SO_3	0.04	1.44

Table 3. Physical properties of LS and BA

	LS	BA
Retained percentage (wt.%)		
No.4 (4.75 mm)	0	0
No.10 (2 mm)	2.09	0
No.40 (0.425 mm)	13.81	10.23
No.100 (0.15 mm)	74.48	20.11
No.200 (0.075 mm)	6.02	68.22
Pan	3.60	1.44
Coefficient of uniformity, C_u	2	2
Coefficient of curvature, C_c	1	1
Liquid limit, LL (%)	14.08	-
Plastic limit, PL (%)	12.36	-
Specific gravity (g/m^3)	2.78	1.56

2.3 Characterization of raw materials

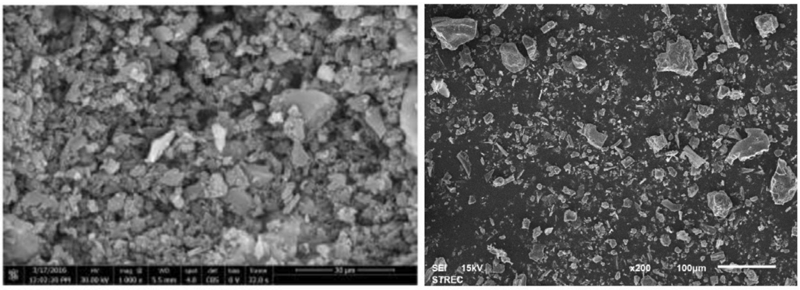
The chemical compositions of LS and BA were analyzed with a X-ray fluorescence spectrometer (XRF) equipped with Cu Kα radiation. The particle size distribution was determined by sieve analyzer according to ASTM C136M-14 (ASTM C136, 2014). Basic soil properties, including liquid limit and plastic limit, were measured by Atterberg test device. Characterization of interlocking blocks

The compressive strength of interlocking blocks was carried out using a universal testing machine (UTM) and calculated on the following ASTM C31-15 (ASTM C31, 2015). The water adsorption was tested by using three replications of each interlocking block. All samples were dried at temperature of 110 °C for 24 h and then weighed. Next the samples were soaked with water for 24 h and weighed again. Calculation of water adsorption value accorded with ASTM C642-13 (ASTM C642, 2013).

3. Results and Discussion

3.1 Characterization of raw materials

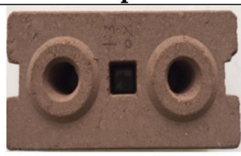
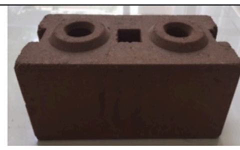
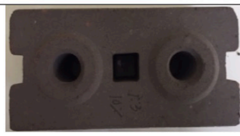
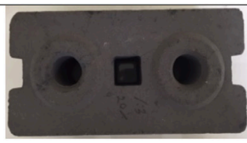
The chemical compositions of LS and BA are shown in Table 2. LS and BA had high content of SiO_2 (90.49 and 68.60 wt.%, respectively). SiO_2 and Al_2O_3 were the main components of BA. Other phases, such as Al_2O_3, Fe_2O_3, K_2O, MgO and CaO, were presented as impurities in both raw materials. Table 3 shows physical properties of LS and BA. At sieve number of 100 and 200, the retained percentage values of LS and BA were relatively high, resulting from the large particle size in



A B

Figure 1. SEM images of (A) LS and (B) BA.

Table 4. Textural properties of original and modified interlocking blocks at OPC:LS ratio of 1: 3.

BA content (%)	Top view	Side view
0		
10 wt.%BA		
15 wt.%BA		
20 wt.%BA		

these raw materials. The particle sizes of LS and BA were in range of 0.15-0.425 mm and 0.075-0.15 mm, respectively. However, the uniformity coefficients of both starting materials was 2 that indicated that were uniform soil. For curvature coefficient of both materials was 1 that shown the good distribution of materials. The atterberg limit of LA was 14.08 and 12.36 wt.% water content for liquid limit and plastic limit. LS had low plasticity index expressing as slightly sticky soil. Furthermore, LS (2.78) was higher specific gravity than BA(1.56). These results corresponded to the microstructures of LS (Figure 1 (A)) and BA (Figure 1 (B)): LS was larger particle size than BA.

