CHAPTER 5

RESULTS AND DISCUSSION (PART II): THE PHYSICAL AND MECHANICAL PROPERTIES AND MICROSTRUCTURE OF FIRED TEST BRIQUETTES

In this chapter, the results of the comparison between pure Hang Dong clay and Hang Dong clay mixed with different proportions of charcoal particles: 0, 2.5, 5.0, 7.5 and 10% by weight were presented. Three sizes of charcoal particles were: size 1 (2 - 3 mm.), size 2 (1 - 2 mm.) and size 3 (less than 0.5 mm.). Then, each size of charcoal particle was mixed with Hang Dong clay and molded into test briquettes. The test briquettes were grouped into 2 groups: the control group without any charcoal addition as reference and the experimental group with charcoal addition. The experimental group was divided into 3 subgroups of test briquettes added with 3 different sizes and 4 different percentages of charcoal addition: 2.5%, 5.0%, 7.5% and 10%. In other words, subgroup 1 was added with different percentages of charcoal particles size (1): 2.5% to 10 %, subgroup 2 with those of size (2): 2.5% to 10%, and subgroup 3 with those of size (3): 2.5% to 10%. The results are shown in Tables 5.1-5.4 and Figures. 5.1 – 5.4.

Table 5.1 The physical and mechanical properties of test briquettes after being fired at 900 °C.

Test briquette code. HDC+Charcoal size	Firing shrinkage (%)	Apparent porosity (%)	Water absorption (%)	Bulk density (g/cm^3)	Apparent density (g/cm^3)	Compressive strength (kg/cm^2)
HDC 100 %	2.00	31.16	17.38	1.79	2.46	97.63
1 / 2.5 %	2.00	36.44	22.87	1.57	2.14	63.49
1 / 5.0 %	1.58	40.57	29.53	1.45	1.93	45.24
1 / 7.5 %	0.63	49.31	35.75	1.35	1.87	25.55
1 / 10.0 %	1.47	57.86	41.40	1.14	1.68	19.36
2 / 2.5 %	2.00	34.17	20.60	1.60	2.15	60.17
2 / 5.0 %	0.53	39.85	23.89	1.49	2.09	23.30
2 / 7.5 %	0.42	48.72	30.56	1.44	1.96	23.67
2 / 10.0 %	0.42	52.19	37.83	1.32	1.90	18.91
3 / 2.5 %	2.26	31.56	18.90	1.65	2.22	66.96
3 / 5.0 %	0.74	35.68	20.60	1.55	2.19	35.58
3 / 7.5 %	0.53	41.09	25.16	1.50	2.12	32.27
3 / 10.0 %	0.95	47.69	35.98	1.48	2.04	31.77

HDC = Hang Dong clay, 1, 2 and 3 = particle sizes, 2.5, 5.0, 7.5 and 10 % wt. = percentages of charcoal addition.

Table 5.2 The physical and mechanical properties of test briquettes after being fired at 950 ^{o}C.

Test briquette code. HDC+Charcoal size	Firing shrinkage (%)	Apparent porosity (%)	Water absorption (%)	Bulk density (g/cm^3)	Apparent density (g/cm^3)	Compressive strength (kg/cm^2)
HDC 100 %	2.00	28.96	17.18	1.80	2.58	152.66
1 / 2.5 %	2.10	35.34	21.84	1.61	2.19	77.75
1 / 5.0 %	2.21	38.27	27.80	1.50	2.07	77.43
1 / 7.5 %	2.17	47.18	34.75	1.37	1.95	47.66
1 / 10.0 %	2.05	53.93	40.73	1.17	1.87	29.00
2 / 2.5 %	2.16	33.78	19.21	1.65	2.24	106.97
2 / 5.0 %	2.10	35.50	22.58	1.58	2.14	64.74
2 / 7.5 %	2.04	45.96	29.89	1.52	2.01	41.90
2 / 10.0 %	2.00	48.76	35.67	1.42	1.91	37.81
3 / 2.5 %	1.80	31.45	18.27	1.68	2.30	143.45
3 / 5.0 %	1.70	35.14	19.98	1.63	2.24	90.57
3 / 7.5 %	1.42	38.93	24.34	1.57	2.13	85.70
3 / 10.0 %	1.80	46.85	33.21	1.48	2.07	78.59

HDC = Hang Dong clay, 1, 2 and 3 = particle sizes, 2.5, 5.0, 7.5 and 10 % wt. = percentages of charcoal addition.

Table 5.3 The physical and mechanical properties of test briquettes after being fired at 1000 °C.

Test briquette code. HDC+Charcoal size	Firing shrinkage (%)	Apparent porosity (%)	Water absorption (%)	Bulk density (g/cm^3)	Apparent density (g/cm^3)	Compressive strength (kg/cm^2)
HDC 100 %	2.53	22.56	16.96	1.83	2.65	173.09
1 / 2.5 %	2.53	31.10	17.14	1.63	2.23	116.83
1 / 5.0 %	2.23	37.47	24.35	1.52	2.09	80.82
1 / 7.5 %	2.13	45.34	32.67	1.45	1.98	56.69
1 / 10.0 %	2.42	50.17	39.54	1.24	1.88	32.41
2 / 2.5 %	2.56	24.94	16.14	1.69	2.30	146.27
2 / 5.0 %	2.12	33.60	21.45	1.62	2.18	105.86
2 / 7.5 %	2.43	42.10	27.85	1.57	2.09	60.67
2 / 10.0 %	2.31	47.50	33.34	1.48	1.92	40.37
3 / 2.5 %	2.31	23.96	16.89	1.73	2.32	147.31
3 / 5.0 %	2.42	32.45	20.98	1.68	2.30	123.25
3 / 7.5 %	2.33	37.76	23.49	1.63	2.24	119.78
3 / 10.0 %	2.31	42.29	30.56	1.58	2.15	105.30

HDC = Hang Dong clay, 1, 2 and 3 = particle sizes, 2.5, 5.0, 7.5 and 10 % wt. = percentages of charcoal addition.

Table 5.4 The physical and mechanical properties of test briquettes after being fired at 1100 ^oC.

Test briquette code. HDC+Charcoal size	**Firing shrinkage (%)**	**Apparent porosity (%)**	**Water absorption (%)**	**Bulk density (g/cm^3)**	**Apparent density (g/cm^3)**	**Compressive strength (kg/cm^2)**
HDC 100 %	3.05	20.38	12.89	1.84	2.75	265.87
1 / 2.5 %	3.26	28.44	16.32	1.65	2.30	138.38
1 / 5.0 %	2.67	30.43	21.76	1.60	2.12	89.42
1 / 7.5 %	2.56	40.46	30.62	1.58	2.07	60.71
1 / 10.0 %	2.58	46.17	36.48	1.40	1.98	43.60
2 / 2.5 %	3.79	22.44	14.41	1.72	2.35	152.37
2 / 5.0 %	2.31	31.20	20.86	1.65	2.20	116.60
2 / 7.5 %	2.52	37.13	26.63	1.63	2.12	116.24
2 / 10.0 %	2.53	43.43	30.58	1.54	2.08	46.85
3 / 2.5 %	4.10	20.27	13.54	1.80	2.38	152.82
3 / 5.0 %	2.53	29.73	18.67	1.76	2.34	123.96
3 / 7.5 %	2.53	32.51	22.32	1.68	2.27	128.62
3 / 10.0 %	2.47	36.34	28.67	1.65	2.18	110.52

HDC=Hang Dong clay, 1, 2 and 3 = particle sizes, 2.5, 5.0, 7.5 and 10 % wt. = percentages of charcoal addition.

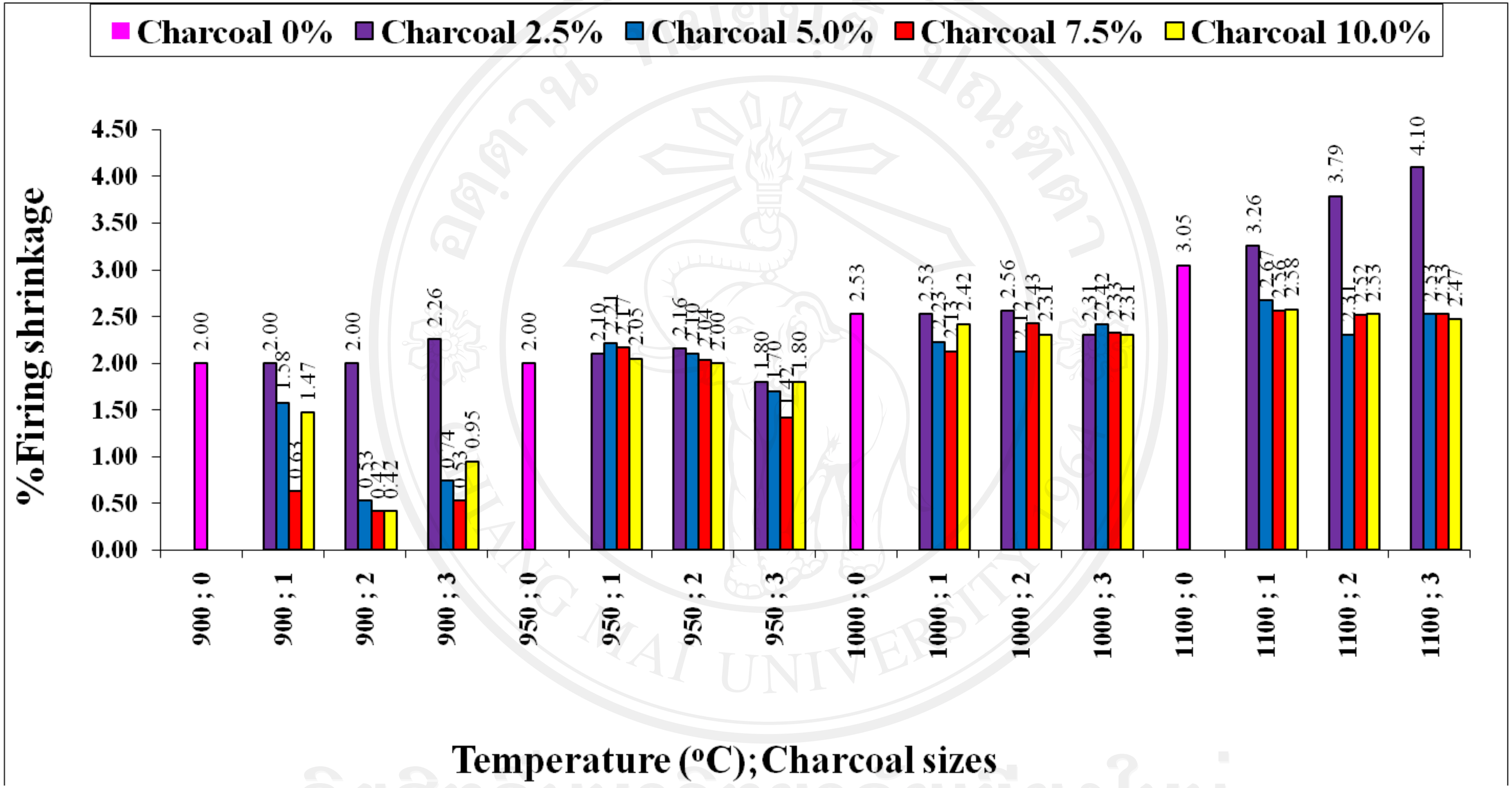

Figure. 5.1 Effects of 0-10% of charcoal addition sizes 1 - 3, fired at 900 - 1100 °C on the firing shrinkage of test briquettes.

5.1 Firing shrinkage

When test briquettes with 7.5% of size (1) charcoal addition were fired at 900 ^{o}C, their firing shrinkage was the lowest (0.63%), while the counterpart with 2.5% showed the highest firing shrinkage (2.00%). The ones with 2.5% of sizes (2) and (3) showed 2.00% and 2.26 % of firing shrinkage and 10% of sizes (2) and (3) showed 0.42 % and 0.95 % of firing shrinkage, respectively. On the other hand, the control group, fired test briquettes without any charcoal addition showed 2.00% of firing shrinkage.

Also, when test briquettes with 7.5% of size (1) charcoal addition were fired at 1100 ^{o}C, it resulted in fired test briquettes with the lowest shrinkage (2.56%). The ones with 2.5% of sizes (2) and (3) showed 3.79% and 4.10 % of firing shrinkage and 10% of sizes (2) and (3) showed 2.53 % and 2.47 % firing shrinkage respectively. On the other hand, the control group, fired test briquettes without any charcoal addition showed the highest firing shrinkage, 3.05% (Table 5.1 and 5.4).

