Mechanical Properties of Fine-Grained Concrete Using Fine-Red Sand and Fly Ash for Road Construction: A Case Study in Vietnam

Nguyen Thanh Sang, Thai Minh Quan, May Huu Nguyen, and Lanh Si Ho

Abstract Nowadays, in order to decrease environmental impacts such as exhaustion of natural resources and CO_2 discharge, the partial replacement of cement by fly ash and coarse aggregate by crushed fine aggregate in concrete have been attracted many researchers. This study concentrated on an experimental examination of the mechanical properties of fine-grained concrete using fine-red sand placement for crushed sand. Experimental tests were performed to investigate compressive, splitting tensile, and flexural strength. The results reveal that the compressive, splitting tensile, and flexural strength increased with curing time for all mixtures. The increase in the amount of fine-red sand replacement caused a decrease in all mixtures. It was also found that there is a strong correlation between compressive and splitting tensile strength with a high coefficient of determination. Besides, the results of compressive, splitting tensile, and flexural strength satisfied the requirement of concrete used for pavement.

Keywords Compressive strength · Fine-grained concrete · Splitting tensile strength · Flexural strength

N. T. Sang · T. M. Quan
University of Transport and Communications, Hanoi, Vietnam
e-mail: nguyenthansang@utc.edu.vn

T. M. Quan
e-mail: minhquan.thai@utc.edu.vn

M. H. Nguyen · L. S. Ho (✉)
University of Transport Technology, 54 Trieu Khuc, Thanh Xuan, Hanoi 100000, Vietnam
e-mail: lanhhs@utt.edu.vn

M. H. Nguyen
e-mail: maynh@utt.edu.vn

Civil and Environmental Engineering Program, Graduate School of Advanced Science and Engineering, 1-4-1, Kagamiyama, Higashi-Hiroshima, Hiroshima 739-527, Japan

S. A. Kristiawan et al. (eds.), *Proceedings of the 5th International Conference on Rehabilitation and Maintenance in Civil Engineering*, Lecture Notes in Civil Engineering 225,
https://doi.org/10.1007/978-981-16-9348-9_94

1 Introduction

In the construction field, the utilization of Portland cement and coarse aggregate as the main ingredient is a common manner to manufacture conventional concrete. However, overexploitation has led to the depletion of these resources and caused numerous environmental problems [1, 2]. Thus, the need for friendly replacement material is crucial in adapting to environmental requests and sustainable development [3, 4].

In line with the need for friendly construction material, the utilization of fine materials as a substitute replacement solution for coarse aggregate is becoming a typical topic [5, 6]. Theoretically, a fine-grained concrete either does not consist of any coarse aggregate at all or only a small proportion ensuring the fine/coarse ratio keeps higher than 1.0 [7, 8]. In this kind of concrete, the local materials (e.g., seawater, saline sand) and the various industrial wastes (e.g., ground blast furnace slag (GGBFS), fly ash) can be effectively used and also further brings many environmental and economic benefits [9, 10].

The reuse of local sand to utilize fine-grained concrete has been broadly investigated [11, 12]. Bédérina et al. [11] studied the applicability of local sand available in Algeria as a partial effort to substitute coarse aggregate in concrete. Three types of local sand, including dune, river, and a mixture of dune and river sands were employed to produce three corresponding sand concretes that were used to examine the workability and mechanical strength. The obtained results indicated that the local sands could be used to manufacture a more workable, more compact, and more resistant sand concrete while still meeting the requirement in compressive strength compared to conventional concrete. Li et al. [13] presented an investigation to investigate the application of 100% replacement of river and manufactured sand to produce san concrete. A series of low and medium strengths (25–60 MPa) was then achieved, which indicated the application of these sands in producing sand concretes.

The utilization of fly ash (FA) in a concrete mixture can lead to changes in the hydration process and hence influencing concrete properties such as workability, mechanical, and durability characteristics [14, 15]. For example, Agrawal et al. [14] investigated the influence of replacement of natural sand with FA on hardened properties of concrete including mechanical and durability characteristics. The results indicated that the FA fine-grained concrete could obtain a comparable mechanical strength compared to the conventional concrete. The influence of fly ash on the mechanical properties and other properties such as shrinkage, chloride permeability, and carbonation of coral sand concretes was also carried out by Cheng et al. [15]. They indicated that the compressive strength development of fine-grained concrete was higher than conventional concrete at 3 and 7 days, but then lower at 28 days.