3.2 Characterization of interlocking blocks

The original interlocking blocks were prepared from mixing various OPC and LS mixtures with water . With reference to Table 4, color of interlocking blocks at OPC:LS ratio of 1:3 was red, following on the LS color. Their surfaces depended on the particle size of LS. Other ratios (1:5, 1:7, 1:9 and 1:11) were similar to above results. The interlocking blocks with partial replacing LS with 10 wt.% BA were red brown to dark brown color and smooth surface, relating to small particle size of BA. Although the adding BA to interlocking blocks increased more than 10 wt.%, the interlocking blocks turned black color and easy cracking. It might be due to partial OPC and water drained away from the mixture during compression molding process. The high BA content in interlocking blocks cannot make completely molded because it was low cement binder (Uygunoğlu, 2012).

3.3 Compressive strength

Compressive strength of original interlocking blocks at various OPC:LS ratios is illustrated in Figure 2. The compressive strength of all interlocking blocks was rapidly raised in the first 7 days and then slightly increased. It was due to the cement hydration producing calcium silicate hydrate and calcium aluminate hydrate compounds having adhesive property (Loh, 2013). At the curing time of 28 days, the compressive strength value of interlocking blocks with the increased OPC:LS ratio from 1:3 to 1:9 was continuously changed from 4.29 to 1.56 MPa. The reduction of compressive strength resulted from increase of BA that resulted in reduction of cement binder (Uygunoğlu, 2012). Figure 3 shows compressive strength of modified interlocking blocks at curing time of 28 days. An increasing of BA content in interlocking blocks significantly decreased the compressive strength value because the specific gravity of BA was lower than that of LS: the 20 wt.% BA was equal to 40 w/v% one. Therefore, the OPC component did not thoroughly dispersed in interlocking blocks, total volume of all modified interlocking block mixtures was raised. It was especially OPC:LS ratio of 1:9. According to Thai Community Product Standard (TCPS 602/2547) for interlocking blocks (Minor strusture type) (Thai Community Product Standard, 2004), the compressive strength value must be at least 2.5 MPa. Thus, the suitable conditions for interlocking blocks production following the TCPS 602/2547 were using OPC:LS ratio of 1:3 + 0-20 wt.% of BA, 1:5 + 0-15 wt.% of BA and 1:7 + 0-10 wt.% of BA.

3.4 Dry density

Figure 4 demonstrates dry density of original and modified interlocking blocks at various OPC:LS ratios. The raising of OPC:LS ratio from 1:3 to 1:9 gradually decreased the dry density value of interlocking blocks from 1.73 to 1.43 g/m^3 (approximately 20 %), resulting from the specific gravity value of OPC as 3.15 g/m^3 which was higher than that of LS. The weight of interlocking blocks became lighter than the usual. Using the 10 wt.% BA as a replacement to LS reduced dry density value by 2-6 % and further lessened to 20-25 % with increased BA content to 20-30 wt.%. The reduction of dry density made increase porevolume that leaded to low compressive strength (Zareei, *et.al.*, 2018).

3.5 Water adsorption

Figure 5 illustrates water adsorption of original and modified interlocking blocks at various OPC:LS ratios. The water adsorption value of interlocking blocks raised from 181 to 246 kg/m^3 (approximately 35 %) when increased

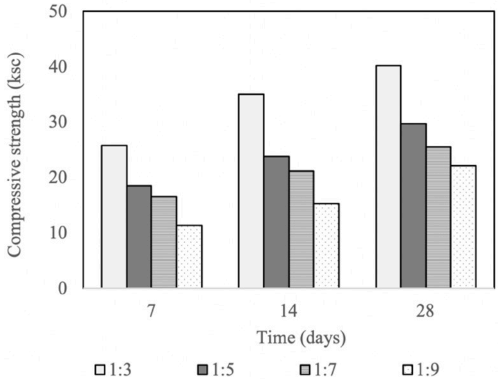


Figure 2. Compressive strength of original interlocking blocks.