Then, when test briquettes were fired at temperatures from 950 ^{o}C to 1000 ^{o}C and the results yielded: the values of firing shrinkage of test briquettes fired at 950 C with 2.5% of size (1) showed firing shrinkage 2.1 %, at 1000 ^{o}C 2.5% of size (1) firing shrinkage 2.53 %. The ones with 2.5% of sizes (2) and (3) at 950 ^{o}C and 1000 ^{o}C showed firing shrinkage 2.16%, 1.80%, 2.56% and 2.31% and 10% of sizes (2) and (3) 950 ^{o}C and 1000 ^{o}C showed firing shrinkage 2.00%, 1.80 %, 2.31% and 2.31%, respectively. On the other hand, the control group, test briquettes without any charcoal addition fired at 950 ^{o}C and 1000 ^{o}C showed firing shrinkage 2.00% and 2.53%, respectively (Table 5.2 and 5.3).

Shrinkage used in shaping fired test briquettes occurred due to water leaving clay body. This is speculated when water between clay particles leaves, particles come closer and shrinkage occurs. Then firing temperature which is an important parameter affecting the degree of shrinkage is the key factor to be controlled to minimize the shrinkage in the firing process [8]. Normally, a good quality of brick exhibits shrinkage below 8% [10]. However, increasing the temperature in firing bricks results in an increase in shrinkage. In this study, the fired test briquettes were fired at the temperatures between 900 and 1100 °C.

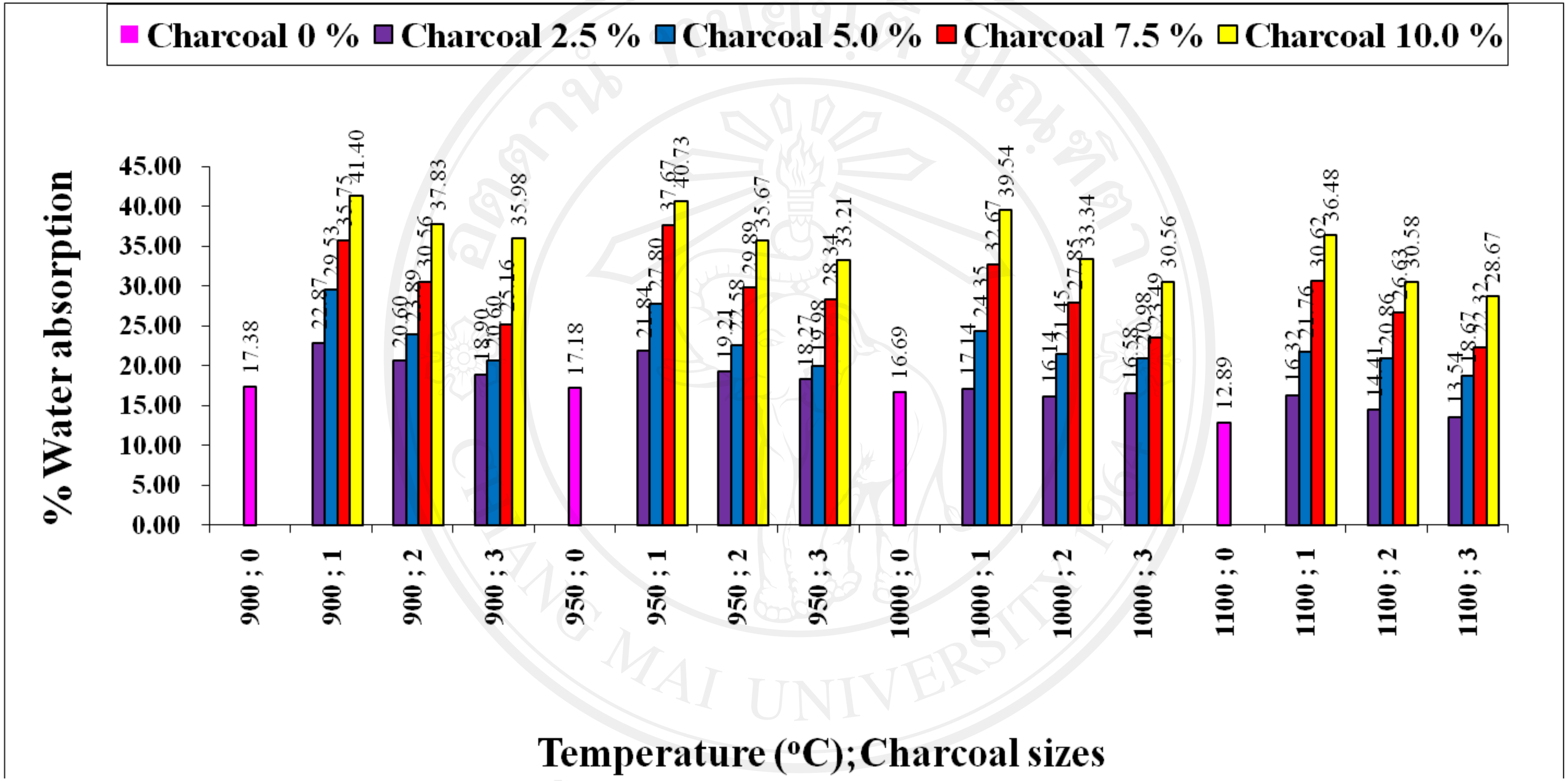

Figure. 5.2 Effects of 0-10% of charcoal addition sizes 1 - 3, fired at 900 - 1100 °C on the water absorption of test briquettes.

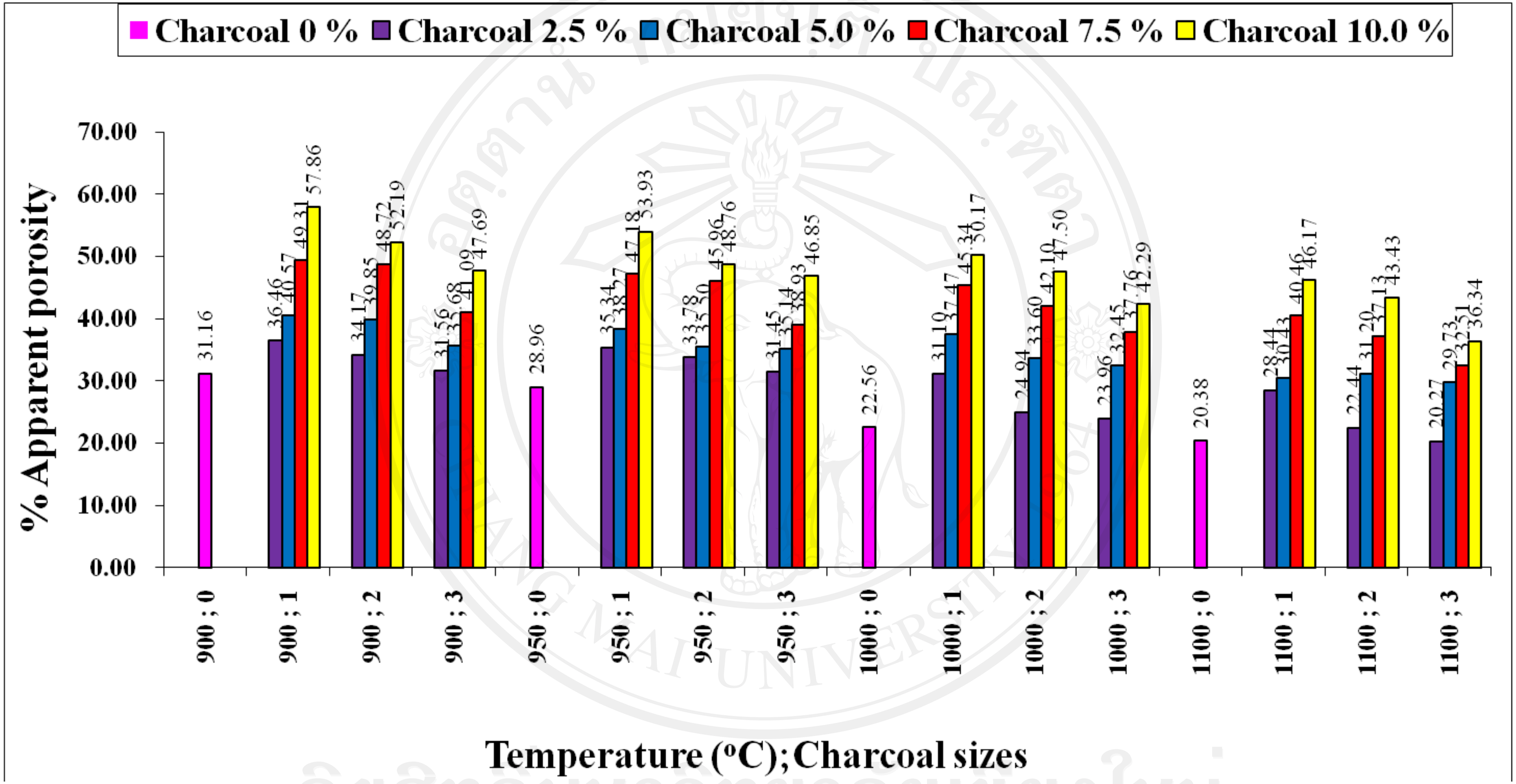

Figure. 5.3 Effects of 0-10% of charcoal addition sizes 1 - 3, fired at 900 - 1100 ^{o}C on the apparent porosity of test briquettes.

5.2 Water absorption and apparent porosity

When test briquettes with 2.5% of size (1) charcoal addition were fired at 900°C, it resulted in fired test briquettes with the lowest absorption (22.87%), and lowest apparent porosity (36.44%) while the counterpart with 10% showed the highest absorption (41.40%), and highest apparent porosity (57.86%) The ones with 2.5% of sizes (2) and (3) showed water absorption 20.60% and 18.90 %, apparent porosity 34.17% and 31.56% and 10% of sizes (2) and (3) showed water absorption 37.83 % and 35.98 %, apparent porosity 52.19% and 47.96%, respectively. On the other hand, the control group, fired test briquettes without any charcoal addition showed water absorption 17.38% and apparent porosity 31.16% (Table 5.1, Figure. 5.4).

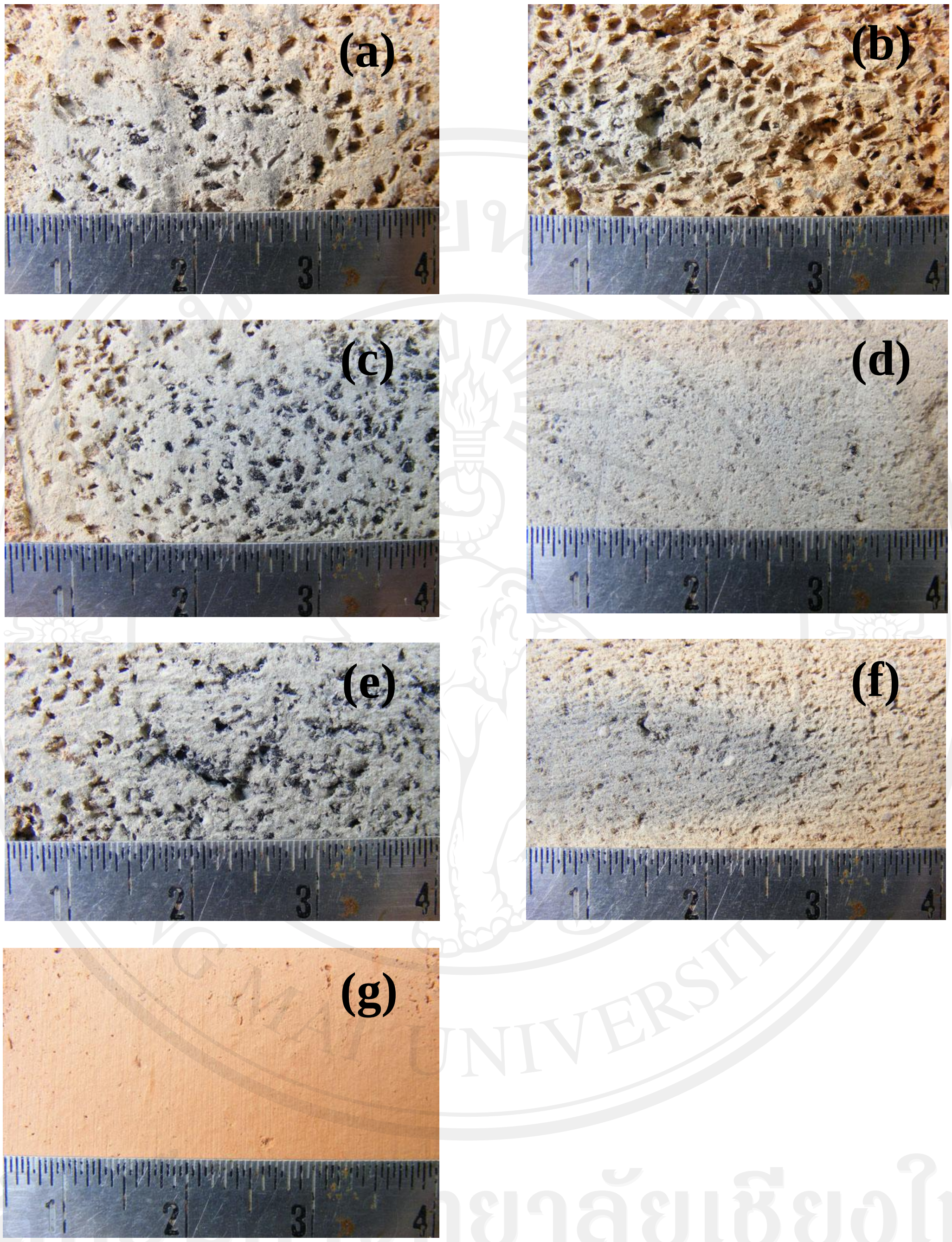

Figure. 5.4. Charcoal addition on the water absorption and apparent porosity of fired clay briquettes fired at 900 ^{o}C (a, b) mixed with charcoal particle size 1 (2-3 mm.) 2.5% and 10%, (c-f) mixed with charcoal size 2, 3 (1-2 mm.), (less than 0.5 mm.) 2.5%, 10% and (g) original Hang Dong clay.

