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MECHANICAL PROPERTIES OF SYNTHETIC AGGREGATE PELLETIZED FROM WASTE CONCRETE RECYCLED FINE POWDER IN VIETNAM

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Abstract

Due to rapid industrialization and economic growth, the generation of construction and demolition waste (CDW) from the demolishing of buildings is increasing in Vietnam. At present, the Vietnamese government is promoting proper CDW management and reuse/recycling of CDW, supporting protection of the environment (Circular No. 08/2017/TT-BXD) and sound socio-economic development (Directive No. 41/2000/CT-TTg). Waste concrete fine powder (WCP; typically, < 300 µm in diameter) is a secondary product generated during building demolition and concrete aggregate production. The generation of WCP is increasing with the increase of CDW recycling, and most WCP is currently dumped/stored without any treatment. However, reuse and recycling of WCP is expected to save natural construction resources. To increase the recycling of CDW in Vietnam his study, therefore, aimed to investigate the mechanical properties of synthetic aggregates (SA) of the size of 5–20 mm made from pelletized WCP. A disk pelletizer (1.5 m in diameter and 0.3 m in depth) with a tilt angle of 55o and a rotation speed from 15–22 rpm was used to produce SA in this study. The results showed that the SA newly produced using WCP meets well the requirement of the recycled aggregate (type II) for concrete in TCVN 11969 (2018): the apparent specific gravity ranged from 2.45–2.55 g/cm^3, the dry bulk specific gravity ranged from 1.85-1.95 g/cm^3, the crushed value ranged from 19.2–29.9%, the Los Angeles abrasion value was 23–33%, and the water absorption of SA became approximately 13.2%.

Keywords: waste concrete fine powder (WCP); synthetic aggregates (SA); recycled concrete aggregates (RCA); construction and demolition waste (CDW); reuse and recycling; Vietnam.

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1. Introduction

The construction industry is growing rapidly worldwide, especially in developing regions of the world. Due to the increased consumption of natural resources by the construction industry, the shortage of construction materials as well as the resulting environmental issues caused by the unplanned use of natural resources and improper management of construction and demolition waste (CDW) have become vital social problems [1]. To solve these problems, the reuse and recycling of CDW to produce recycled construction materials are highly required.

Till now, recycled CDW such as recycled concrete aggregates (RCA) has been used widely for various civil engineering purposes in the construction industry. The reuse and recycling of waste concrete fine powder (WCP; typically, < 300 µm) generated during building demolition and concrete aggregate production, on the other hand, have received less attention compared to the use of RCA, and

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most WCP generated is dumped/stored without any treatment in many developing regions, including Vietnam. Zhang et al. [2], for example, reported that the RCA production generated WCP of approximately 15–35% by weight against total treated waste concrete and that WCP is normally discarded at the landfill site without reuse and recycling. Additionally, improper management and uncontrolled disposal of WCP cause serious air pollution and respiratory diseases such as asthma and lung cancer [3].

Nowadays, the production of synthetic aggregates (SA) made from WCP attracts attention as an alternative source of natural aggregates and/or RCA for concrete to save natural construction resources (i.e., natural aggregates), and many researchers have carried out studies to develop SA using various types of materials, such as fly ash, rice husk ash, and iron ore dust, mixed with cement as a binder [4–6]. Wainwright and Cresswell [7], for example, used quarry waste with a particle size < 300 µm mixed with clay or paper sludge as a binder to manufacture SA. Bach et al. [8] investigated whether manufacturing SA from fly ash was applicable to produce ACOTEC® wall panels while satisfying the technical requirements of TCVN 11524 in 2016 [9].

In Vietnam, the demand for aggregates for concrete is increasing rapidly due to active construction activities such as new building construction and renovation while the total supply of natural aggregates for concrete is decreasing [10]. To promote the recycling of waste concrete and the use of RCA for concrete, the TCVN 11969 of 2018 [11] specified two types of RCA depending on their mechanical properties. However, there is still a lack of technical standards as well as legal frameworks for producing SA using WCP and for promoting the use of SA for civil engineering purposes. This study, therefore, aimed to manufacture new SA for concrete using WCP mixed with cement as a binder and to evaluate the mechanical properties of SA compared to the specified technical requirements of RCA for concrete in TCVN 11969 [11] in Vietnam.

