INFLUENCE OF PARTIAL AND FULL REPLACEMENT OF NATURAL SAND WITH QUARRY STONE DUST ON PROPERTIES OF FRESH AND HARDENED CONCRETE

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Abstract: *The shortage of natural sand for concrete production in Vietnam,especially in the Southern area, requires to find an alternative to relieve this issue. In this paper, quarry stone dust was used as an alternative to natural sand for concrete mix proportion. Moreover, the effect of partial to full replacement of natural river sand with this type of aggregate on the workability, compressive strength and flexural strength of concrete was studied. The results showed that although the use of quarry stone dust caused a reduction in slump value, compressive and flexural strength were comparable to the case of using natural sand.However, in case the superplasticizer was used for concrete mix with 80%-100% quarry stone dust replacement, both of fresh and hardened state properties of concrete were improved significantly.*

Keywords: Quarry stone dust, natural sand, concrete mix proportion, workability, compressive strength, flexural strength.

1. INTRODUCTION

Rapid growth in the infrastructure has made concrete the most widely and commonly used construction material throughout the world as well as in Vietnam. This has created immense pressure on the concrete industry to produce a large quantum of concrete to meet the growing demand for infrastructure development. The cost of concrete production primarily depends on the cost of its constituent raw materials, cement, aggregates (coarse and fine) and water (Aitcin, 1998). Among the constituent raw materials, fine aggregate or mostly natural sand which forms around 35% of the concrete volume plays an important role in deciding the cost of concrete (Neville, 2002; Nguyen & Dang, 2016). In Vietnam, currently there are merely few sand quarries and they are distributed unevenly from the North to the South. Hence, in many regions of the country sand has to be transported from far away for concrete production. In addition, depleting sources of natural river sand and strict environmental guidelines on mining from the government has gradually shifted the attention of the concrete industry towards a suitable fine aggregate alternative that can replace the presently used natural sand (Mundra et al., 2016; Nguyen, 2017).

One of the substantial solutions for reducing the sand excavation from natural resources as well as diminishing the cost of concrete is to use quarry stone dust with an equivalent grading to natural sand (Sukesh et al., 2013; Le & Nguyen, 2017). This type of sand, which has a grading of 0-5mm, is a by-product in the seiveing process of coarse aggregate manufacture at the stone quarry. Up to the present, this sand has been used mostly to make floor tiles, brick, and additives for precast pipes and road building as well as for other construction materials. According to a detailed statistic for Ho Chi Minh City area and nearby, which is geographically adjacent to some stone quarries in Bien Hoa - Dong Nai and Di An - Binh Duong, the use of quarry stone dust as fine aggregate might reduce the cost of raw material

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for concrete production up to 50% in comparison with the case of natural river sand owing on mainly transportation cost (Pham, 2014).

So far, several studies have been conducted to study the effect of natural sand replacement with quarry stone dust (Sukesh, 2013; Pham, 2014; Mundra, 2016; Le & Nguyen, 2017). Although the partial replacement up to 50% natural sand resulted in decreasing slump value, concrete made using quarry stone dust attained the comparable compressive strength as the control concrete. However, a significant reduction in the cost of concrete without affecting the strength property was also reported (Nguyen, 2017). In order to explore more thoroughly on the theme, the present paper dedicates to examine in detail how the partial to full replacement of natural river sand with quarry stone dust effects on the workability, compressive strength and flexural strength of concrete, which has not been studied yet.

2. MATERIALS USED AND EXPERIMENTAL PROGRAM

The material used for this study are presented as follows:

2.1. Cement

Cement used in this study is ordinary Portland Blended cement PCB40 with commercial band Ha Tien, which is conforming to the standard TCVN 2682:2009. Physical and mechanical characteristics of cement are given in Table 1.

Table 1. Physical and mechanical characteristics of cement

Parameters	Units	Test results
Specific density	g/cm^3	3.11
Bulk density	g/cm^3	1.3
Blaine fineness	cm^2/g	3350
Consistency	%	28.2
Initial setting time	min.	105
Final setting time	min.	295
Soundness of cement	mm	2.1
3 days compressive strength	N/mm^2	33.0
28 days compressive strength	N/mm^2	48.5

2.2. Fine and coarse aggregates

Natural sand from Dong Nai River was used as fine aggregate for concrete mix. In addition, both of crushed stone and quarry stone dust were brought from the stone quarry Di An-Binh Duong. Characteristic of fine and coarse aggregates is provided in Table 2. Besides, in order to obtain grading of aggregates, sieve analysis was also carried, the results are shown in Table 3.