Also, when test briquettes with 2.5% of size (1) charcoal addition were fired at 1100 °C, it showed the lowest water absorption (16.32%), and lowest apparent porosity (28.44%) while the counterpart with 10% showed the highest water absorption (36.48%), and highest apparent porosity (46.17%) The ones with 2.5% of sizes (2) and (3) showed water absorption 14.41% and 13.54 % , and apparent porosity 31.20% and 20.27% and 10% of sizes (2) and (3) showed water absorption 30.58 % and 28.67 % , and apparent porosity 43.43% and 36.34% , respectively. On the other hand, the control group, fired test briquettes without any charcoal addition showed water absorption 12.89% and apparent porosity 20.38%, respectively (Table 5.4, Figure. 5.5).

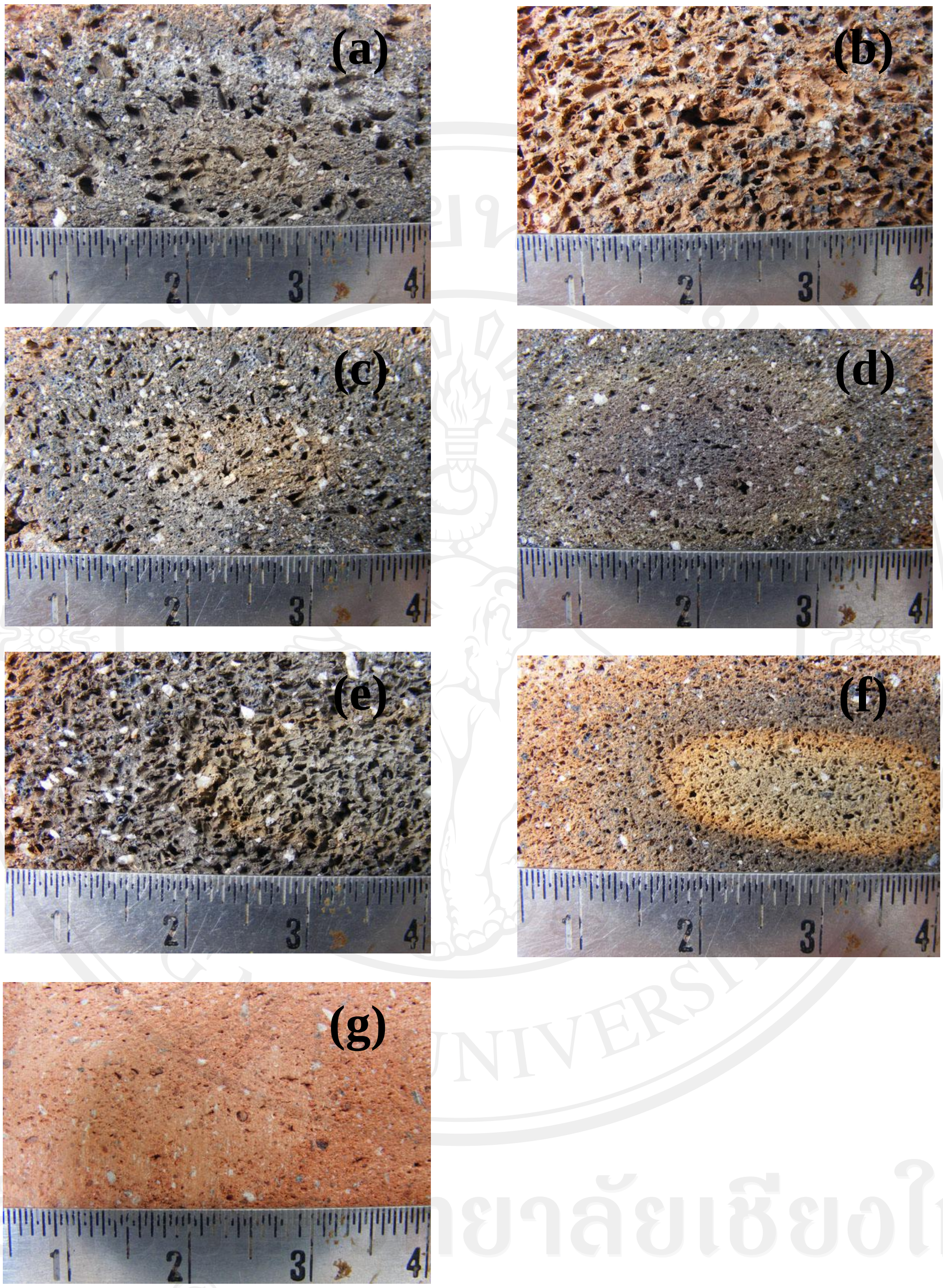

Figure. 5.5. Charcoal addition on the water absorption and apparent porosity of fired clay briquettes fired at 1100 ^{o}C (a, b) mixed with charcoal size 1 (2-3 mm.) 2.5% and 10%, (c-f) mixed with charcoal sizes 2, 3 (1-2 mm.), (less than 0.5 mm.) 2.5%, 10% and (g) Hang Dong clay without addition.

When test briquettes were fired at 950 °C and 1000 °C, the results showed that the values of water absorption and apparent porosity were as follows: at 950 °C 2.5% of size (1) yielded 21.84% water absorption and 35.34% apparent porosity, at 1000 °C 2.5% of size (1) 17.14% water absorption, 31.10% apparent porosity, at 950 °C 10% of size (1) 40.73% water absorption, 53.93% apparent porosity at 1000 °C 10% of size (1) 39.54% water absorption, 50.17% apparent porosity (Figure. 5.6). The ones with 2.5% of sizes (2) and (3) at 950 °C and 1000 °C showed 33.78%, 46.85%, 16.17% and 16.89 % water absorption, 33.78%, 31.45%, 24.94% and 23.96% apparent porosity and 10% of sizes (2) and (3) 950 °C and 1000 °C showed 35.67 %, 33.21%, 33.34% and 30.56 % water absorption, 48.76%, 46.85%, 47.50% and 42.29% apparent porosity, respectively (Figures. 5.7-5.8). On the other hand, the control group, fired test briquettes without any charcoal addition at 950 °C and 1000 °C showed 17.18% and 16.96% water absorption, 28.96% and 22.56% apparent porosity, respectively (Table 5.2,5.3 and Figure. 5.9).

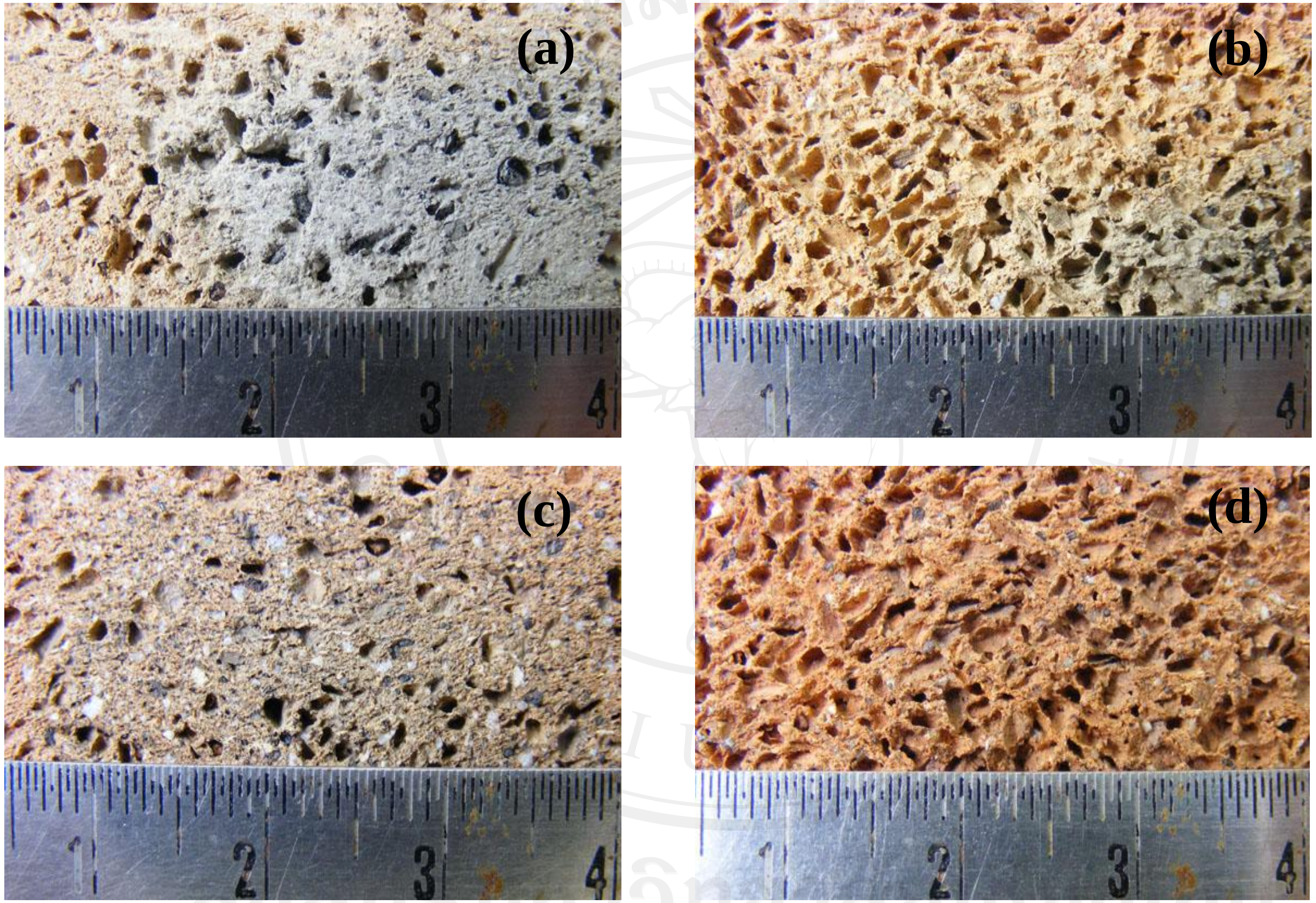

Figure. 5.6 Charcoal addition on the water absorption and apparent porosity of fired clay briquettes (a, b) mixed with charcoal size 1 (2-3 mm.) 2.5%, 10% fired at 950 ^{o}C and (c, d) mixed with charcoal size 1 (2-3 mm.) 2.5%, 10% fired at 1000 ^{o}C.