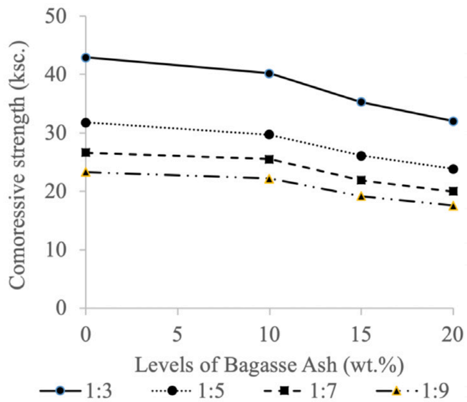


Figure 3. Compressive strength of modified interlocking blocks.

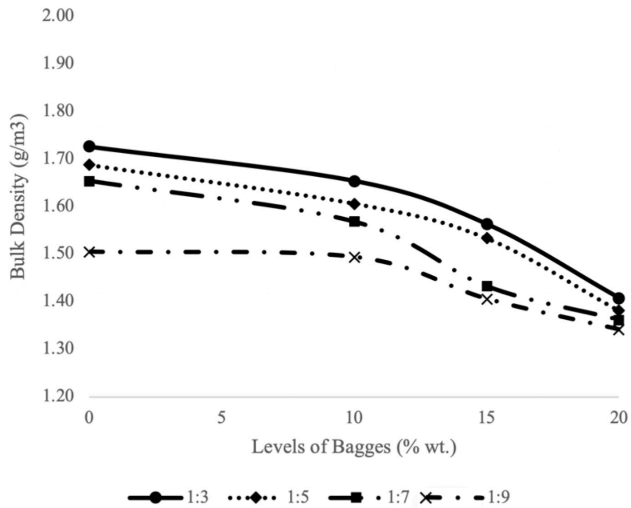


Figure 4. Bulk density of modified interlocking blocks.

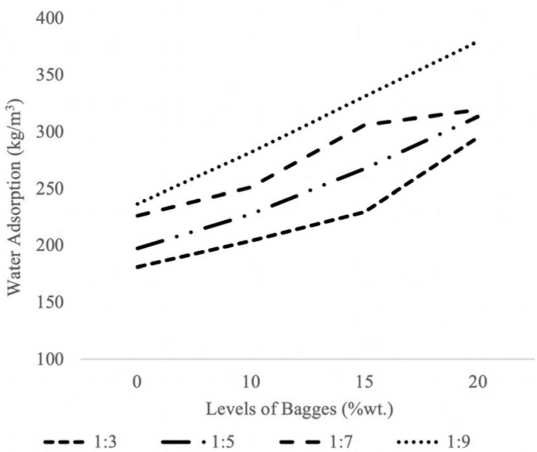


Figure 5. Water adsorption of original interlocking blocks.

OPC:LS ratio from 1:3 to 1:9. The water adsorption of LS was better than that of OPC since the hydration between OPC and water created adhesive compounds having low water adsorption capacity. The partial replacement of LS by BA improved the water adsorption efficiency of interlocking blocks. From the SEM results of starting materials (Figure 1), the LS structure composed plenty of soil beads aggregation causing interparticle void within its structure, but structure of BA was the porosity on surface. It was suggested that the porosity of BA was more than LS. The increased water adsorption of interlocking blocks associated with decreasing of dry density. The water adsorption value complied with TCPS 602/2547 for minor structure interlocking blocks, which was between 130 and 270 kg/m^3, was optimum using OPC:LS ratio of 1:3 + 0-15 wt.% of BA, 1:5 0-15 wt.% of BA and 1:7 0-10 wt.% of BA.

4. Conclusions

Engineering properties of interlocking blocks depended on OPC:LS ratio and BA content. The interlocking blocks with increased OPC:LS ratio and BA content slightly decreased compressive strength and dry density values. The water adsorption was raised, especially when using BA replaced to LS because OPC binder cannot perfectly dispersed in interlocking blocks. The interlocking blocks were molded and joined by only compressive force. BA had a lot of porosity and good water adsorption, leading to void within interlocking blocks structure. The maximum BA content and engineering properties of inter interlocking blocks passing TCPS 602/2547 (minor structure type) was found in 1:5 0-15 wt.% of BA that was the most suitable in creation of interlocking blocks for indoor and outdoor construction.

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