Table 2. Characteristic of coarse and fine aggregates

Parameters	Units	Crushed stone	Sand	Stone dust
Specific density	g/cm^3	2.71	2.64	2.7
Bulk density	g/cm^3	1.48	1.55	1.65
Water absorption	%	0.9	1.5	1.9
Clay, silt and dust content	%	1.5	0,96	1.5
Fineness modulus	-	-	2.34	3.01

Table 3. Gradation of aggregates by sieve analysis

Sieve size	Crushed stone	Stone dust	Sand
	Cumulative % retained		
70	0.0		
40	2.9		
20	49.5		
10	80.3		
5	98.0	0.0	0.0
2.5		19.5	9.5
1.25		37.8	21.8
0.63		61.6	36.6
0.315		84.2	71.2
0.14		98.4	95.4
Pan	100	100	100

2.3. Chemical admixture and water

Chemical admixture used is a high-range water reducer admixture with commercial name SikaPlast®-151V, which is a third generationpolycarboxylate superplasticizer that was provided from Sika-Vietnam factory at Nhon Trach-Dong Nai. Water used in this study is tap water at Ho Chi Minh City area. Characteristic of water and admixture is shown in Table 4.

Table 4. Characteristic of water and admixture

Parameter	Units	Admixture	Water
Specific density	g/cm^3	1,075 ÷1,095	1
pH value	-	4 ÷ 6	7

2.4. Experimental program

In this study, concrete design mixes corresponding to strength class of 30MPa at the age of 28 days were prepared. This strength class was chosen on the basis of the discussion with the research partner (Bao Viet Consulting Company) and this concrete grade is currently considered as the most commonly-used at Ho Chi Minh City area and nearby.

In total, eight concrete mixes were prepared; among them in terms of fine aggregate the first one (M1) was concrete with 100% natural river sand, the following ones nominated as M2, M3, M4, M5, and M6 are mixes that 20%, 40%, 60%, 80%, and 100% respectively natural sand were replaced by quarry stone dust. The last mixes M7 and M8 are similar to mixes M5 and M6, except the addition of chemical admixture. The admixture content is considered in accordance with the supplier recommendation. All of the aforementioned concrete mixes are included in Table 5 below.

Concrete preparation was done by means of pan-mixer with the following procedure: firstly fine and coarse aggregates plus half of water content were mixed for two minutes and then cement was added and mixed for one minute, finally the rest of water was added and mixed for one more minute before concrete is discharged for test at fresh state. If the chemical admixture or superplasticizer is used, it will be added at the final step. Concrete slump test was carried out right after mixing.

In order to obtain compressive strength and flexural strength of the concrete mixes at different ages (3, 7 and 28 days), after slump test of each concrete mix 9 cubic (150x150x150mm^3) and 9 prism (100x100x400mm^3) specimens were prepared. After casting into the mould, the specimens were kept in the laboratory for 24 hours, then they were removed from the moulds and cured under standard condition (T=20±2^{o}C; W>95%) up to the testing date.

Table 5. Mix proportion of concrete strength class 30MPa

Mix	Cement	Natural sand	Quarry stone dust (replacement percentage)	Crushed stone	Admixture (relation to cement content)	Water
	kg	kg	kg	kg	L	L
M1	310	750	-	1070	-	195
M2	310	600	150 (20%)	1070	-	195
M3	310	450	300 (40%)	1070	-	195
M4	310	300	450 (60%)	1070	-	195
M5	310	150	600 (80%)	1070	-	195
M6	310	-	750 (100%)	1070	-	195
M7	310	150	600 (80%)	1070	1,8 (0.6%)	195
M8	310	-	750 (100%)	1070	1.8 (0.6%)	195

3. RESULTS AND DISCUSSION

3.1. Fresh state properties

The workability of concrete is defined in terms of the slump value. This value is exhibited in mm and presented in Figure 1. The results indicate that the more natural sand is replaced by quarry stone dust, the less slump value. It might be due to the fact that surface roughness of the stone dust is much greater than that of natural river sand, which consists of mostly round particles with smooth surface. Hence, concrete made with the stone dust has become less workable. Besides, the mixes using stone dust (M2-M6) need more vibration or energy to compact into the mould in comparison with the mix M1 using natural sand.