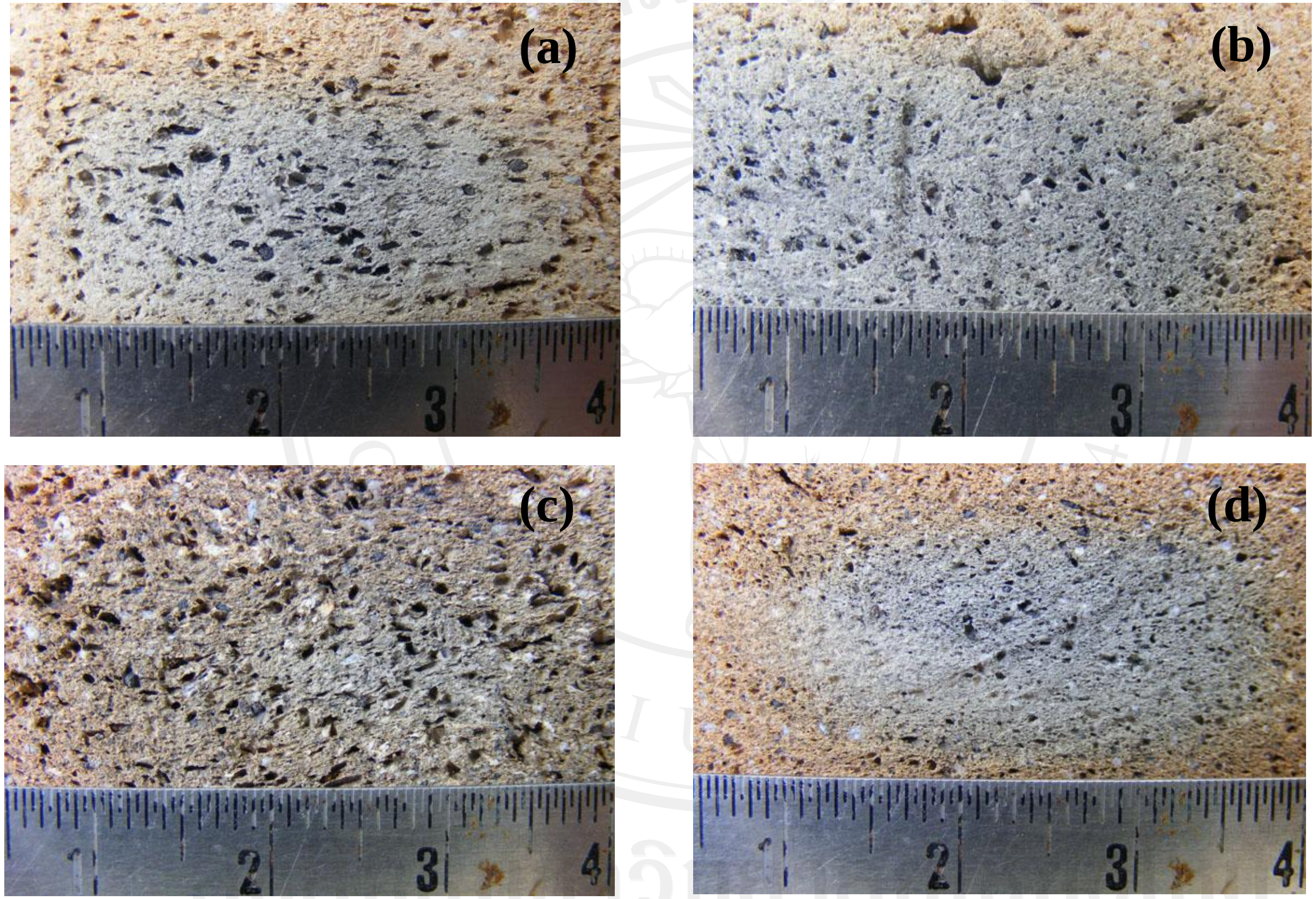

Figure. 5.7 Charcoal addition on the water absorption and apparent density of fired test briquettes (a, b) mixed with charcoal size 2 (1-2 mm.), size 3 (less than 0.5 mm.) 2.5% fired at 950 ^{o}C and (c, d) mixed with charcoal sizes 2 and 3, 2.5%, fired at 1000 ^{o}C.

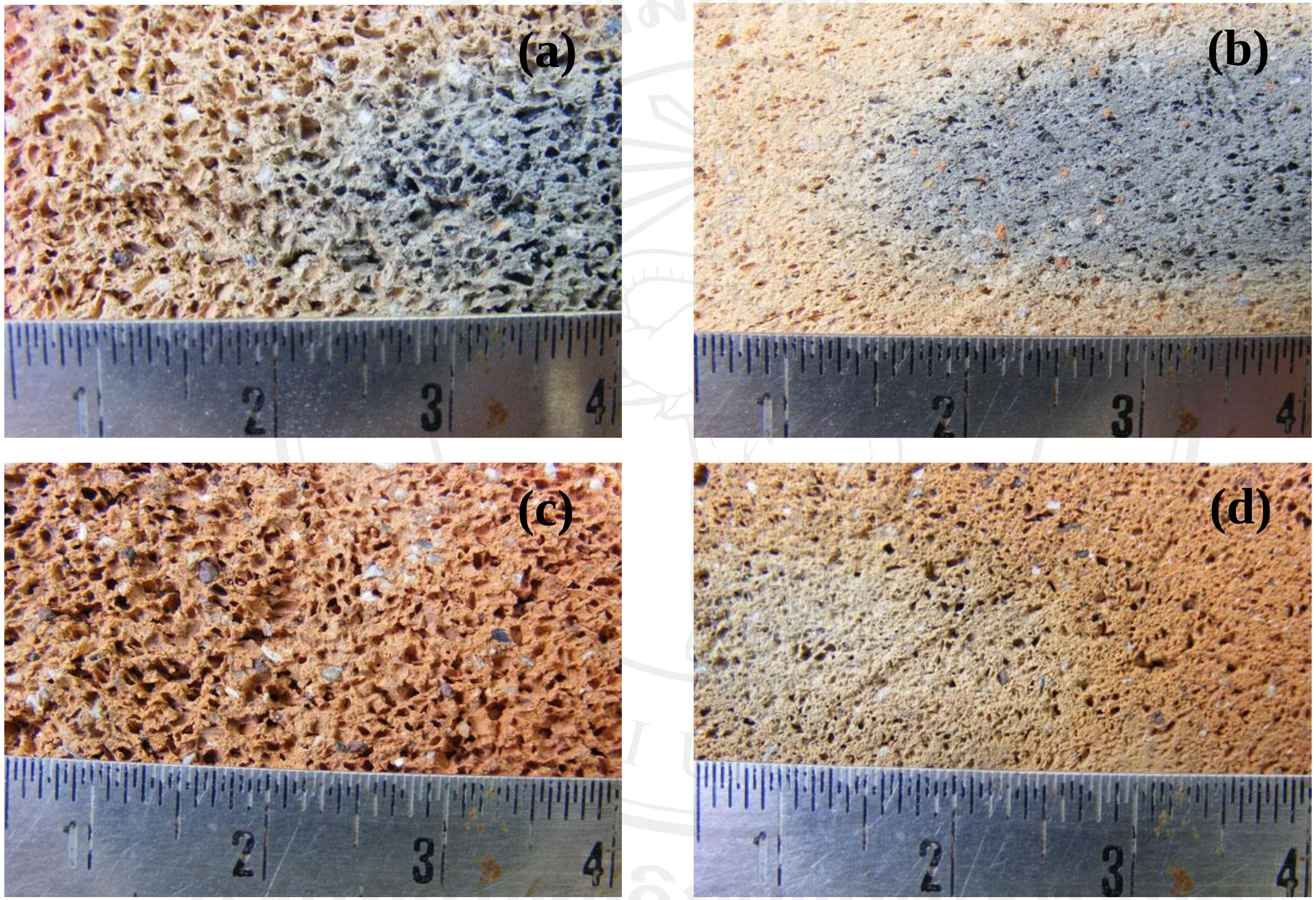

Figure. 5.8 Charcoal addition on the water absorption and apparent porosity of fired test briquettes (a, b) mixed with charcoal size 2 (1-2 mm.), size 3 (less than 0.5 mm.) 10% fired at 950 ^{o}C and (c, d) mixed with charcoal sizes 2 and 3, 10%, fired at 1000 ^{o}C.

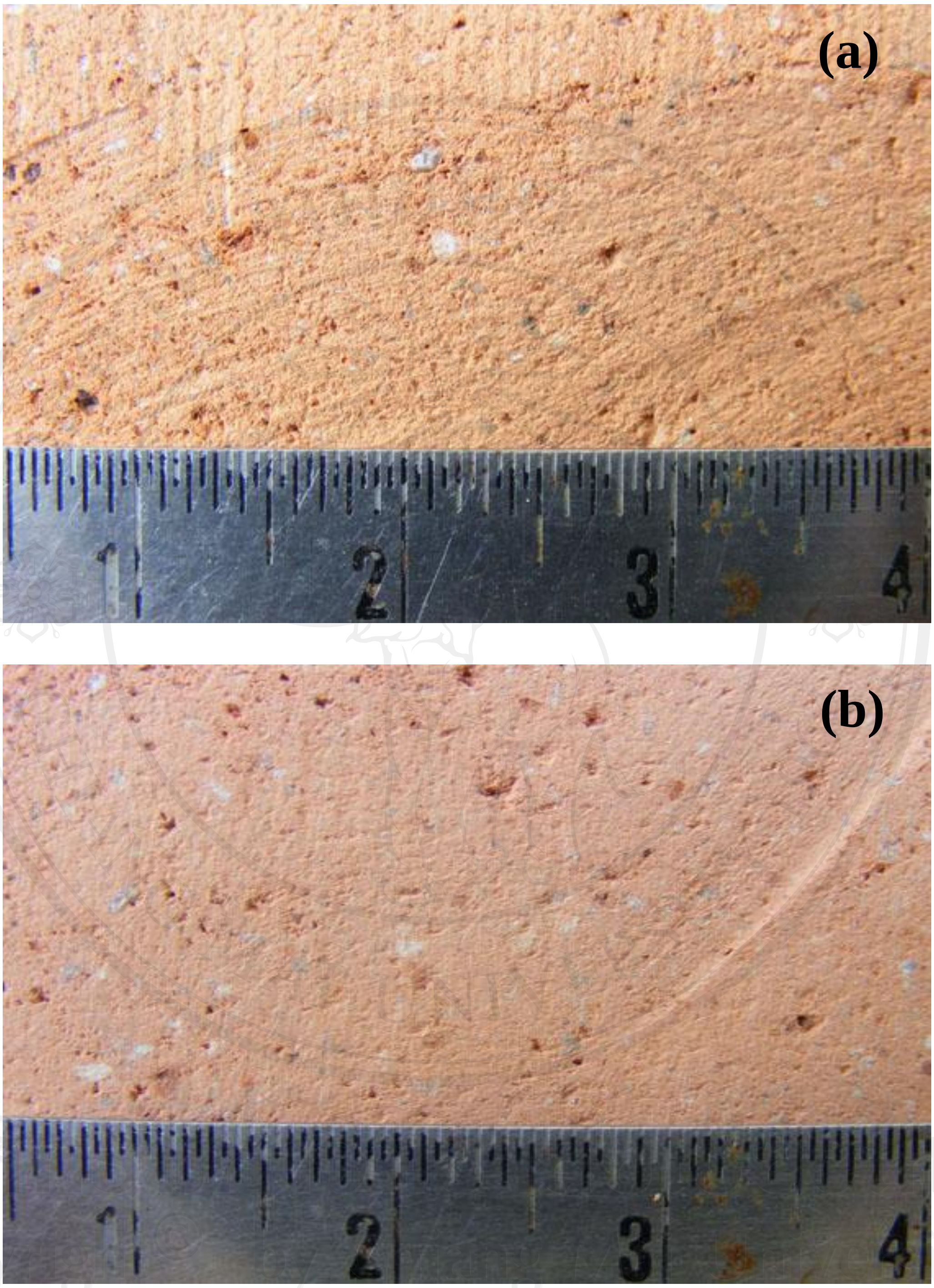

Figure. 5.9 Hang Dong clay without addition fired at (a), 950 and (b), 1000 ^{o}C.

Water absorption is an important factor affecting the durability of clay bricks. When water absorption infiltrates the bricks, it decreases the durability of bricks [62]. Thus, the internal structure of the bricks must be dense enough to void the intrusion of water [10]. In this study, the water absorption rate was decreasing in a linear manner relative to apparent porosity. Decreasing water absorption caused fired test briquettes to adhere to each other and fortified the wall strength. Another important factor of water absorption of bricks is the amount and size of apparent porosity of bricks. In other words, the capacity of water absorption is directly proportional to apparent porosity. The higher amount and the larger size of porosity the bricks have, the more water absorption of the bricks can occur. Therefore, in this study, similar trends were observed in water absorption and apparent porosity of fired test briquettes [62]. This result showed that high percentage of charcoal addition in fired test briquettes caused high porosity in them. Furthermore, the water absorption of porous fired clay bodies is indicative of the quantum of overall apparent porosity. Thus porosity in test fired briquettes occurred due to the fact that charcoal addition was burnt out during firing and this agrees with literature [63].

5.3 Density of fired test briquettes

When test briquettes with 10% of size (1) charcoal addition were fired at 900 °C, they showed the lowest bulk density (1.14 g/cm^3) and apparent density (1.68 g/cm^3) while the counterpart with 2.5% showed the highest (1.57 g/cm^3), apparent density (2.14 g/cm^3) The ones with 10% of size (2) and (3) showed 1.32 g/cm^3 and 1.48 g/cm^3 bulk density, 1.90 g/cm^3 and 2.04 g/cm^3 apparent density and 2.5% of sizes (2) and (3) 1.60 g/cm^3 and 1.65 g/cm^3 bulk density, 2.15 g/cm^3 and 2.22 g/cm^3 apparent density, respectively. On the other hand, the control group, fired test briquettes without any charcoal addition showed 1.79 g/cm^3 bulk density and 2.46 g/cm^3 apparent density (Table 5.1). Also, when test briquettes with 10% of size (1) charcoal addition were fired at 1100 °C, they showed the lowest bulk density (1.40 g/cm^3), apparent density (1.98 g/cm^3) while the counterpart with 2.5% showed the highest bulk density (1.65 g/cm^3) and highest apparent density (2.30 g/cm^3) The ones with 10% of sizes (2) and (3) showed 1.54 g/cm^{3}and 1.65 g/cm^3 bulk density, 2.08 g/cm^3 and 2.18 g/cm^3 apparent density and 2.5% of sizes (2) and (3) showed 1.72 g/cm^3 and 1.80 g/cm^3 bulk density, 2.35 g/cm^3 and 2.38 g/cm^3 apparent density, respectively. On the other hand, the control group, fired test briquettes without any charcoal addition showed 1.84 g/cm^3 bulk density and 2.75 g/cm^3 apparent density, respectively (Table 5.4).