In Vietnam, as a developing country, the development of fine-grained concrete utilizing fine sand and fly ash is a promising approach [8, 16]. Le et al. [8] experimentally studied the performance of fine-grained concrete utilizing sea sand and fly ash. Several properties of the concrete including workability, compressive strength under influence of curing conditions were examined. The obtained results indicated that it is feasible to manufacture fine-grained concrete with high strength using sea sand and fly ash. Nevertheless, an investigation of mechanical properties of fine-grained concrete using red-fine sand and fly ash for road construction has not been carried out so far in a condition of Vietnam. Thus, the purpose of this study is, therefore, to investigate mechanical properties of fine-grained concrete using local fine-red sand as a partial replacement for road-pavement construction in a case study in Vietnam.

2 Materials and Methods

2.1 Materials and Specimen Preparation

Materials

To produce fine-grained concrete, ordinary Portland cement (PC 40), crushed sand, and local fine-red sand (dune sand) were used. To reduce the amount of cement used, cement was partially replaced with FA, and the content of fly ash was fixed by 90 kg/m^3. The crushed sand (hereafter, CS) was taken from Binh Thuan province, which can satisfy ASTM C33 standard on grain size distribution. The local fine-red sand (hereafter, RS) was obtained from a red fine sand mine in Binh Thuan province. The RS used in this study partially replaces CS to utilize local materials. The chemical compositions of cement, CS, RS, and FA are introduced in Table 1. The grain size distribution of CS, RS, and four combined mixtures of two sands is shown in Fig. 1. The specific density of cement, crushed sand, red sand, and fly ash is 3.10, 2.69, 2.57, and 2.50 g/cm^3, respectively.

Mixture Proportions

The mixtures of fine-grained concrete were calculated based on the absolute volume of materials. This study used an admixture to reduce the quantity of free water; as a result, the water/binder (w/b) of 0.37 was prepared for entire mixtures to reduce the

Table 1 Chemical compositions of materials used

Chemical composition (%)	PC40	Fly ash (FA)	Red sand	Crushed sand
SiO_2	21.49	49.60	92,69	62.48
Al_2O_3	5.4	21.97	1.61	16.82
Fe_2O_3	3.49	4.90	2.1	1.04
CaO	63.56	0.66	0.50	1.17
MgO	1.40	0.78	1.08	0.45
Na_2O	0.12	0.16	0.27	4.33
K_2O	0.3	3.52	0.46	2.19
LOI	0.19	12.63	–	1.46

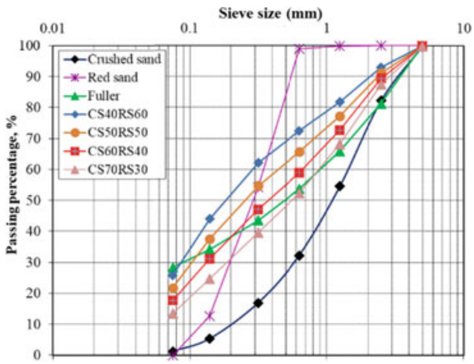


Fig. 1 The grain size distribution of crushed sand, red sand, and different mixtures

Table 2 Mixing proportion of fine-grained concrete

Mixture	w/b	Water (kg/m^3)	Cement (kg/m^3)	Fly ash (kg/m^3)	Crushed sand (kg/m^3)	Red sand (kg/m^3)	Admixture (kg/m^3)
70CS30RS	0.37	165	360	90	1259	540	4.50
60CS40RS	0.37	165	360	90	1075	717	4.50
50CS50RS	0.37	165	360	90	892	892	4.50
40CS60RS	0.37	165	360	90	711	1066	4.50

Note mixture name 70CS30RS indicates that this mixture containing 70% crushed sand and 30% red sand. This is also applied to all remaining mixtures

porosity of this concrete. Four different mixtures were prepared, in which the amount of crushed sand was partially replaced with red sand at 30, 40, 50, and 60%. The amount of fly ash (FA) was kept constant for all mixtures (90 kg/m^3). The amount of admixture (superplasticizer—a water reduction agent with the name RoadCon-SPR3000) was designed as 1.25% by mass of cement. The designed mix proportions of different mixtures are shown in Table 2.