The addition of superplasticizer only about 0.6% of cement content to mixes M7-M8 has made concrete mix much more workable in comparison with the corresponding mixes M5-M6, as the slump values can be seen in Figure 1, eventhough 100% natural river sand was replaced by quarry stone dust in M8. This means that in case of using stone dust for concrete production it is suggested to employ superplasticizer in order to make concrete workable at the fresh state.

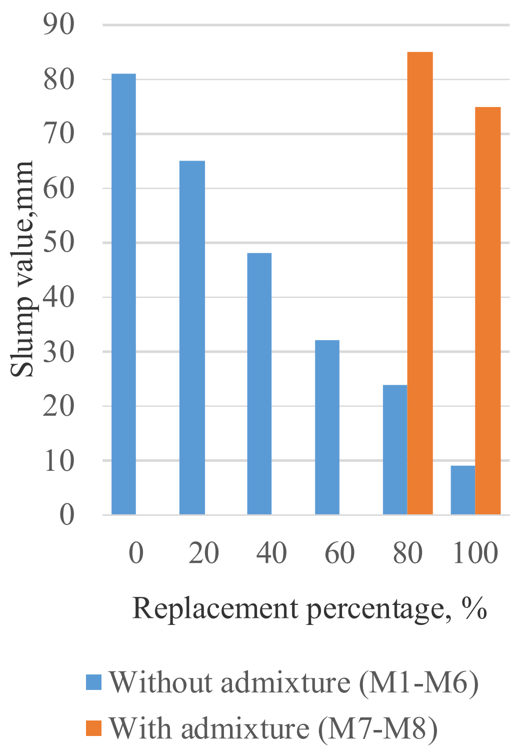

Figure 1. Slump value versus sand replacement percentage

The fresh state performance of concrete mixes M5 and M7 without and with chemical admixture are shown in Figure 2 and Figure 3 respectively. Evidently, during the experiment, it recognizes that the mix M5 requires vibration by hand poker much more than the mix M7 does in order to compact the mixes into the moulds.

Figure 2. Fresh state performance of M5 (without chemical admixture)

Figure 3. Fresh state performance of M7 (with chemical admixture)

3.2. Hardened state properties

Compressive and flexural strength of concrete mixes are checked at the age of 3, 7, and 28 days. It is well-known that concrete strength class is determined in accordance with the 28-day compressive strength of concrete, nevertheless an awareness of concrete strength at the early age clarifies the strength evolution of concrete, which is useful data for contractor from practical point of view, because it might accelerate the construction process thought the quality of construction is still maintained (Aitcin, 1998; Neville, 2002; Le & Nguyen, 2017). Flexural strength is defined by third-point bending test on 100x100x400mm^3 specimens. Compressive and flexural strength of concrete evolution are shown in Figure 4 and Figure 5 respectively. In these figures, for every concrete mixes (M1-M8) at the age of 3, 7 and 28 days each of the plotted data is an average of three test values.

Looking into the Figure 4, it can be seen that all of the concrete mixes attain strength class of 30MPa at the age of 28 days, except mixes M5-M6 with the replacement percentage of 80% and 100% respectively. The replacement of 20% and 40% natural sand by stone dust results in a comparable compressive strength, while the replacement of 60% sand causes reduction about 10% in strength. This result is similar to that of Sukesh et al. (2013) obtained before. However, the use of superplasticizer makes the concrete mixes M7 and M8 resulting in higher compressive strength than the others at the age of 3, 7 and 28 days, eventhough the replacement percentage is 80% and 100% respectively. This indicates that the superplasticizer improves compressive strength at the early age significantly. In general, it is observed that compressive strength of concrete at the age of 3 and 7 days is about 60% and 85% respectively the corresponding ones at the age of 28 days.