When test briquettes were fired at 950 °C and 1000 °C, the investigation yielded the values of bulk density and apparent density of fired test briquettes fired at temperatures from 900 °C to 1100 °C as follows: at 950 °C 10% of size (1) the bulk density was 1.17 g/cm^3 and apparent density was 1.87 g/cm^3, at 1000 °C 10% of size

(1) bulk density 1.24 g/cm^3 apparent density 1.88 g/cm^3 , at 950 °C 2.5% of size (1) bulk density 1.61 g/cm^3 , apparent density 2.19 g/cm^3 at 1000 °C 2.5% of size (1) bulk density 1.63 g/cm^3 , apparent density 2.23 g/cm^3. The ones with 10% of sizes (2) and (3) at 950 °C and 1000 °C showed 1.42 g/cm^3, 1.48 g/cm^3, 1.48 g/cm^3 and 1.58 g/cm^3 bulk density, 1.91 g/cm^3, and 2.07 g/cm^3, 1.92 g/cm^3 and 2.15 g/cm^3 apparent density and 2.5% of sizes (2) and (3) 950 °C and 1000 °C showed 1.65 g/cm^3, 1.68 g/cm^3, 1.69 g/cm^3 and 1.73 g/cm^3 bulk density, 2.24 g/cm^3, 2.30 g/cm^3, 2.30 g/cm^3 and 2.32 g/cm^3 apparent density, respectively. On the other hand, the control group, fired test briquettes without any charcoal addition at 950 °C and 1000 °C showed 1.80 g/cm^3 and 1.83 g/cm^3 bulk density, 2.58 g/cm^3 and 2.65 g/cm^3 apparent density, respectively (Table 5.2 and 5.3).

The data of bulk density and apparent density collected are shown in Tables 5.1 – 5.4. Density of clay bricks depends on several factors: namely, specific gravity of the raw material used, method of manufacturing and degree of burning [8]. As the density of a clay brick decreases, its strength also decreases, while its water absorption increases. The bulk density of samples was inversely proportional to the quantity of charcoal particles added in the mixture. The bulk density of samples decreased with an increase in the amount of charcoal from 2.5 to 10%. However, bulk density of fired test briquettes increased with an increase in firing temperature (Figure. 5.10). The apparent density varied according to the amount of charcoal addition in clay body. Thus charcoal was an appropriate agent used as a control mix. The results shown in (Tables 5.1 – 5.4 and Figure. 5.11) indicate that the apparent density of fired test briquettes which were fired at temperatures from 900-1100 ^{o}C varied from 1.86 to 2.38 g/cm^3.

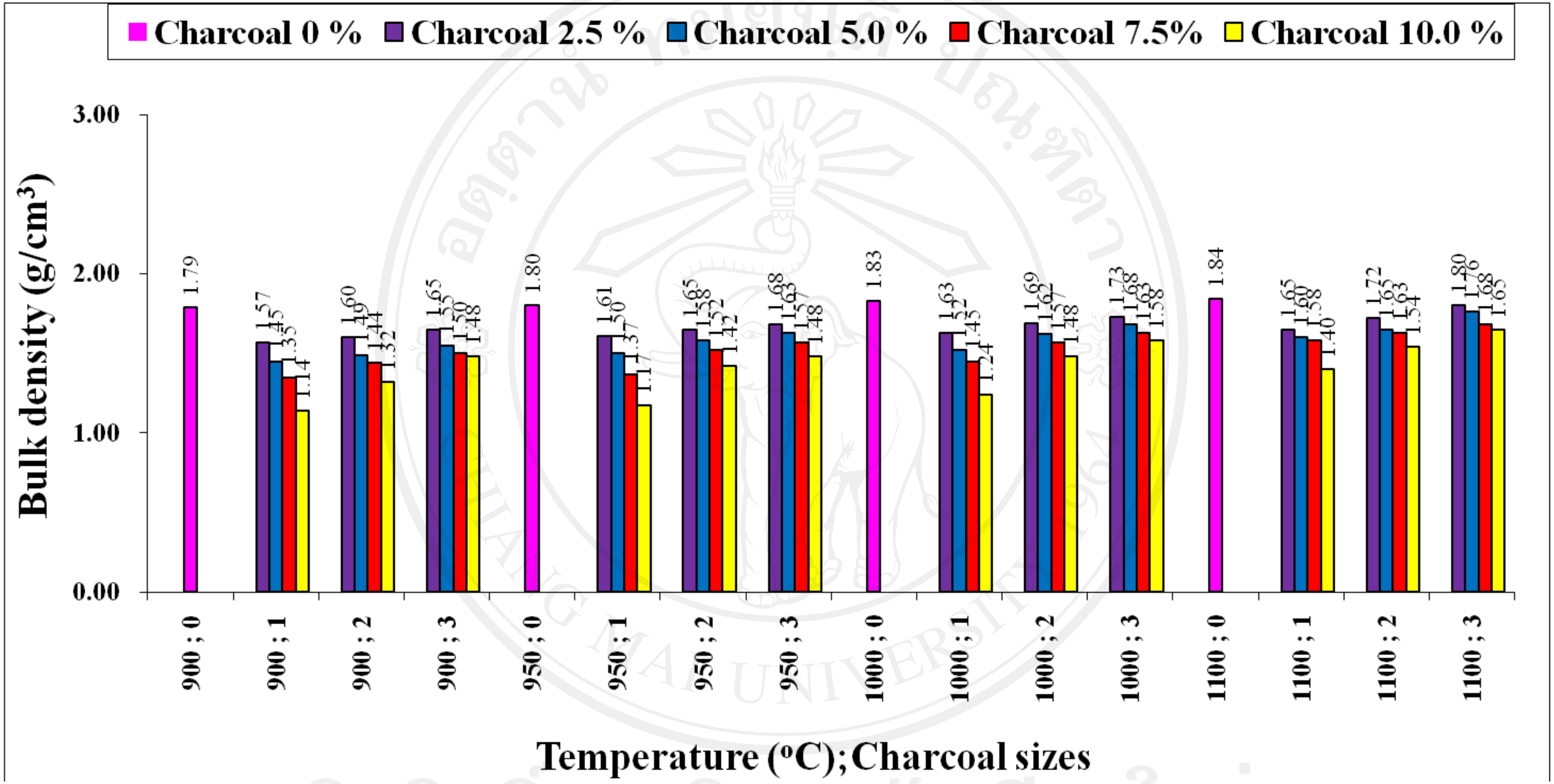

Figure. 5.10 Effects of 0-10% of charcoal addition sizes 1 – 3, fired at 900 - 1100 °C on the bulk density of fired test briquettes.

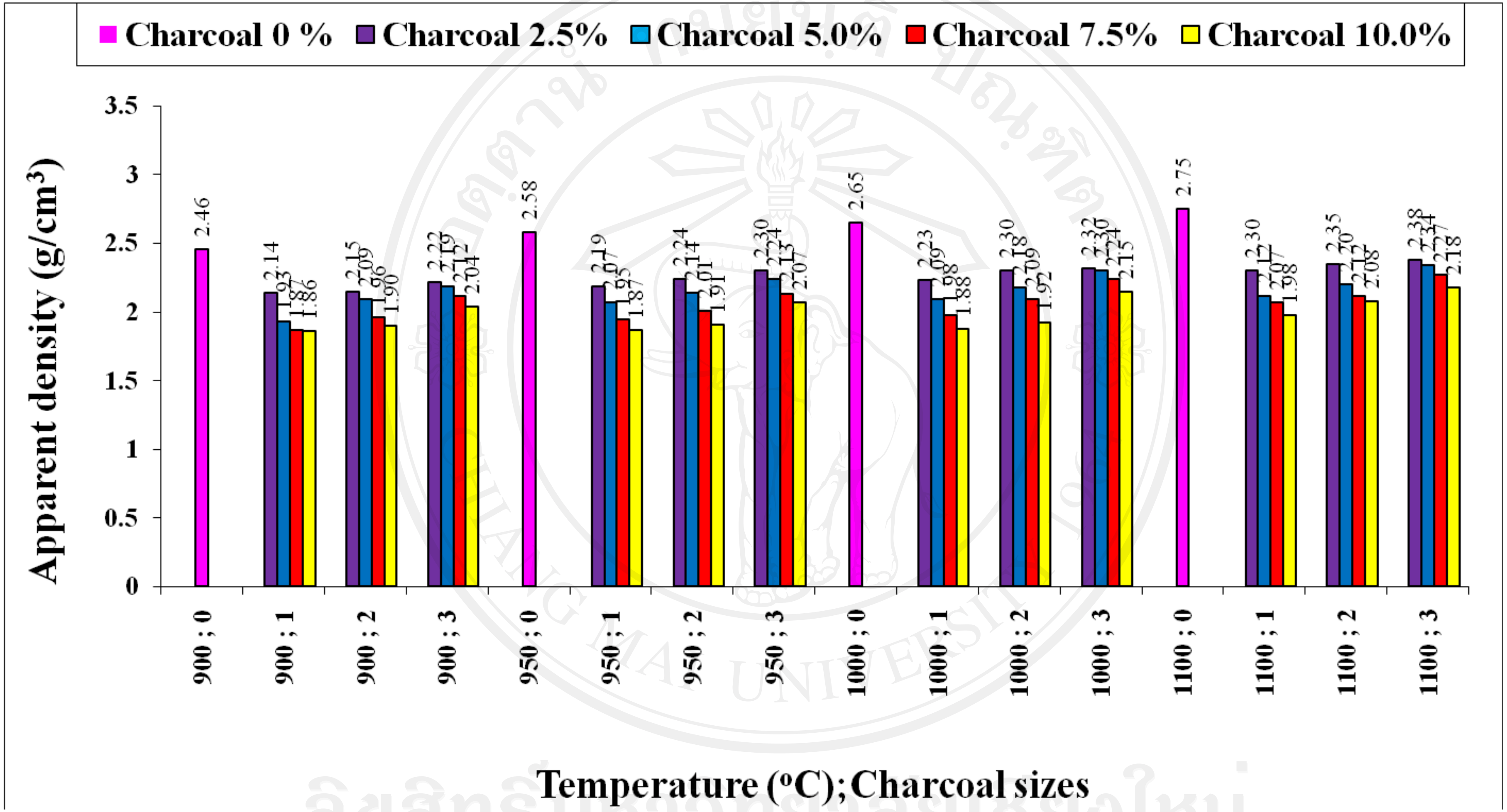

Figure. 5.11 Effects of 0-10 % of charcoal addition sizes 1 - 3, fired at 900 - 1100 ^{o}C on apparent density of test briquettes.