2. Materials and producing method

2.1. Materials

(a) WCF collected from crushing line

(b) Mini crushing machine

Figure 1. WCF production

The materials used in this study, fine waste concrete powder (WCP) and Portland cement (PCB40; Cam Pha cement; Km6, NR 18A, Cam Thach Ward, Cam Pha City, Quang Ninh Province, Vietnam), were prepared at the crushing line of waste concrete installed by the JST-JICA Science and Technology Research Partnership for Sustainable Development (SATREPS) project [12] at Dong Anh District, Hanoi, Vietnam. To control the uniform size of WCP, the WCP collected after the crushing line was further crushed by a mini crushing machine to the size of < 300 μm in this study (Fig. 1). In this study, not only pelletized SA samples but also RCA (5–10 and 10–20 mm) and natural aggregates (5–10 and 10–20 mm) were used to assess the mechanical properties.

2.2. *Pelletizing of synthetic aggregates (SA)*

The percentages of mixed materials used to pelletize the SA are shown in Table 1. In this study, the WCP-to-cement ratio was set at 5.66 and the water-to-cement ratio was set at 1.44 on a mass basis for pelletized SA. The SA pelletizing followed the method proposed by the Institute of Research and Application for Tropical Building Materials (Hanoi, Vietnam) [13]. The pelletizing of SA was carried out using a disk pelletizer 1.5 m in diameter and 0.3 m in depth. The tilt angle was set to 55°, and the rotation speed was controlled from 15–22 rpm in this study. The production capacity was 0.5–0.8 tons/hour in this condition. The pelletizing line and disk pelletizer used in this study [Doan Minh Cong Joint Stock Company (DMCLINE), Hai Duong, Vietnam] are shown in Fig. 2(a) and 2(b).

Table 1. Mixing proportions of WCP, cement, and water

	WCF (%)	Cement (%)	Water (%)
Mixing Proportion (% by mass)	70.8	12.5	16.7

(a) Pelletizing line

(b) Disk pelletizer

(c) Mixing WCP and cement

(d) Pelletized synthetic aggregate

Figure 2. SA production

The process of SA pelletizing is as follows: First, WCP and cement were blended, then 70% water was supplied to the mixture for the initial moisturizing (Fig. 2(c)). Then, the moisturized mixture was fed into the disk pelletizer and rotated for 5 minutes. Finally, the remaining 30% of water was poured into the pelletizer, and it was rotated until the mixture formed pellets (i.e., SA; Fig. 2(d)). The size of the pelletized aggregates was 5–20 mm to apply the SA as an alternative material of RCA for concrete in this study (Fig. 3(b)).

(a) SA have particle size 10-20 mm

(b) SA have particle size 5-10 mm

Figure 3. SA materials after curing 28 days

2.3. Experimental program for the measurements of mechanical properties

The mechanical properties of pelletized SA in this study were measured using samples after the 28–day curing. The SA samples were sieved into two fractions, 10–20 mm and 5–10 mm (Fig. 3), and used to measure the mechanical properties such as apparent specific gravity, dry bulk specific gravity, water absorption, crushing value, and Los Angeles abrasion value following the testing methods in the TCVN 7572 [14] of the aggregates and mortar for concrete in Vietnam.

For the measurements of apparent specific gravity, dry bulk specific gravity, and water absorption, the samples were first stored in a 1–kg container and soaked in water for 24 ± 4 hours at the temperature of 27 °C ± 2 °C (Fig. 4(a)). Then, the samples were air-dried, and the mass of the sample (m_1) was measured (Fig. 4(b)). Next, the surface dried samples were placed in a water-filled plastic cup, and the cup was shaken gently to remove air bubbles from the samples (covering the cup with a glass plate), and the mass of the samples + cup + water + glass plate (m_2) was measured (Fig. 4(c)). After removing the sample from the cup, the plastic cup was filled with water, and the mass of cup + water + glass plate was recorded as m_3. Finally, the samples were oven-dried and the dry mass of the samples was measured as m_4 (Fig. 4(d)).

The apparent specific gravity of SA samples (ρ_a, g/cm^3) was calculated by the following formula:

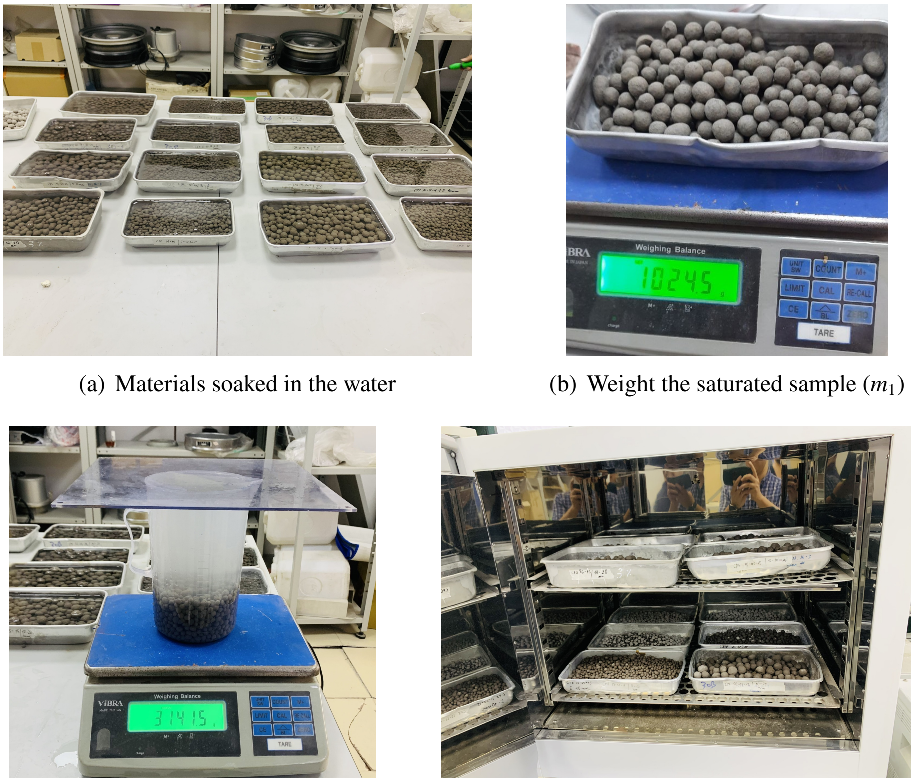
$$\rho_a = \rho_n \times \frac{m_4}{m_4 - (m_2 - m_3)} \tag{1}$$

The dry bulk specific gravity of SA samples (ρ_{vk}, g/cm^3) was calculated by the following formula:

$$\rho_{vk} = \rho_n \times \frac{m_4}{m_1 - (m_2 - m_3)} \tag{2}$$

The saturated bulk specific gravity of SA samples (ρ_{vk}, g/cm^3) was calculated by the following formula:

$$\rho_{vbh} = \rho_n \times \frac{m_1}{m_1 - (m_2 - m_3)} \tag{3}$$



(a) Materials soaked in the water

(b) Weight the saturated sample (m_1)

(c) Weight the sample + tube + water + glass plate (m_2)

(d) Dry the samples to constant mass (m_4)

Figure 4. Measurements of apparent specific gravity, dry bulk specific gravity, and water absorption of the SA samples

where ρ_n is the apparent specific gravity of water (= 1.00 g/cm^3). The water absorption of SA samples (W, %) was calculated by the following formula:

$$W = \frac{m_1 - m_4}{m_4} \times 100 \tag{4}$$

The crushing value (ACV: aggregates crushing value) of SA was measured using a steel mold of 75 mm diameter and a hydraulic compressor with a capacity of 200 tons [14]. A 400-g sample was packed into the steel mould, and the compressive load was increased at the interval of 1 kN/sec till the compressive load reached 50 kN (Fig. 5). After the compression, the samples were sieved to remove the fines < 1.25 mm for SA of 5–10 mm and the fines < 2.5 mm for SA of 10–20 mm. The ACV (%) of the SA samples was calculated by the following formula:

$$ACV = \frac{m_5 - m_6}{m_5} \times 100 \tag{5}$$

where m_5 is the mass of the sample before compression (g) and m_6 is the mass of the sample after sieving (g).

According to the TCVN 7572 [14], Los Angeles abrasion (LA, %) was measured using the SA samples with the size 10–20 mm (gradation B) and the size of 5–10 mm (gradation C). The LA abrasion test machine rotated the samples for 500 drum revolutions at 30–33 revolutions/min. After

Figure 5. Measurement of crushed values of the SA samples

the rotation, the tested samples were sieved to remove fines < 1.7 mm, and the remaining samples were washed and oven dried. The LA value is the loss in mass of the tested samples before and after the test and was calculated by the following formula:

$$LA = \frac{m_7 - m_8}{m_7} \times 100 \tag{6}$$

where m_7 is the mass of the sample before the LA abrasion test (g) and m_8 is the mass of the sample after the test (g).