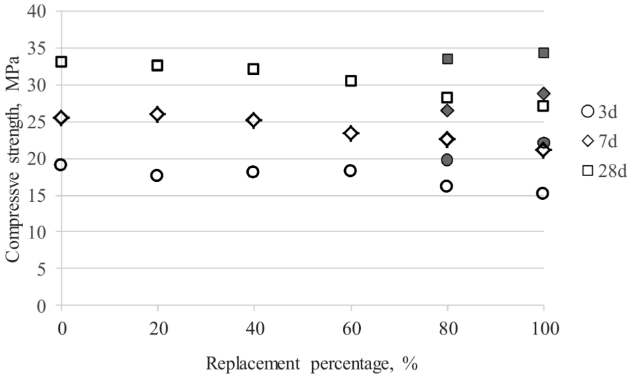

Figure 4. Compressive strength of concrete versus quarry stone dust replacement percentage at different ages (filling maker illustrates mixes with admixture)

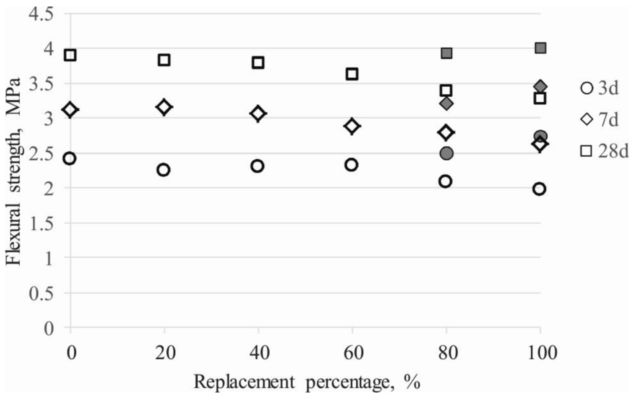

Figure 5.Flexural strength of concrete versus quarry stone dust replacement percentage at different ages (filling maker illustrates mixes with admixture)

Regarding flexural strength, similar behavior is also observed. Although in concrete mix M8 100% natural river sand is replaced by quarry stone dust, flexural strength is about 3-15% higher in comparison with mix M1. This also points out thatthe use of superplasticizer for concrete mix with 100% quarry stone dust enhance flexural strength particularly at the early age (3 and 7 days).

4. CONCLUSION

The concrete of strength class 30MPa at the age of 28 days with partial to full replacement of natural river sand by quarry stone dust was studied in this paper. The results indicated that in terms of fresh state properties the use of stone dust caused a remarkable reduction in slump value or concrete mix at fresh state becomes less workable. This requires more vibration or energy to compact the mix into the mould. Hence, it is suggested to employ the superplasticizer when using the dust for concrete production, especially for the case of full replacement. Regarding the hardened state of concrete mixes, compressive and flexural strength of mixes using quarry stone dust were comparable to that of the mixes using natural river sand at the age of 3, 7 and 28 days up to replacement of 40%. Beyond this value, the reduction in strength was observed. Furthermore, among eight concrete mixes studied the addition of superplasticizer resulted in the concrete mix with the highest strength, eventhough it was involved with 100% replacement of quarry stone dust.

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Tóm tắt:

NGHIÊN CỨU ẢNH HƯỞNG CỦA VIỆC THAY THẾ MỘT PHẦN VÀ HOÀN TOÀN CÁT TỰ NHIÊN BẰNG ĐÁ MI BỤI ĐẾN CÁC TÍNH CHẤT CỦA BÊ TÔNG TƯƠI VÀ BÊ TÔNG SAU KHI ĐÃ ĐÓNG RẮN

Cát tự nhiên dành cho sản xuất bê tông đang ngày càng cạn kiệt ở Việt Nam đặc biệt ở khu vực phía Nam đòi hỏi cần phải nghiên cứu vật liệu thay thế để giải quyết vấn đề này. Trong bài báo này đá mi bụi được sử dụng như vật liệu thay thế cho cát tự nhiên trong các thiết kế cấp phối bê tông. Ngoài ra, ảnh hưởng của việc thay thế một phần và hoàn toàn cát tự nhiên bằng loại cốt liệu này lên tính công tác, khả năng kháng uốn và nén của bê tông đã được nghiên cứu. Kết quả chỉ ra rằng mặc dù việc sử dụng đá mi bụi làm giảm độ sụt của hỗn hợp bê tông tươi, tuy nhiên khả năng kháng uốn và nén của bê tông khi đã đóng rắn là tương đương với trường hợp bê tông sử dụng cát tự nhiên. Tuy vậy, khi sử dụng phụ gia hóa dẻo cho bê tông có sử dụng 80%-100% đá mi bụi, chất lượng của bê tông tươi và bê tông đã đông cứng được cải thiện rõ rệt.

Từ khóa: Đá mi bụi, cát tự nhiên, cấp phối bê tông, tính công tác, khả năng kháng nén, khả năng kháng uốn.

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