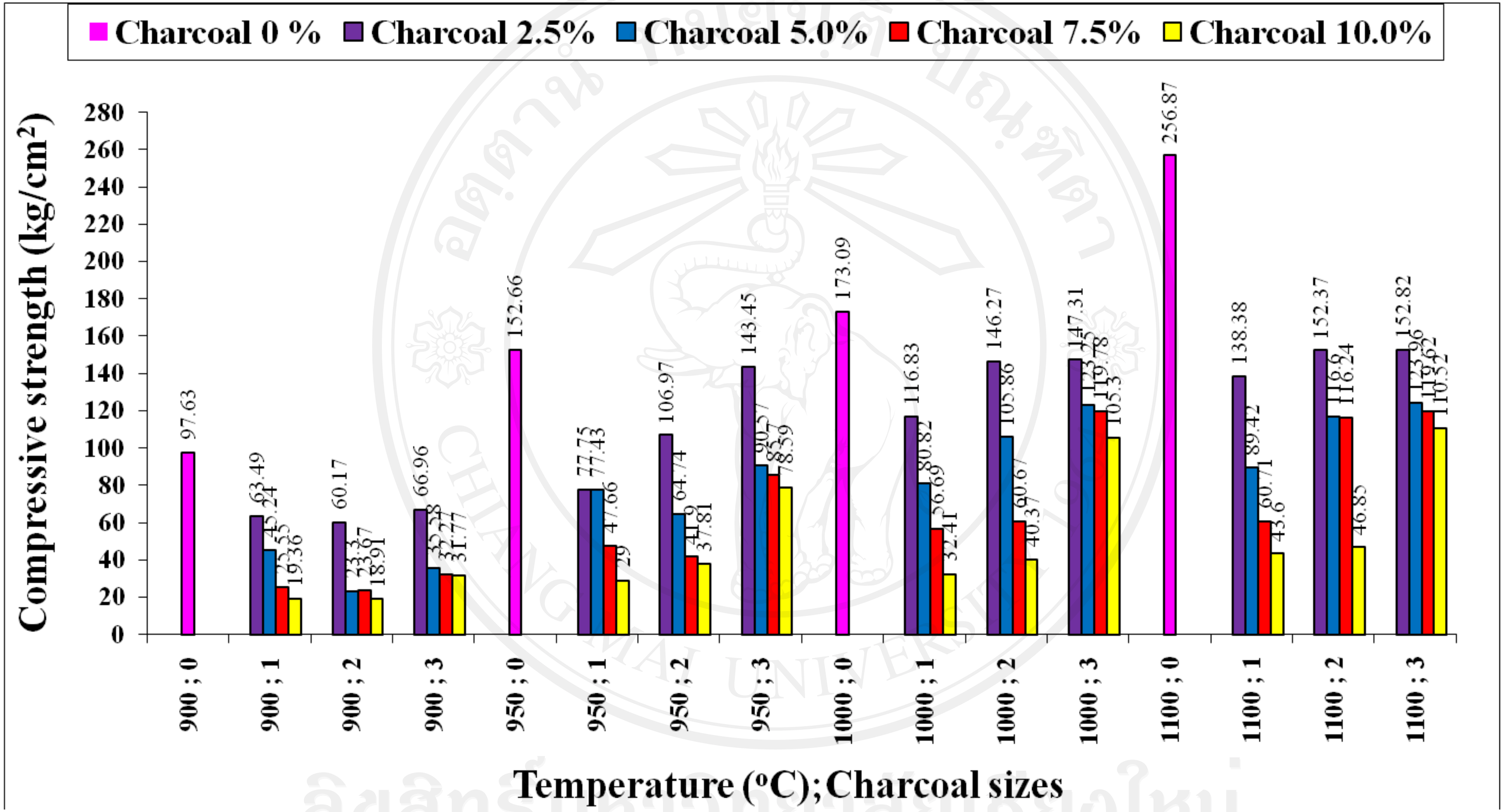

Figure. 5.12 Effects of 0-10% of charcoal addition sizes 1 – 3, fired at 900 - 1100 °C on compressive strength of test briquettes.

5.4 Compressive strength

When test briquettes were fired at 900 ^{o}C, fired test briquettes with 10% of size (1) charcoal addition showed the lowest compressive strength (19.36 kg/cm^2) while the counterpart with 2.5% showed the highest (63.49 kg/cm^2). The ones with 2.5% of sizes (2) and (3) showed 60.17 kg/cm^2 and 66.96 kg/cm^2 of compressive strength and 10% of sizes (2) and (3) showed 18.91 kg/cm^2 and 31.77 kg/cm^2 of compressive strength, respectively. On the other hand, the control group, fired test briquettes without any charcoal addition showed 97.63 kg/cm^2 of compressive strength (Table 5.1, Figure. 5.13).

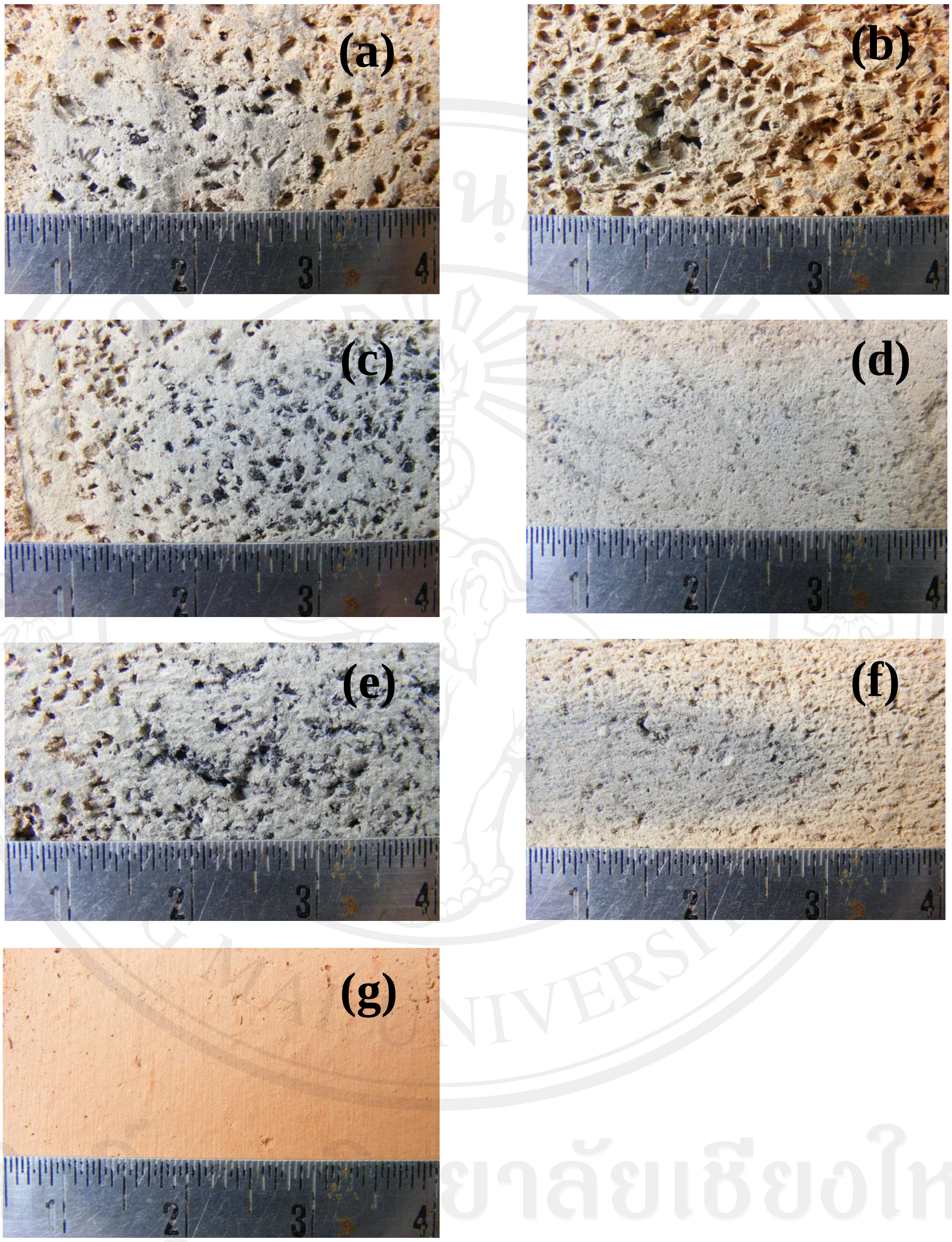

Figure. 5.13 Charcoal addition on the compressive strength of fired test briquettes fired at 900 °C (a, b) mixed with charcoal size 1 (2-3 mm.) 2.5% and 10%, (c-f) mixed with charcoal sizes 2, 3 (1-2 mm.), (less than 0.5 mm.) 2.5%, 10% and (g) Hang Dong clay without addition.

When test briquettes with 10% of size (1) charcoal addition were fired at 1100 ^{o}C showed the lowest compressive strength (43.60 kg/cm^2). The ones with 2.5% of sizes (2) and (3) showed 152.37 kg/cm^2 and 152.82 kg/cm^2 of compressive strength and 10% of sizes (2) and (3) showed 46.85 kg/cm^2 and 110.52 kg/cm^2 compressive strength, respectively. On the other hand, the control group, fired test briquettes without any charcoal addition showed 265.87 kg/cm^2 of compressive strength (Table 5.4, Figure. 5.14).

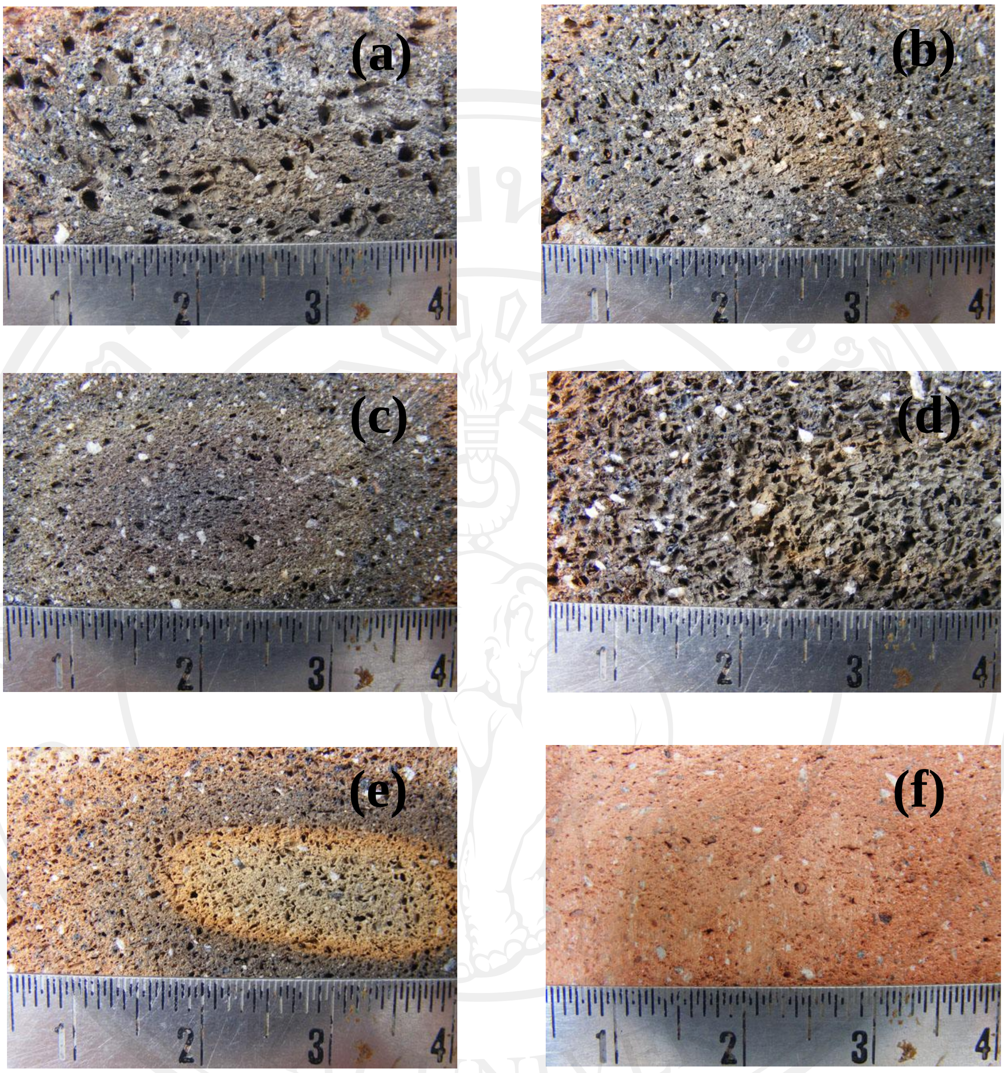

Figure. 5.14 Charcoal addition on the compressive strength of fired test briquettes fired at 1100 ^{o}C (a) mixed with charcoal size 1 (2-3 mm) 2.5% (b-e) mixed with charcoal sizes 2, 3 (1-2 mm.), (less than 0.5 mm.) 2.5%, 10% and (f) Hang Dong clay without addition.

The value of compressive strength of test briquettes with 2.5% of charcoal addition size (1) fired at 900 ^{o}C was 77.75 kg/cm^2, and at 1000 ^{o}C was 116.83 kg/cm^2 (Figure. 5.15).