Preparation and Casting of Specimens

All concrete mixtures were produced using a mechanical mixer and the total mixing time was 8 min. First, aggregates (crushed sand and red sand) including fly ash, and cement were mixed together in 2 min under dry conditions. Then, approximately 80% of the water was supplied and mixed for 2 min. Finally, the remaining water and admixture were added, and the mixtures were mixed again for 4 min., The cylindrical specimens having a size of 100 × 200 mm were used to determine compressive, tensile strength and elastic modulus. Regarding the flexural strength, the beam specimens with a size of 400 × 100 × 100 mm were adopted. The cylindrical specimens were prepared with three layers, each layer was compacted 25 times using a steel rod. For beam specimens, they were cast with two layers, and they were compacted using a vibration table. After completing compaction, the top surfaces of the mold were sealed with polyethylene sheets and stored in room condition at 20 °C. After one day, all specimens were demolded and cured in water at 20 ± 2 °C until designated ages. All tests in this study were conducted in triplicate and the mean value was used.

2.2 Testing of the Specimens

Compressive Strength and Elastic Modulus Tests

The compressive strength of this concrete was determined via the compression test according to ASTM C39. The compression tests were conducted for the specimens at 3, 7, and 28 days. The value of compressive strength is the mean value of three specimens. The elastic modulus of concrete was calculated based on ASTM C469 standard for the specimen at 28 days. The elastic modulus of each specimen was computed using the following Eq. (1).

$$E_0 = \frac{\sigma_2 - \sigma_1}{\varepsilon_2 - 0.000050} \tag{1}$$

where:

E: elastic modulus, Mpa,
σ_2: stress corresponding to 40% of ultimate load, Mpa,
σ_1: stress with a longitudinal strain, ε_1 of 50 millions, MPa,
ε_2: longitudinal strain caused by stress σ_2.

Splitting Tensile Strength, and Flexural Strength Tests

It is known that the splitting tensile strength is an important property that influences many characteristics of concrete such as controlling cracks, stiffness, bonding capacity to reinforcement, and durability. The splitting tensile strength was carried out based on ASTM C496 on specimens at 3, 7, and 28 days of curing. To determine the flexural behavior of this fine-grained concrete, the flexural strength test was then conducted for the beam specimens at 28 days in accordance with ASTM C293/C293M–16 standard.

3 Results and Discussion

3.1 Compressive Strength and Elastic Modulus

Figure 2 shows the compressive strength development of different mixtures. It can be observed that the compressive strength increased with curing time for all mixtures as

Fig. 2 Compressive strength of different mixtures

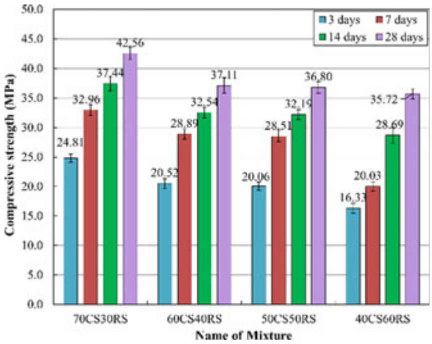
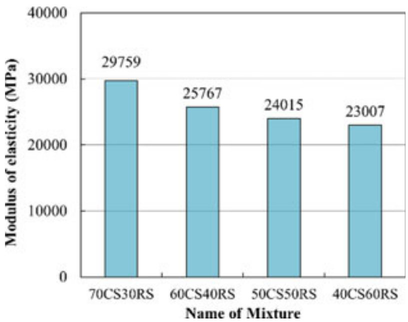


Fig. 3 Elastic modulus of different mixtures at 28 days



found in previous studies [8, 16]. The increase in compressive strength, in this case, is mainly contributed to the hydration of cement. For all curing ages, the compressive strength decreased with an increase in the amount of RS. This decrease can be caused by the low strength and frictionl of red sand compared to that of crushed sand. The rate of decrease in the compressive strength of all curing ages is approximately the same for all mixtures, this can also be explained by the decrease in the amount of crushed sand.

The elastic modulus of four mixtures at 28 days is presented in Fig. 3. Similar to the case of the compressive strength, the elastic modulus decreases with increase in the amount of red sand (i.e. from 30 to 60%). This was also caused by the increase in the amount of RS that causes the reduction of compressive strength and modulus. The highest elastic modulus was observed in mixture 70CS30RS (the lowest amount of RS), while the lowest value was found in mixture 40CS60RS.