Table 2. Measured mechanical properties of SA samples, RCA, and natural aggregates. The technical requirements in the TCVN 11969 (2018) are also given

Properties	SA (This study)		RCA [15]		Nature aggregate [15]		TCVN 11969:2018 Type 2 [9]
Size (mm)	5 – 10	10 – 20	5 – 10	10 – 20	5 – 10	10 – 20	
ρ_a (g/cm^3)	2.55	2.45	2.65	2.66	2.72	2.72	-
ρ_{vk} (g/cm^3)	1.90	1.85	2.33	2.35	2.62	2.61	$\geq$ 1.80
ρ_{vbh} (g/cm^3)	2.15	2.10	2.47	2.47	2.62	2.61	-
W (%)	13.2	13.2	6.3	5.2	0.2	0.1	$\leq$ 20
ACV (%)	19.2	27.9	20.4	16.7	13.9	12.9	$\leq$ 30
LA (%)	23.0	33.0	32.1	26.7	28.4	22.7	$\leq$ 50

3. Results and discussion

The measured mechanical properties of pelletized SA samples in this study, as well as the properties of RCA and natural aggregates, are summarized in Table 2. In the table, the technical requirements of TCVN 11969 in 2018 [11] are given for comparison.

The results show that the ρ_a and ρ_{vk} values of SA samples in this study became smaller than those of RCA and natural aggregates, and the W values of the SA became much higher than those of RCA and natural aggregates. This indicates that the SA have a more porous structure than other aggregates, as reported in the previous studies (e.g., [8]). Compared to the technical requirements of TCVN 11969 [11] on the recycled coarse aggregate type II for concrete, all mechanical properties of tested SA in this study satisfied the designated technical requirements. Having a close look at the measured values of SA in this study, however, the ACV value for tested SA with 10–20 mm (27.9%) is close the technical requirement (≤ 30%) and is much larger than that of natural aggregates (13.9% and 12.9%). This implies that the use of SA for concrete significantly affects the strength of concrete as well the design of the concrete structure.

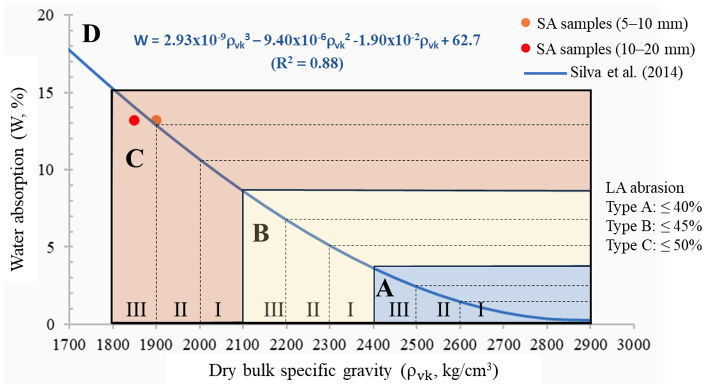


Figure 6. Aggregate classification based on the relationship between water absorption (W) and dry bulk specific gravity (ρ_{vk}) reported by Silva et al. [16]

Silva et al. [16] examined the mechanical properties of various types of recycled aggregates from CDW and categorized the grade of recycled aggregates for concrete based on the mechanical properties shown in Fig. 6. The quality of recycled aggregates for concrete downgrades from Type A to Type C depend on the LA values, and the grade is further classified into grades I, II, and III. As shown in the Fig. 6, a unique polynomial relationship between ρ_{vk} and W has been suggested by categorizing the grade of recycled aggregates for concrete. After plotting the measured values of SA samples in the figure, it can be found that both SA samples (5–10 mm and 10–20 mm) in this study were categorized as Type C-III, showing that the tested samples are the weakest aggregates (the lowest quality) for concrete. This also implies that it is necessary to pay special attention to use the SA in this study for concrete production.

Besides, it was observed from the ACV tests that the compressive strength of SA of 10-20 mm was 40 MPa and that of SA of 5–10 mm was 60 MPa, and those values became lower than that of natural aggregates (crushed stone; 100 MPa). According to the TCVN 7570 [17], therefore, the aggregate strength of SA in this study is qualified for use as coarse aggregates for concrete and the compressive strength of the concrete is 25–40 MPa (that is equivalent to the strength level of B20 to B30 [18]).

4. Conclusions

Based on the tested results of mechanical properties, the pelletized SA using waste concrete fine powder (WCP) in this study had similar properties to those of RCA. The tested SA samples satisfied well the Vietnamese technical standards such as TCVN 11969 [11] on the recycled coarse aggregate for concrete and TCVN 7570 [17] on the aggregates for concrete. Compared to the previously reported data, the SA tested in this study was classified as Type C-III, that is, the weakest aggregate for concrete production. For evaluating the applicability of proposed SA in this study for concrete, a series of laboratory experiments to investigate the mechanical properties of concrete made from the SA (as alternative aggregates) are scheduled. Especially, it is important to pay careful attention to the effects of substitution percent of natural aggregates/RCA by the SA on the mechanical properties of concrete.

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