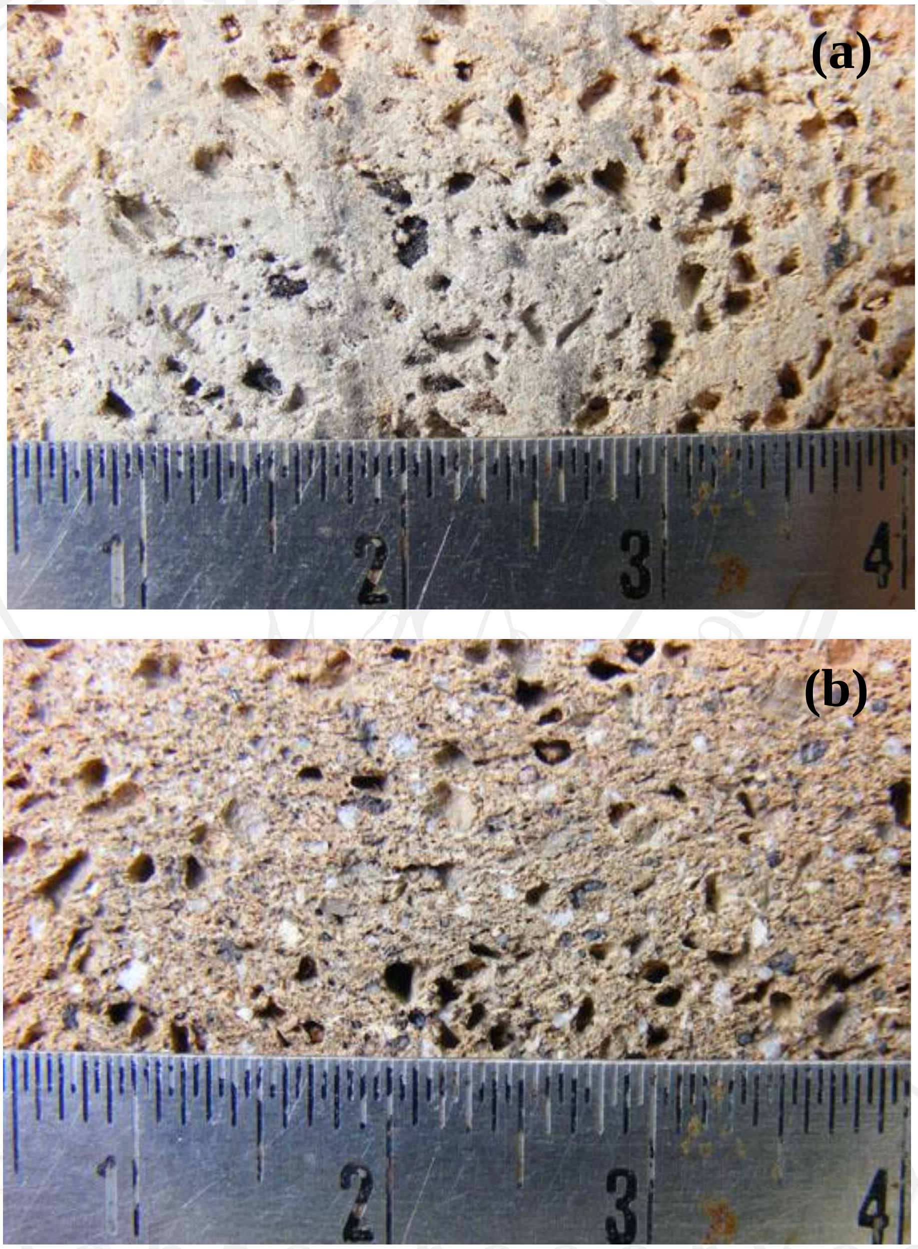

Figure. 5.15 Charcoal addition on the compressive strength of fired test briquettes mixed with charcoal size 1 (2-3 mm.), (a) fired at 900^{o}C and (b) fired at 1000 ^{o}C.

The ones with 2.5% of charcoal addition sizes (2) and (3) fired at 950 C and 1000 C, the compressive strengths were 106.97 kg/cm^2, 143.45 kg/cm^2, 146.27 kg/cm^2 and 147.31 kg/cm^2, respectively and with 10% of charcoal addition sizes (2) and (3) fired at 950 ^{o}C and 1000 ^{o}C they were 37.81 kg/cm^2, 78.59 kg/cm^2, 40.37 kg/cm^2 and 105.30 kg/cm^2, respectively. On the other hand, the control group, fired test briquettes without any charcoal addition, fired at 950 ^{o}C and 1000 ^{o}C, the values of compressive strength were 152.66 kg/cm^2 and 173.09 kg/cm^2 , respectively (Tables 5.2, 5.3 and Figures. 5.16-5.18).

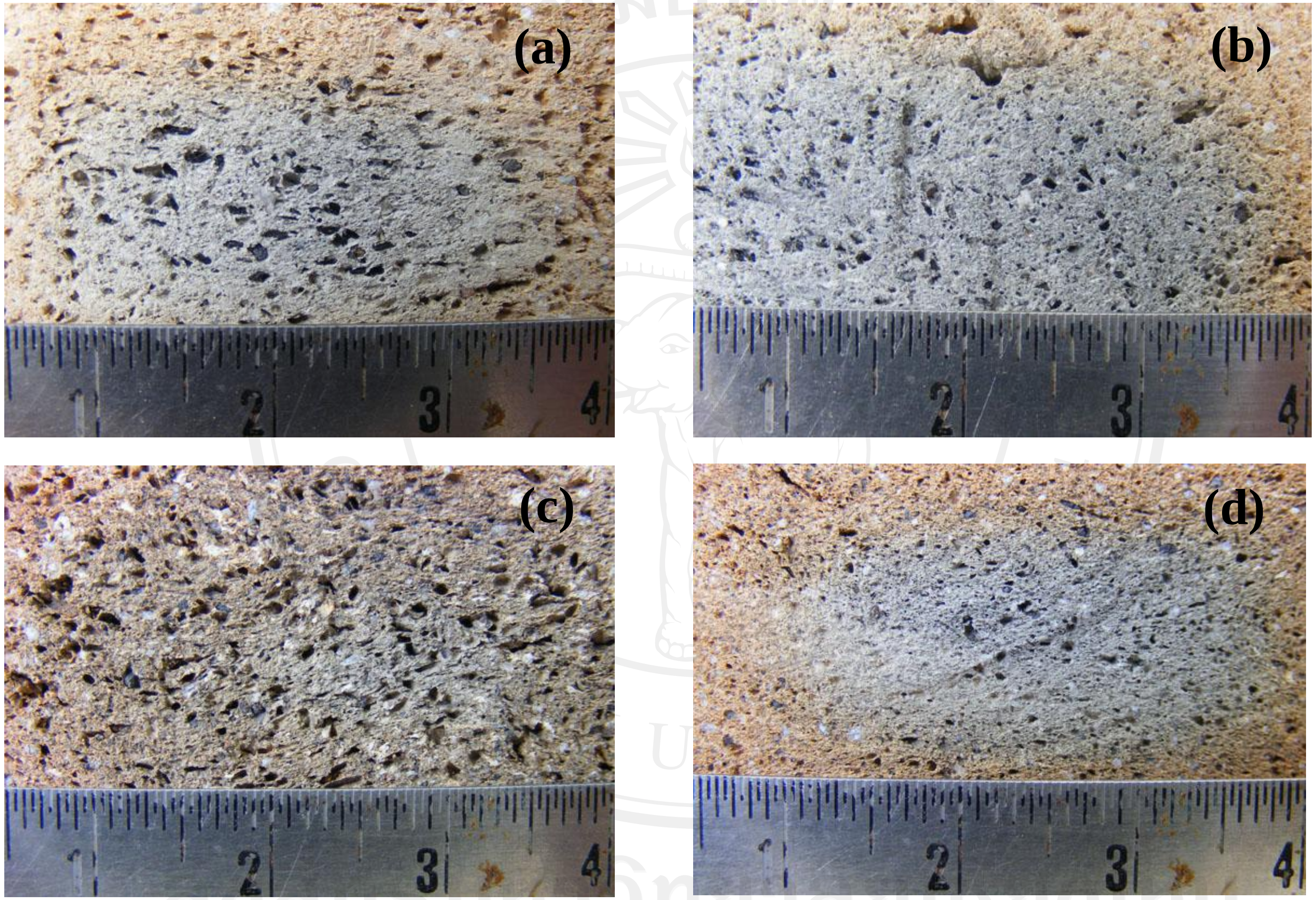

Figure. 5.16 Charcoal addition on the compressive strength of fired test briquettes (a, b) mixed with charcoal size 2 (1-2 mm.), size 3 (less than 0.5 mm.) 2.5% fired at 950 °C and (c, d) mixed with charcoal sizes 2 and 3, 2.5%, fired at 1000 °C.

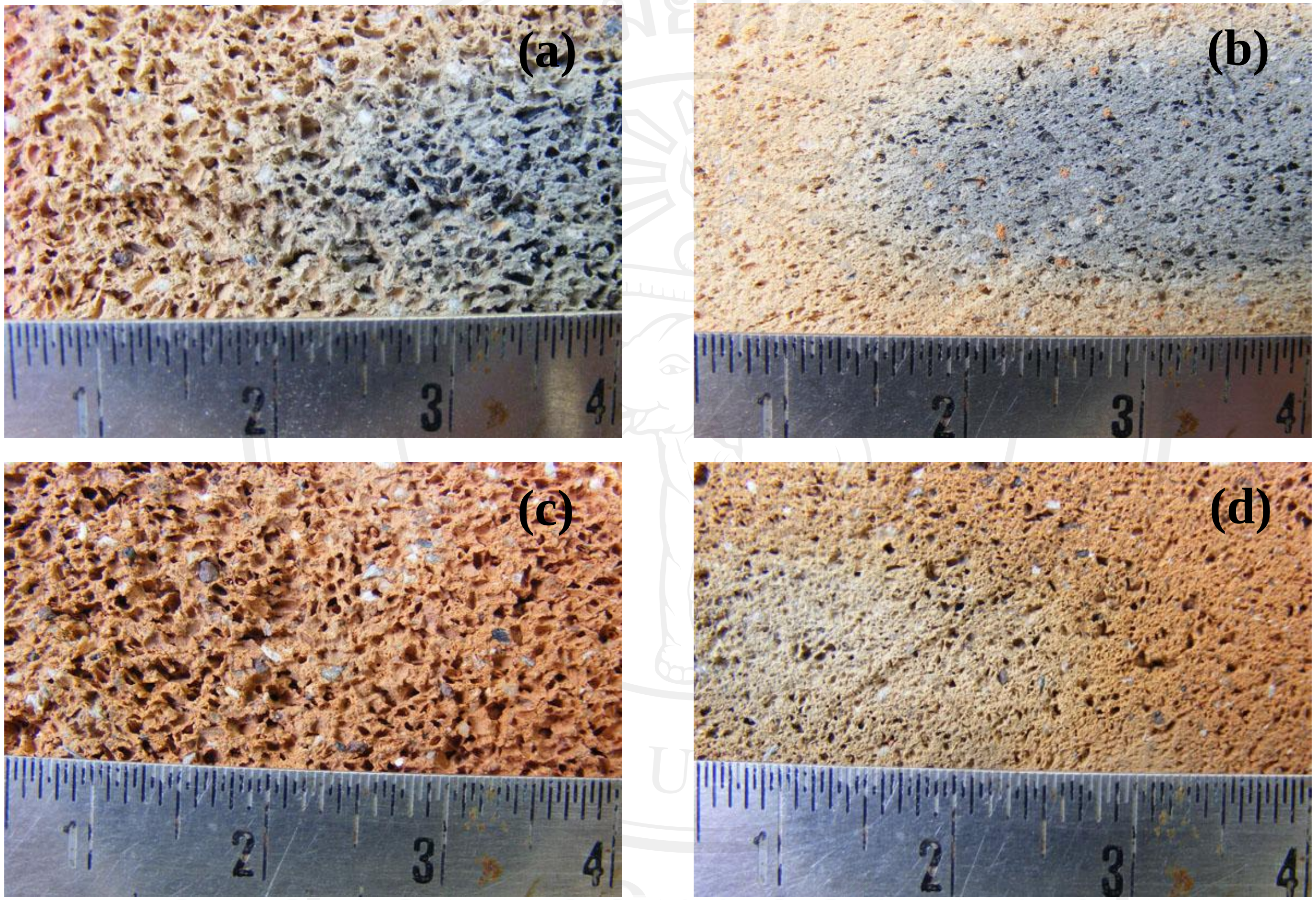

Figure. 5.17 Charcoal addition on the compressive strength of fired test briquettes (a, b) mixed with charcoal size 2 (1-2 mm.), size 3 (less than 0.5 mm.) 10% fired at 950 ^{o}C and (c, d) mixed with charcoal sizes 2 and 3, 10%, fired at 1000 ^{o}C.