3.2 Splitting Tensile and Flexural Strength

The splitting tensile strength of different mixtures is presented in Fig. 4. It can be seen that the splitting tensile strength increased with curing time for all mixtures,

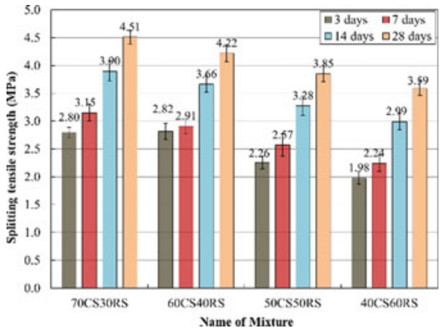


Fig. 4 The splitting tensile strength of different mixtures

as found in previous studies [8, 16]. Comparable to the compressive strength, the increase in the splitting tensile with time is mainly attributed to the cement hydration. Comparing with different mixtures, in general, it can be observed that the splitting tensile strength also decreased with increasing in the amount of RS, it is confirmed with the result of compressive strength. At the age of 3 days, the splitting tensile of mixture 70CS30RS was also almost equal to that of mixture 60CS40RS, while it decreased rapidly from mixture 60CS40RS to mixture 50CS50RS. For other curing ages, including 7, 14, and 28 days, the splitting tensile strength decreased gradually from mixture 70CS30RS.

Figure 5 shows the flexural strength of four mixtures at the age of 28 days. It was found that the flexural strength generally decreased with decreasing amount of crushed sand (CS) (i.e. increasing amount of RS) and it also agreed well with the results of the compression test. The flexural strength gradually decreased from mixture 70CS30RS to mixture 50CS50RS, and then it decreased rapidly from mixture 50CS50RS to mixture 40CS60RS. The highest value (7.70 MPa) of flexural strength was observed in mixture 70CS30RS, and the lowest value (5.18 MPa) was found in mixture 40CS60RS. It indicates that the increase in the amount of red sand leads to a decrease in flexural strength of this type of concrete.

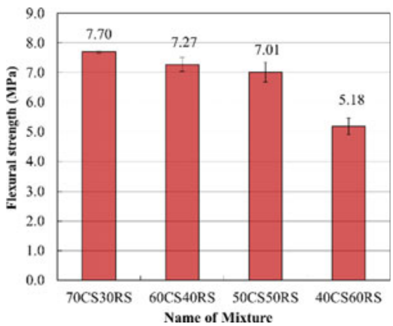


Fig. 5 The flexural strength of different mixtures at 28 days

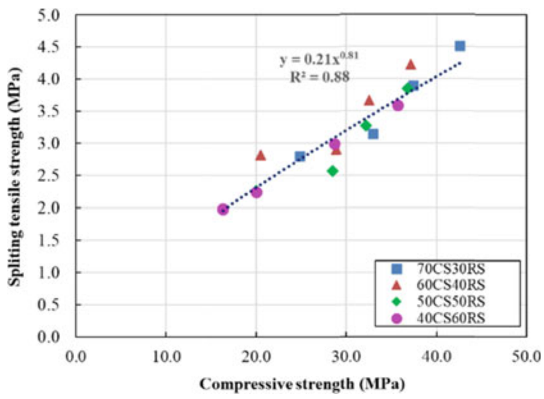


Fig. 6 Relation between splitting tensile strength and compressive strength

3.3 Correlation Between Compressive Strength and Splitting Tensile Strength

The correlation between compressive and splitting tensile strength is described in Fig. 6. Generally, this relationship is presented in a power-type equation as being seen in many previous studies of conventional concrete [17, 18] and fine-grained concrete [16]. According to the figure, it can be seen that the splitting tensile strength grew up with an increment of compressive strength as found in normal concrete and fine-grained concrete in previous publications [16, 19]. In addition, it is also found that this relationship has a high coefficient of determination, as found in the previous study of fine-grain concrete [16]. It indicates that this fine-grained concrete using red sand has similar behavior compared to normal concreted and fine-grained concrete using saline sand in the previous study.