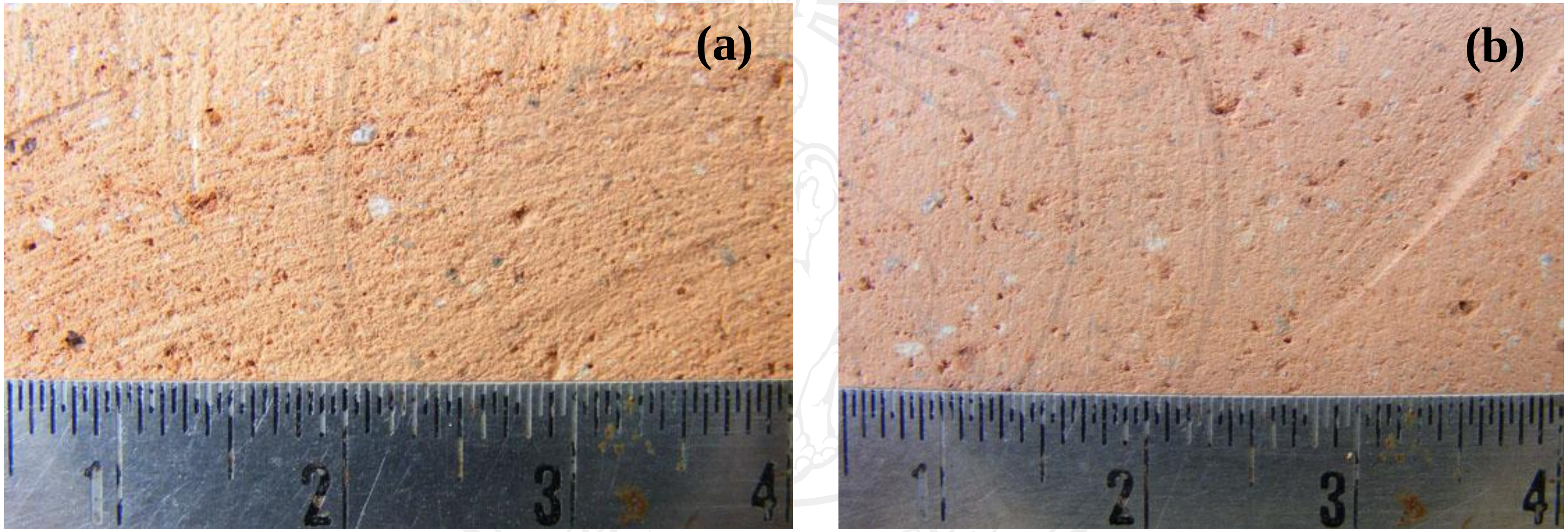

Figure. 5.18 Effects of different temperature on the compressive strength of Hang Dong clay without addition fired at (a), 950 and (b), 1000 ^{o}C.

The compressive strength test is the most important test for assuring the engineering quality of a building material [10]. In this study the result indicated that the strength greatly depended on the amount of charcoal addition mixed in the fired test briquettes and the firing temperatures. The results of compressive strength (Tables 5.1-5.4) indicated that compressive strength of fired test briquettes decreased with an increase in the amount of charcoal addition in the fired test briquettes and firing temperature. An increase in compressive strength was due to a decrease in porosity and an increase in bulk density with an increasing temperature. The results revealed that the compressive strength was in the ranges between 18.91 and 152.82 kg/cm^2 (Figure. 5.12). In other words, when the charcoal content varied from 2.5% to 10%, the compressive strength of the fired test briquettes changed from 31.77-63.49, 78.59-143.45, 32.41-146.27 and 46.85-152.82 kg/cm^2 with respect to firing temperatures: 900, 950, 1000 and 1100 ^{o}C, respectively.

In short, in this study, when test briquettes with 10% of charcoal addition size 2 were fired at 900 ^{o}C, their compressive strength was 18.91 kg/cm^2 which were the lowest. However, with 2.5% of charcoal addition size 3, their compressive strength became the highest at 143.45 kg/cm^2. For the test briquettes fired at 1100 ^{o}C, the ones with 10% of charcoal addition size 1 yielded the lowest compressive strength of 43.60 kg/cm^2 and the highest of 152.82 kg/cm^2 was the ones with 10% charcoal addition size 3. The test briquettes without any charcoal addition fired at the temperatures from 900 to 1100 ^{o}C resulted in the compressive strengths of 97.63 - 256.87 kg/cm^2. (Figure. 5.12) The comparison between the test briquettes with charcoal addition and without one revealed that the trend of the decreasing compressive strength varied depending on the amount and size of charcoal addition (Figure.5.12) The compressive strength and apparent porosity of fired test briquettes related inversely, i.e., the compressive strength decreased as the apparent porosity increased (Figure. 5.3). This relation was similar to that of the amount and size of charcoal addition and compressive strength of fired test briquettes. This can be explained when the test briquettes were fired, the charcoal addition was burnt out thereby apparent porosity occurring. The apparent porosity decreased the load bearing of surface area thereby reducing load bearing. The small size of the porosity caused an increase in the load bearing of the surface area and more than the test briquettes with bigger size of charcoal particles added (Figure. 5.19). Therefore, the test briquettes with size 3 charcoal additions which was the smallest size had the highest compressive strength.

5.5 Microstructure analysis

The morphological characteristics of fired test briquettes are demonstrated in Figures. 5.19 (a)-(d). original Hang Dong clay brick sample (a), a sample with the charcoal particle sizes ranging from 2-3 mm. (size 1, b), 1-2 mm. (size 2, c) and less than 0.5 mm. (size 3, d). The structure of clay specimens had an influence on the values of water absorption. The fired test briquettes with the addition of fine charcoal addition exhibited the lowest water absorption capacity, which could be explained by the least porosity.

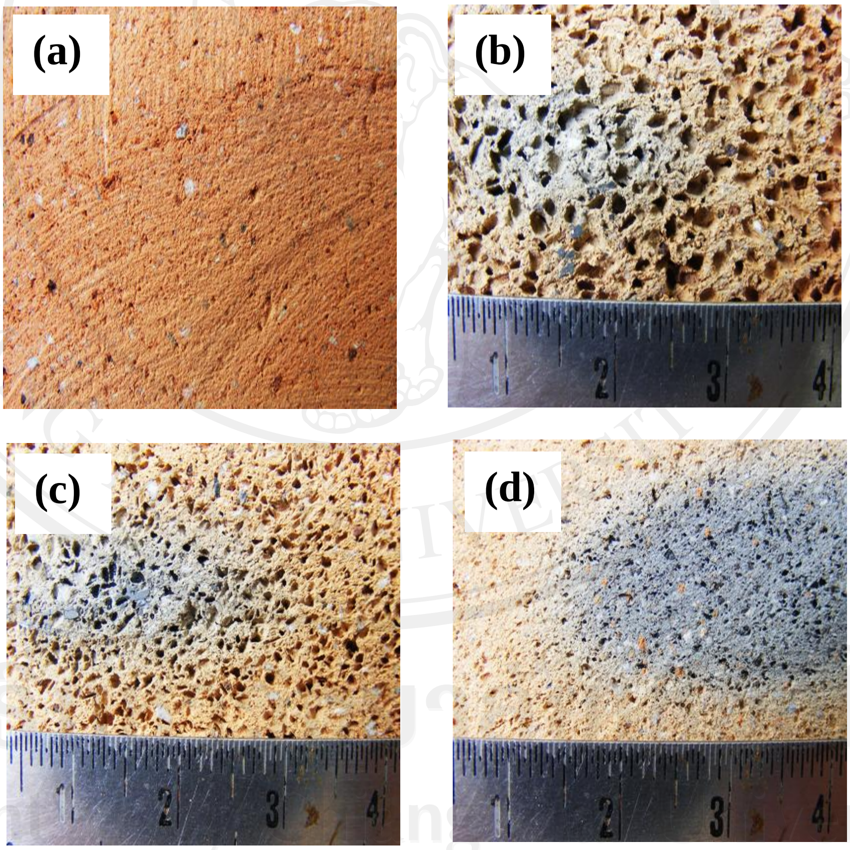

Figure. 5.19 Surface texture of fired test briquettes (a) Hang Dong clay without addition (b) mixed with charcoal addition size 1 (2-3 mm.), (c) mixed with charcoal addition size 2 (1-2 mm.) and (d) mixed with charcoal addition size 3 (less than 0.5 mm.).

By using the SEM to examine the fired test briquettes, it yields the results of their vitrification occurring at the temperatures between 900-1100 ^{o}C and different amounts of charcoal addition shown in Figures. 5.20 (a)-(e). The images show that as the amount of charcoal addition increased, the micropores of the fired test briquettes also increased. This is the main reason why there was an increase in water absorption of the fired test briquettes. However, when the firing temperature increased, it caused the size of micropores to decrease. As a result, the water absorption of the fired test briquettes decreased. However, when the amounts of charcoal increased and the test briquettes were fired, they also increased the size and amount of micropores. Thus, their compressive strength was reduced because compressive strength would be increased when there were a decrease in porosity and an increase in bulk density with increasing firing temperature [64]. In this study, 950 ^{o}C was the most appropriate firing temperature for the fired test briquettes. Thus, it is also speculated that 950 ^{o}C should be the most appropriate temperature for manufacturing bricks with charcoal addition as construction materials because bricks are more durable and stronger than current commercial bricks with TISI standard shown in Table 5.5.

Table 5.5 Comparison of physical and mechanical properties of the ordinary brick building with fired test briquettes of charcoal addition size 3 (less than 0.5 mm.) were fired at 950 ^{o}C and without charcoal addition.

Properties	**Specimens mixed with charcoal**					**TISI***
	0%	**2.5%**	**5.0%**	**7.5%**	**10%**	
Water absorption (%)	17.18	18.27	19.98	28.34	33.21	25
Compressive strength (kg/cm^2)	152.66	143.45	90.57	85.70	78.59	35

*(Thai Industrial Standards Institute; TISI77-2531).

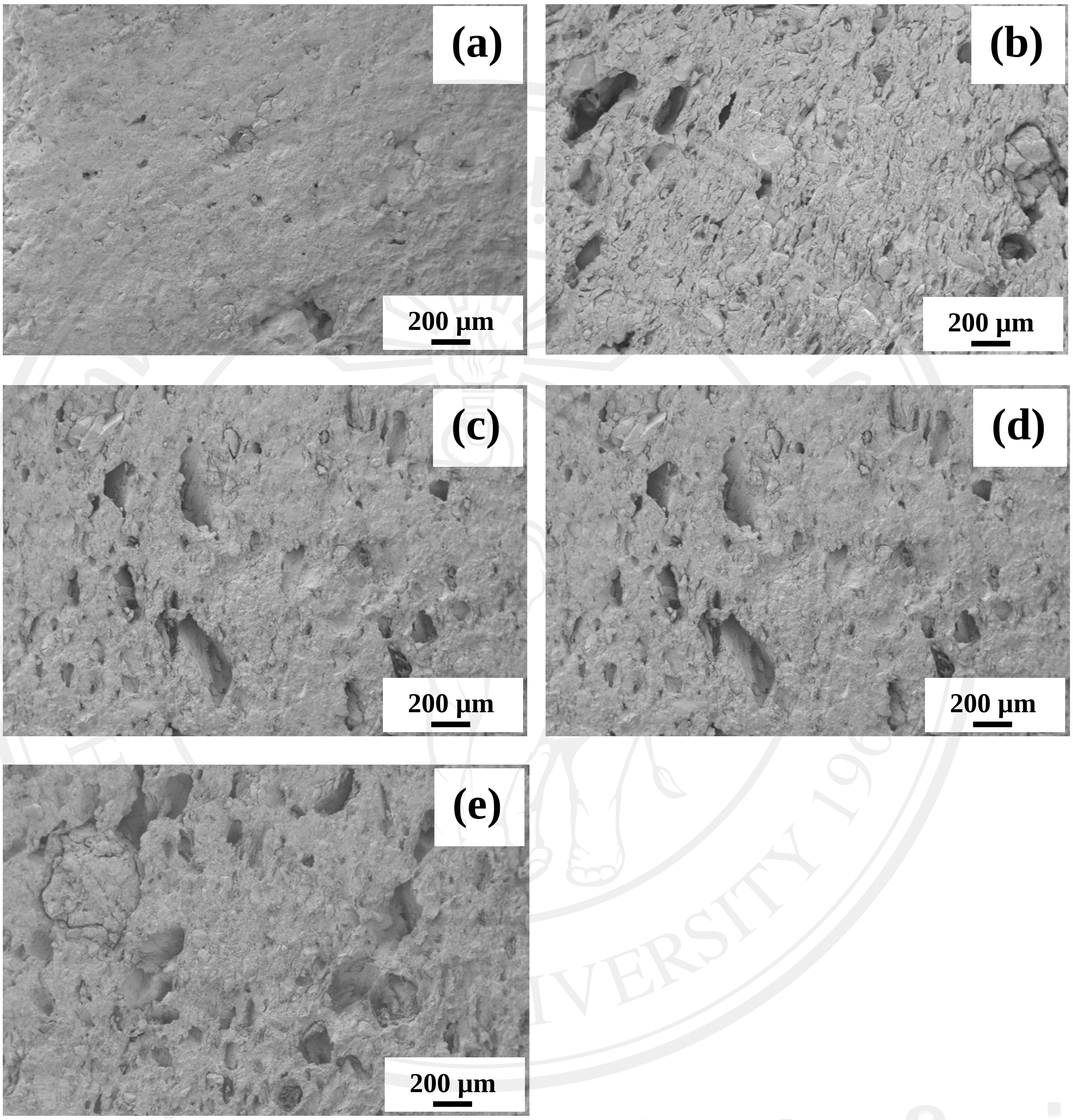

Figure. 5.20 SEM photomicrographs of fired test briquettes with various amounts of charcoal size 3 fired at 950 ^{o}C (20x): (a) Hang Dong test briquettes without charcoal addition, (b) 2.5%, (c) 5.0%, (d) 7.5% and (e) 10%.