4 Conclusions

In this study, the mechanical properties such as compressive, tensile, and flexural strength of fine-grained concrete using local fine red sand as a partial crushed sand replacement and fly ash. Some main concluding remarks can be derived from the experiment results as follows.

- The compressive, tensile, and flexural strength increased with curing time. When the amount of fine red sand increased, those strengths decreased.
- The increase in the amount of fine-red sand replacement caused a decrease in all mixtures.
- There is a strong correlation between compressive strength and splitting tensile strength with a high coefficient of determination, as found in previous studies.

- Compressive, tensile, and flexural strength results satisfied the requirement of concrete used for the requirement of concrete for pavement.

Acknowledgements This research is funded by the Project of Vietnam Ministry of Science and Technology, "Study on using saline sand to build transport work" under grant number DTDL.CN-23/19."

References

1. El-Fadel M, Zeinati M, El-Jisr K, Jamali D (2001) Industrial-waste management in developing countries: the case of Lebanon. J Environ Manage 61:281–300
2. Henry RK, Yongsheng Z, Jun D (2006) Municipal solid waste management challenges in developing countries–Kenyan case study. Waste Manage 26:92–100
3. Troschinetz AM, Mihelcic JR (2009) Sustainable recycling of municipal solid waste in developing countries. Waste Manage 29:915–923
4. Dash MK, Patro SK, Rath AK (2016) Sustainable use of industrial-waste as partial replacement of fine aggregate for preparation of concrete—a review. Int J Sustain Built Environ 5:484–516
5. Akono A-T, Zhan M, Chen J, Shah SP (2021) Nanostructure of calcium-silicate-hydrates in fine recycled aggregate concrete. Cem Concr Compos 115:103827
6. Li J, Yang E-H (2017) Macroscopic and microstructural properties of engineered cementitious composites incorporating recycled concrete fines. Cem Concr Compos 78:33–42
7. Bederina M, Marmoret L, Mezreb K, Khenfer MM, Bali A, Quéneudec M (2007) Effect of the addition of wood shavings on thermal conductivity of sand concretes: experimental study and modelling. Constr Build Mater 21:662–668
8. Le HT, Nguyen ST, Ludwig H-M (2014) A study on high performance fine-grained concrete containing rice husk ash. Int J Concr Struct Mater 8:301–307
9. Bai Y, Darcy F, Basheer PAM (2005) Strength and drying shrinkage properties of concrete containing furnace bottom ash as fine aggregate. Constr Build Mater 19:691–697
10. Xiao J, Qiang C, Nanni A, Zhang K (2017) Use of sea-sand and seawater in concrete construction: current status and future opportunities. Constr Build Mater 155:1101–1111
11. Bédérina M, Khenfer MM, Dheilly RM, Quéneudec M (2005) Reuse of local sand: effect of limestone filler proportion on the rheological and mechanical properties of different sand concretes. Cem Concr Res 35:1172–1179
12. Gurumoorthy N, Arunachalam K (2016) Micro and mechanical behaviour of treated used foundry sand concrete. Constr Build Mater 123:184–190
13. Nanthagopalan P, Santhanam M (2011) Fresh and hardened properties of self-compacting concrete produced with manufactured sand. Cem Concr Compos 33:353–358
14. Agrawal US, Wanjari SP, Naresh DN (2019) Impact of replacement of natural river sand with geopolymer fly ash sand on hardened properties of concrete. Constr Build Mater 209:499–507
15. Cheng S, Shui Z, Sun T, Yu R, Zhang G, Ding S (2017) Effects of fly ash, blast furnace slag and metakaolin on mechanical properties and durability of coral sand concrete. Appl Clay Sci 141:111–117
16. Sang NT, Quan TM, Nguyen MH, Ho LS (2021) Performances of eco-fine-grained concrete containing saline sand as partial fine aggregate replacement. J Appl Sci Eng 24:527–539
17. Behnood A, Verian KP, Gharehveran MM (2015) Evaluation of the splitting tensile strength in plain and steel fiber-reinforced concrete based on the compressive strength. Constr Build Mater 98:519–529

18. Legeron F, Paultre P (2000) Prediction of modulus of rupture of concrete. Materials Journal 97:193–200
19. Chhorn C, Hong SJ, Lee SW (2018) Relationship between compressive and tensile strengths of roller-compacted concrete. J Traff Transp Eng (English Edn) 5:215–223